Project nº:017900

PRO2CONTROL

On-line Control of Drawing and Blanking Processes and of Quality of the Product by Fusion of Sensors and Artificial Vision Techniques

CRAFT

New Production Processes and Devices

Final Activity Report

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Revision: Final Version

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Forming processes and, in particular, sheet metal blanking and deep drawing are inherently quite unstable manufacturing processes. On one hand, a slight change in the production parameters or in the material quality are usually enough to get the process out of its stability condition and to produce bad parts. On the other hand, when a tooling breakage or excessive wear occurs, the resulting parts are also bad. This situation is especially difficult to detect when producing small size parts, often manufactured in large quantities using high speed and production rate equipment. As a result, production of bad parts goes on until a statistical control is able to detect this and to stop the machine.

The main objective of this project is to develop a complete control system to be fitted on the ensemble press – tooling in order to assure a zero-defect in forming industries consecrated to the manufacturing of small size workparts. The aim is to get a complete diagnosis and control over the quality of the production and of the state of the production goods. As a result, the control system has to be able to integrate the capabilities of state-of-the-art control systems for forming processes and to fulfil the new objective of complete control of the quality of the part.

Two complementary methods are considered: use of Acoustic Emission (AE) and load measurement technologies, which includes a sensor set mounted on the press and the tooling, the electronic needed for the conditioning and a monitoring system installed on a PC, and Artificial Vision (AV) system, which is composed by a set of cameras and a flexible image processing system for the detection of defects in real time. The information of both systems is analysed by a software based control system, installed on the same PC, which has to decide the changes in the press state, the tooling condition or the process parameters needed to avoid the occurrence of defects.

The final strategic industrial objectives of the project PRO2CONTROL are to aim towards zero defects at the customer’s side and to decrease in at least 25% the scraps of manufacture, together with improving the worker condition, specially avoiding the manual quality control tasks. Economic objectives are to decrease the manufacturing costs of at least 5% at the supplier which already use methods of surveillance of the press, and until 20% at those that use only manual methods by minimizing or eliminating costs due to the manual sorting, the costs of premature wear or cracking of tools and the costs of return and customers’ scrap.

The partnership of Pro2Control is composed by six SME companies (BRANKAMP System Prozessautomation GmbH, Delta Technologies Sud Ouest, OFFICINE SANGIACOMO s.r.l., Troqueles y Derivados S.A., Industrias Alzuarán S.L., Industrias Garita S. L.) and two RTD performers (Mondragon Goi Eskola Politeknikoa from Mondragon University and the Institut für Umformtechnik from the Universität Stuttgart).

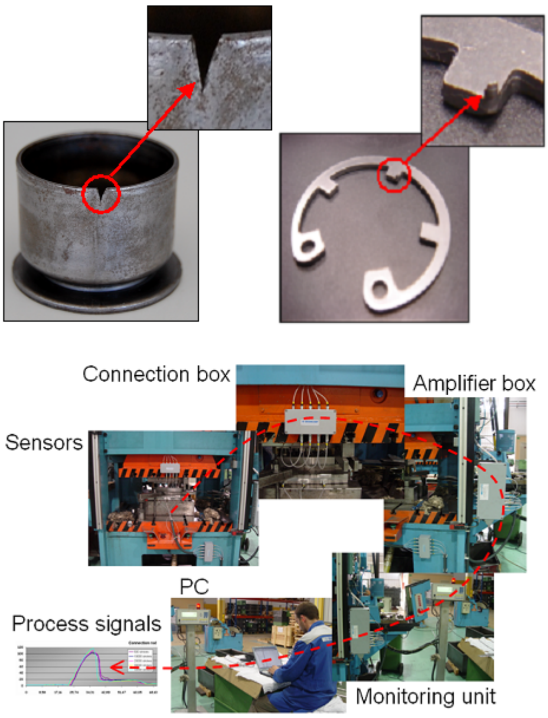
The project coordinator is Dr. Carlos García from the Mondragon University (cgarcia@eps.mondragon.edu).

The project has concluded after 30 months of research activity and the initial objectives have been fulfilled. The first branch of the project was the detection of instabilities in blanking and drawing processes using force and acoustic emission sensors with the purpose of increasing as much as possible the efficiency of the production facilities.

Two monitoring systems have been installed in two different companies, Industrias Alzuaran (in a forming facility consecrated to blanking processes) and Industrias Garita (in a forming facility consecrated to combined drawing and blanking processes).

In the forming facility at Industrias Garita consecrated to combined drawing and blanking operations very good results were achieved. The most critical process faults detected at Industrias Garita were tearing of the material, heating and therefore volume increment of the forming punches leading to catastrophic breakages and misalignment of the lateral dies at the tool leading to bad quality parts.

At the same time the monitoring system installed in Industrias Alzuaran also offered good results. This monitoring system was prepared to work with three different references and up to nine process faults were detected. The most important process faults detected at the blanking references produced in Industrias Alzuaran were punch breakages, bad evacuated parts from the tool, bad evacuated scraps from the tool and feeding faults. In next figure a summary of the process faults detected at Industrias Alzuaran with their reasons and solutions is presented.



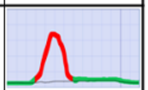
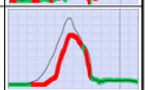
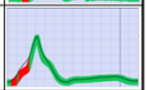
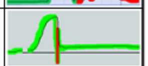
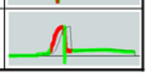
	Defect	Cause	Solution	Variables	Image
1	The steel strip did not move at all.	A badly evacuated scrap is avoiding the movement of the strip.	Extract the scrap of material and check the reason why it was not adequately evacuated.	In most of the channels the maximum real force is much smaller than the hypothetical force.	
2	The steel strip did not move the right distance.	A badly evacuated scrap is avoiding the movement of the strip.	Extract the scrap of material and check the reason why it was not adequately evacuated.	There is a force peak at the beginning of the channels which are measuring force directly in the tool.	
3	A badly evacuated scrap is blocking the first or second station.	The punches in station 1 or 2 are not evacuating the scrap properly.	Make the punches longer, move the ram down and check the dies´wear.	There is a force peak just before the maximum force in channels 4 and 5.	
4	A badly evacuated scrap is blocking the third station.	The punch in station 3 is not evacuating the scrap properly.	Make the punch longer, move the ram down and check the die's wear.	There is a force peak just before the maximum force in the third station.	
5	A badly evacuated scrap is blocking the fourth or fifth station.	The punches in station 4 or 5 are not evacuating the scrap properly.	Make the punches longer, move the ram down and check the dies´wear.	There is a force peak just before the maximum force in fourth or fifth station.	
6	One of the punches is broken.	Excessive wearing of the punches.	Extract the broken punch and replace it with a new one.	The force gradient is bigger than 20 in channel 3.	
7	There is a badly evacuated part inside the tool.	The extraction system is not working properly.	Extract the part and check the extraction system.	The force is very low at the end of the connection rod force curve.	
8	The strip is sticky to the pilot pins or punches.	Excessive wearing of punches or pilot pins.	Replace the faulty punch or pilot pin.	There is a force peak at the end of the curve in fourth or fifth station.	
9	The machine is not working at its nominal speed.	The monitoring system started checking the curves to early.	Re-start the machine.	All the force curves are out of the envelopes during the entire stroke.	

Figure 1: Summary of failures detected at Industrias Alzuaran.

The second branch of the project was the on line detection of defective parts at the forming facilities using artificial vision techniques with two main purposes: first to avoid the sending of any defective parts to the customers and second to decrease as much as possible the internal production of defective parts. An artificial vision system composed of two intelligent cameras (based on FPGAs) has been developed and integrated into the blanking facility at Industrias Alzuaran. The vision system is able to check the quality of more than 100 parts per minute working at the manufacturing rate and therefore analysing the 100% of the parts produced. In next figure a picture of the developed vision system and its results is shown.

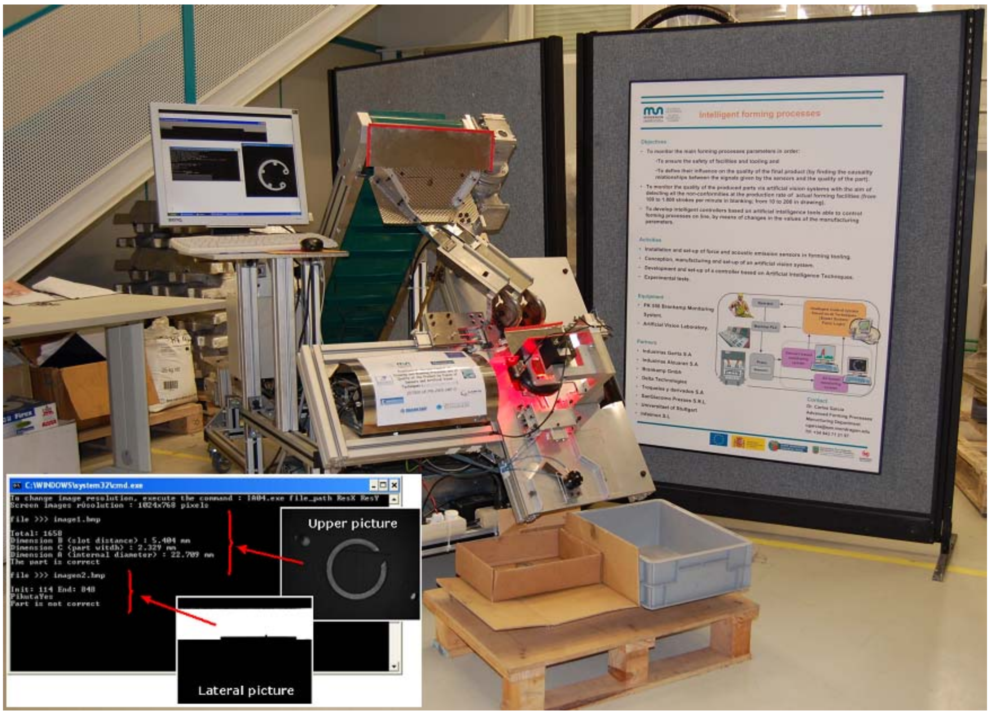


Figure 2: Developed artificial vision system for retaining rings quality assurance.

And third branch of the project was the development of intelligent controllers able to control sheet metal forming processes as human expert operators do but in an automatic way. The advantages of automatic systems over human beings are the achievement of more consistent answers for repetitive tasks, decisions and processes, efficiently and quickly and without any lack of performance because of pressure or tiredness.

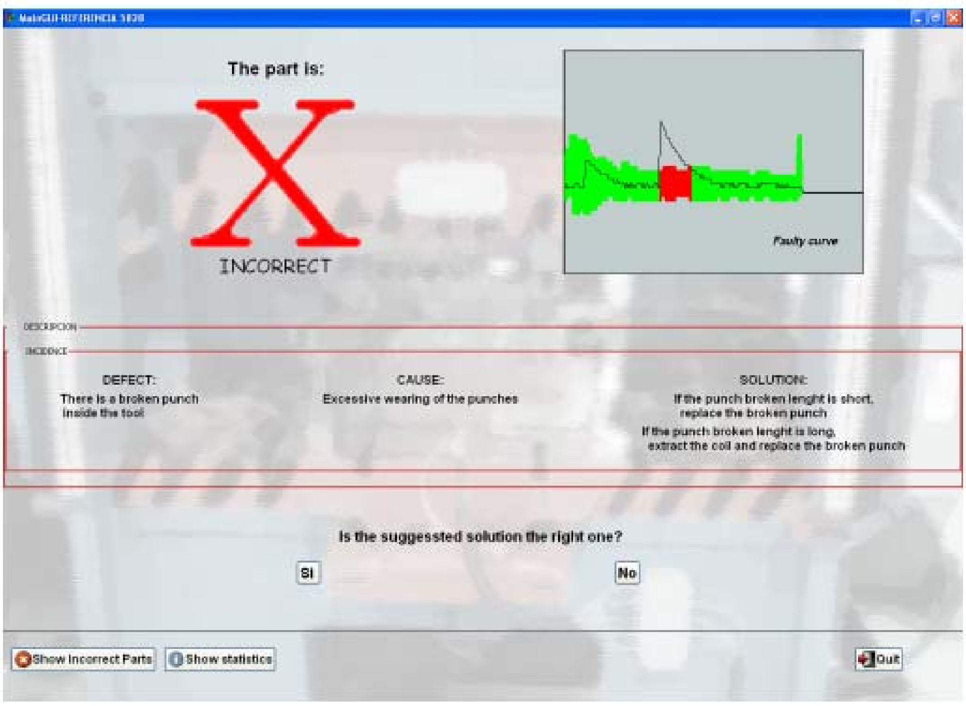


Figure 3: Graphical User Interface of the intelligent control system.

So the main objective of the third branch of the project is to develop a control system able to interpret the information coming from both, the monitoring system and the artificial vision system, and make a diagnosis about the current process performance regarding the stability of the process during production and the quality of the parts produced. The system must be able to detect process faults at the forming facility and lack of quality of the parts produced and modify the settings of the forming facility in order to avoid such situations. At the present project the feedback to the forming facility is given via human operators who can check the diagnosis of the expert system in a graphical user interface also developed at the present project (see previous figure).

And finally the integration of all the previous developed system was made at Industrias Alzuaran (see next figure). The final validation was made during the manufacturing of retaining rings in a 125 tons mechanical press using a progressive blanking tool. The production rate is more or less 60 strokes per minute and two parts per stroke are produced. Therefore the production rate is more or less 120 parts per minute. The raw material, CK 67 spring steel, is fed in the progressive tool from a sheet coil using an automatic feeder.

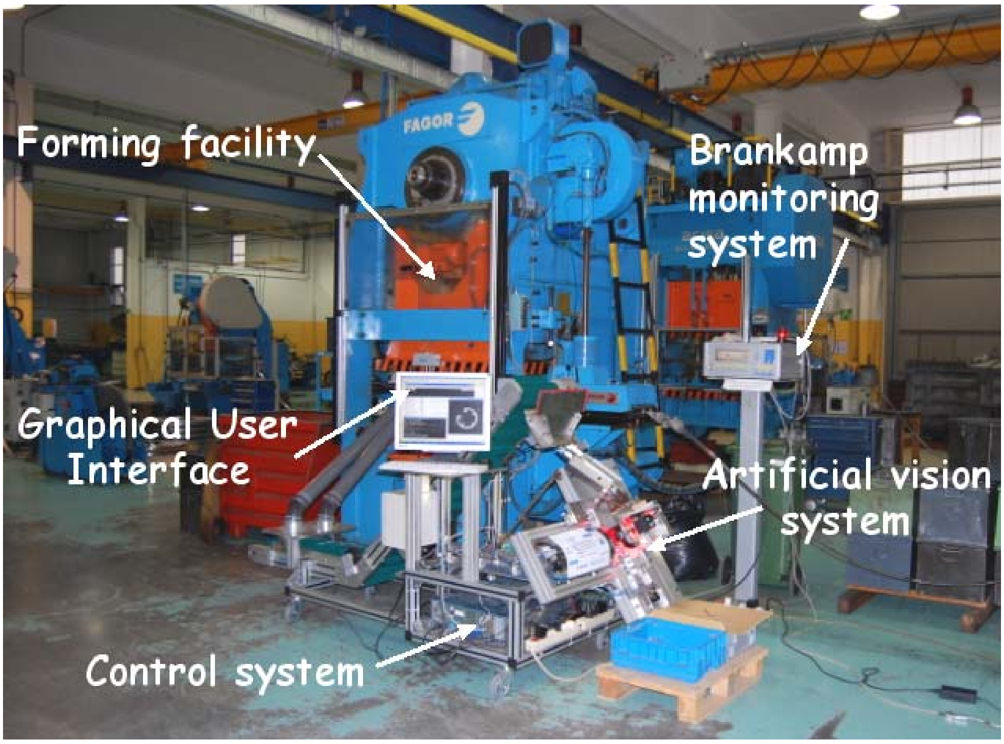


Figure 4: Global intelligent control system installed at Industrias Alzuaran.

The implementation of an intelligent control system based on Artificial Intelligent techniques into a blanking facility has been developed. The intelligent control system has been linked to a sensor based monitoring system and to an artificial vision system and emulates the control of the operator in the blanking facility. Compared to human operators, the developed intelligent control system is able to react quicker and with higher precision and reliability.

The Expert System has been running in the blanking facility during the last six months connected to the sensor based monitoring system. Up to now, four different references are controlled and nine different process faults have been found and implemented into the Expert System (see figure 1). Among the incidences, the most important are: strip feed failures due to bad extracted parts, strip feed failures due to slugs of material inside the tool, misalignment of the strip inside the tool, clogging of the strip to the tool during withdrawal of the ram, detection of broken punches and detection of double parts inside the tool due to bad extracted parts. Besides this, the intelligent controller is able to detect the position within the tool where the incidence has happened. In this way the operator only has to consult in the graphical user interface of the expert system in order to know the incidence, its position in the tool, its cause and the solution.

At the same time during the last two months the Expert System has also been connected to the artificial vision system and has been running in the production line. The artificial vision system was able to detect lateral defects like big localised burrs due to small micro cracks in the punches and evaluate the most important dimensions of the produced parts (see figure 2). With this implementation the 100% of the parts produced at the forming facility are evaluated.

The percentage of defective parts produced at the blanking facility has been slightly decreased from a 0.1% down to a 0.08%, which means a 20%. This decrement in the production of defective parts has been mainly due to the application of the monitoring system although the implementation of the Expert System results also in a better resolution of the process faults what leads to a reduction in trials and production of defective parts when solving the process faults. The percentage of faulty parts sent to the customer has also been reduced because nowadays the 100% of the produced parts are evaluated. Finally, one of the most important achievements of the implementation of the Expert System is the reduction in time, and therefore in cost, when solving machine stops. With the introduction of this Expert System the operator do not need to look for the fault in the facility but he directly finds in the interface of the Expert System a message with the instructions to solve the problem. Although no measurements have been made due to the complexity of measure this short of variables, it is estimated a reduction of about 50% in the time that the operator uses to solve the machine stops in the blanking facility after the implementation of the Expert System.

More information on Pro2Control project can be found at the web site (www.pro2control.net).

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2 Project objectives and major achievements during the reporting period

2.1 General objectives

The main objective of this project is **to develop a complete control system to be fitted on the ensemble press – tooling in order to assure a zero-defect in forming industries consecrated to the manufacturing of small size workparts**. The aim is to get a complete diagnosis and control over the quality of the production and of the state of the production goods. As a result, the control system has to be able to integrate the capabilities of state-of-the-art control systems for forming processes and to fulfil the new objective of complete control of the quality of the part. This main objective will fulfil some other objectives which are the next ones.

The final **strategic industrial objectives** of the project PRO2CONTROL are to aim towards zero defects at the customer's side and **to decrease in at least 25% the scraps of manufacture,** together with improving the worker condition, specially avoiding the manual quality control tasks.

Economic objectives are **to decrease the manufacturing costs of at least 5%** at the supplier which already use methods of surveillance of the press, and **until 20%** at those that use only manual methods by minimizing or eliminating costs due to the manual sorting, the costs of premature wear or cracking of tools and the costs of return and customers' scrap.

Safety and social objectives are to improve the worker safety and condition by avoiding him to operate directly on the machine and by monitoring the process status continuously. The worker's work will then be pointed, after training, towards more developing tasks which will be moreover partly tasks connected to the control (management and maintenance of the control equipments).

Technological objectives are the development of the monitoring and control systems and methods needed to get the "zero defect" in blanking and drawing of small size parts, either in real-time or in masked-time. This will allow an immediate diagnosis of the quality of the part, in order to do a unit and global production control.
The capabilities requested to the system are the following:

- To ensure the safety of the press and the tooling, and hence to avoid breakages and damages dues to overcharges.
- To monitor the main process parameters in order to analyse and know their influence on the quality of the product (and to find the causality relationships between the signals given by the sensors and the quality of the part).
- To detect all the non-conformities in the manufactured product, with the same analyse speed the production facilities have (from 100 to 1.800 strokes per minute in blanking; from 10 to 200 in drawing).
- To control the system on line, by means of changes in the values of the manufacturing parameters.

2.2 State of the art

In this project three different technologies will work together with the aim of fulfilling the previous objectives. These three different technologies are the following ones: Sensors based process monitoring, Artificial Vision based process monitoring, and Artificial Intelligence for process control. A brief summary of the technologies is made here but the complete information can be found in the deliverables of the project.

2.2.1 Process monitoring

Process monitoring systems are used to monitor tool / facility condition and product quality during production by evaluating signals specific to the process. In case something wrong is detected by the system, a faulty production signal is immediately sent to the press control which can react by stopping the facility, issuing a warning or activating a sorter. The use of sensors in the industry has been applied since more than two decades. The main purpose of the sensors in the industry is to assure that the facilities work correctly. The performance of the sensors in the industry has been very good and because of the new developments in electronics and informatics it is becoming better and better. The most common used sensors in forming processes are force and acoustic emission sensors. The purpose of the process monitoring in this project is to get as much information as possible of the process being studied.

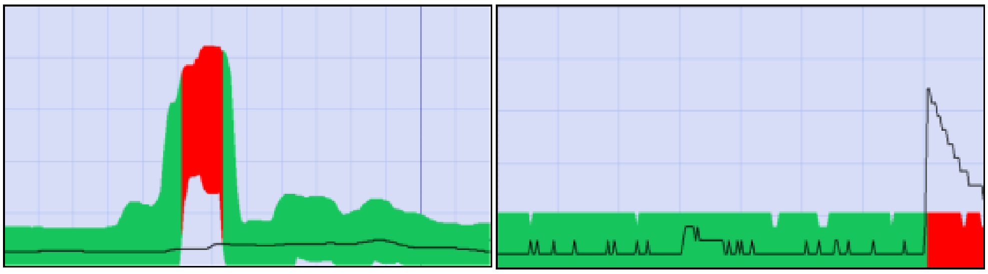


Figure 5: Force and acoustic emission signal during a blanking process.

2.2.2 Artificial vision based process monitoring

Artificial vision or machine vision uses video cameras and computers to replace human vision in evaluation and inspection tasks that are precise, repetitive or high speed. Machine vision is part of an automated inspection system that can improve product quality while lowering costs. Artificial vision, until now, has not been a common tool used in the forming industry mainly due to two reasons: the high cost of the necessary equipments and the ever-present dirtiness, both in the facilities and in the parts that reduces the efficiency of the artificial vision equipments. On the other hand the use of artificial vision applications is growing. Artificial vision can be used to detect defects, to control the position of the objects, to be a part of a manipulator, etc. In this project artificial vision techniques will be used to get information on the quality of the parts in order to control the stamping process.

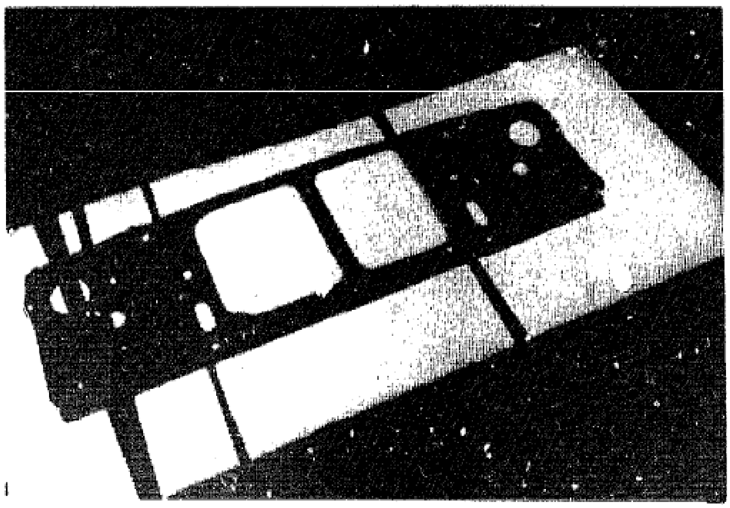


Figure 6: High speed inspection in automotive stamping.

2.2.3 Artificial Intelligence

Artificial intelligence can be considered a branch of computer science that addresses problems requiring human-like reasoning and intelligence. The artificial intelligence, as the artificial vision, has not been strongly developed for industrial applications. The main application of artificial intelligence in the industry is the control of complex facilities. The intelligence artificial techniques are used to control those processes that can not be described with mathematical equations. When this happens the traditional control techniques can not be used and therefore new techniques such as artificial intelligence are used to gather and apply in the control the experience of the operator. This is the main purpose of the artificial intelligence in this project.

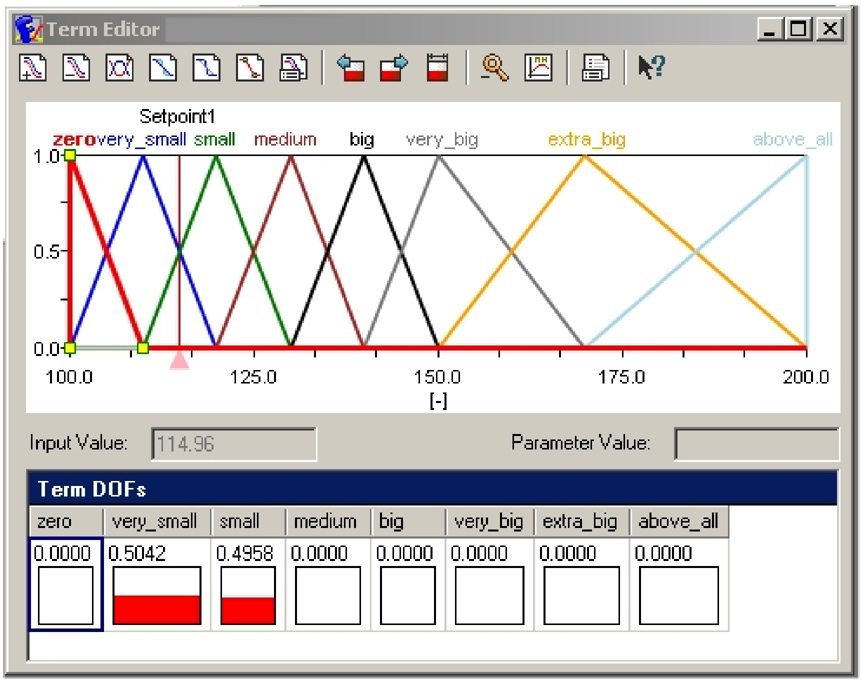


Figure 7: Membership functions of a Fuzzy logic Controller (FLC)

2.3 Main achievements of the project

The main achievements of the project in the first year can be summarised in the following points:

1. Selection of the parts (representative of blanking and drawing operations, both produced in progressive dies) to be analysed in the demonstration activity and identification of the defects to detect and control.
2. Identification of the sensors more suitable to detect those defects, acquisition and set-up in the ensemble tooling-press for both cases: blanking and drawing.
3. Identification of the elements (mechanical devices, cameras, illumination) for the Artificial Vision system, acquisition (of some of them, some others will be defined as a result of the initial tests), and preliminary try-out.
4. Identification of the common hardware and software platforms for all the systems in the project: sensors based monitoring, AV based monitoring and control).
5. Installation, set-up and validation of the monitoring system in the tool consecrated to blanking operations.
6. Development of two prototypes for the final set-up of the artificial vision system.
7. Definition and development of the control system based on artificial intelligence tools: expert system, artificial neural networks and genetic algorithms.

And the main achievements during the second part of the project can be summarised in the following points:

1. Identification of all the possible process faults detected by the Brankamp monitoring system at both forming facilities, SMEP 7 and SMEP8, and development of a process fault database containing for each process fault, its reason and the solutions to restart the production.
2. Realisation of an automatic Expert System for the intelligent surveillance of blanking processes at SMEP7.
3. Development of a co-architecture for the produced parts analysis based on the combination of hardware (intelligent cameras based on FPGAs) and software (C++ codified in PC) that gives as a results a high acceleration of the quality analysis.
4. Design, manufacturing and set up at SMEP 7 of an industrial artificial vision system able to verify on line the correct quality of the 100% of the produced parts at the blanking facility studied during the project.
5. Linkage of the three developed system into a global system at SMEP7, able to detect the process faults and instabilities, detect the production of defective parts and suggest to the operator the steps to restart the production in those cases.

So the final achievement of the project has been the consecution of a global integrated system at SMEP 7 able to surveillance the forming facility, check the quality of the produced parts and identify the problems regarding process stability of part quality suggesting the operator the best way to restart the production.

3 Workpackage progress of the period

In this section of the document, the different workpackages are going to be analysed in order to do a summary of the work done until now. This analysis is structured in the next points:

- Workpackage objectives and starting point of work at beginning of reporting period
- Progress towards objectives – tasks worked on and achievements made with reference to planned objectives, identify contractors involved
- Deviations from the project work programme, and corrective actions taken/suggested, if necessary.
- List of deliverables, including due date and actual/foreseen submission date.
- List of milestones, including due date and actual/foreseen achievement date.

3.1 Workpackage 1. Design, manufacturing and set-up of the mechanical prototype

3.1.1 Workpackage objectives and starting point of work at beginning of reporting period

The objectives of the Workpackage 1 are the following ones:

- To identify different cases of critical workparts produced in the involved companies
- To adapt a prototype tooling for the manufacturing of a workpart by blanking operations in several strokes, reproducing the problems and particularities of critical workparts currently produced in the companies of the project (SMEP7). This tooling will be used for the initial set-up and for the development of the project, as well as for the final validation together with the tooling used in SMEP8.
- To set-up this prototype in a press of the SMEP7 site.
- To build a prototype tooling for the manufacturing of a complex workpart by blanking and deep drawing operations in several strokes (progressive die), reproducing the problems and particularities of critical workparts currently produced in the companies of the project (SMEP6 and SMEP8). This tooling will be used for the final industrial validation of the project, at SMEP8 site.
- To set-up this prototype in a press of the SMEP8 site.

The different tasks defined at the beginning of the project are the following ones:

<u>Task 1.1: Selection of several specific cases and choose of the two industrial cases:</u>

- Visit to the relevant manufacturing workshops and select 5 types of cut and drawing critical workparts belonging to different ranges and intended for various industrial sectors: automotive, connections, electrical, and electro-technical. Each workpart can present one or several geometric or morphological defects. The manufacturing conditions and qualification criteria corresponding to each product have to be identified. Finally, two workparts will be chosen as the most representatives, belonging to SMEP7 and SMEP8 respectively, in order to make the set-up and validation tests on them.

<u>Task 1.2: Design and manufacturing of the mechanical prototypes:</u>

- Design a tooling for the manufacturing of both workparts, which reproduce the critical quality aspects related to the previously mentioned critical workparts. For the blanking tooling, an old die from SMEP7 will be used and modified. For the deep drawing tooling, a new concept has to be manufactured. SMEP6, taking into account the conditions specified by the companies and the constraints associated to the press that will be used in the laboratory tests at SMEP8 and to the monitoring systems and the budget allocated for that, will be responsible for designing and manufacturing the tooling. The tooling will be, in fact, progressive dies working in a continuous way in mechanical presses (frequently used in industry in the production of this type of workparts). Both SMEP3 and SMEP4 have to participate in this design task, in order to take into account that sensors, cameras and monitoring devices will be placed in these tooling.
- Manufacture of the tooling (SMEP6).

<u>Task 1.3: Set-up of the prototype at SMEP7 and SMEP8 site:</u>

- Set-up of the tooling for blanking operations at the SMEP7 site, in the press that will be used for the tests.
- Set-up of the tooling for deep drawing operations at the SMEP8 site. This tooling is usually more complex; this is the reason it has to be considered from the beginning of the project, even when it will be used only at the workpackage 6.

3.1.2 Progress towards objectives

The proposed schedule for the tasks described in the previous section is the one shown in the next picture:

Description of workpackages, tasks and specific reports	Year 1											
	1	2	3	4	5	6	7	8	9	10	11	12
WP 1: Design, manufacturing and set-up of the mechanical prototype												
Task 1.1: Selection of 5 specific cases and the presses for the tests	X	X										
Task 1.2: Design and manufacturing of the 2 mechanical prototypes (for blanking and drawing)			X	X	X							
Task 1.3: Set-up of the prototypes at SME5 site						X						

Figure 8: Schedule of Workpackage 1.

The work done and the most important results achieved in Workpackage 1 are described in the next lines of the present report.

3.1.2.1 Selection of several specific cases and choose of the two industrial cases.

First step in the research project was to select the parts that were going to be studied. Therefore, the selection of the parts which defects were going to be controlled was done for the two different SMEP companies; Industrias Garita and Industrias Alzuarán. In the following lines the chosen parts and the most important defects that have been controlled will be explained.

3.1.2.1.1 Industrias Garita

The name of the reference chosen in this company is “**Synemblock”.** This part is used to fix the engine to the car’s chassis and therefore it is a very important part regarding security.

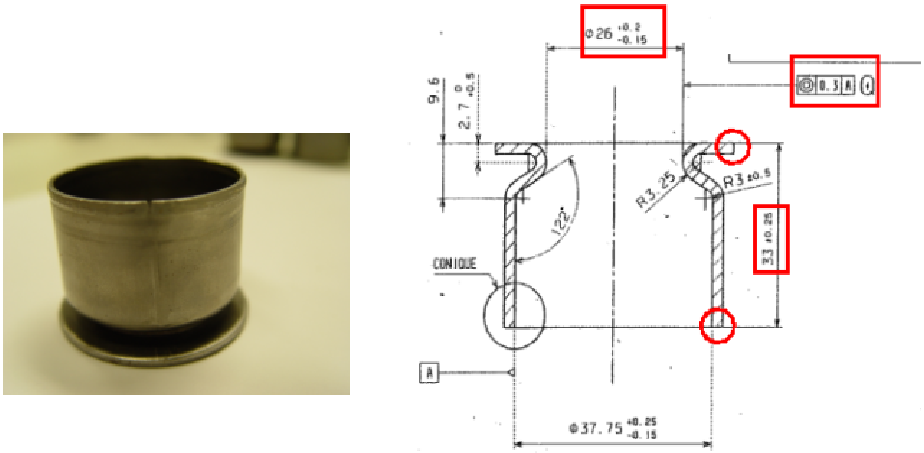


Figure 9: First part to be checked with the control system

The part is produced in a progressive tool and there are some critical defects to be controlled. Nowadays these defects are controlled by visual inspection made by human beings but sometimes this is not enough and some defective parts have been sent to the customer. At the same time since the customer belongs to the automotive industry, Industrias Garita is not allow to send any defective part to its customer. The most typical defects and important dimensions at the present reference are described next:

1. Cracks and tears in the upper diameter (expansion operations)

Figure 10: Tears in the upper diameter of the part

2. Principal diameters of the part and concentricity between them

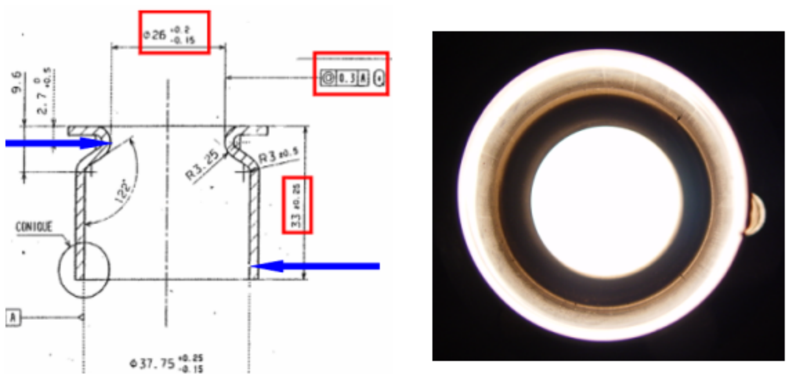


Figure 11: Diameters and concentricity between them

3. Total height of the part and burr in the upper diameter

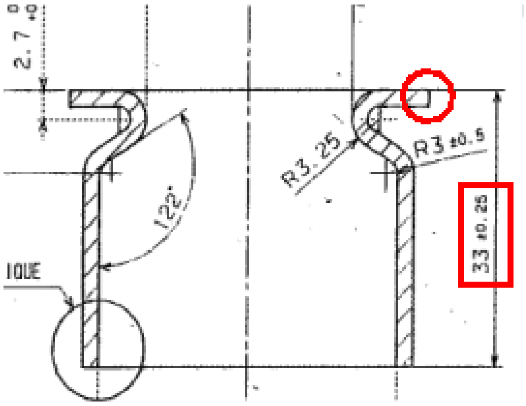


Figure 12: Total height of the part and burr in the upper diameter

Nowadays the most important dimensions are controlled by the operator of the forming facility following an statistical quality control and the defects at the part are controlled by an operator that inspects the 100% of the produced parts. The drawback of this inspection procedure is that the operator could get tired or bored (because of tedious task) and some defective parts would not be detected. In fact this has already happened in Industrias Garita and the consequence is that defective parts has arrived to its customer.

3.1.2.1.2 Industrias Alzuaran

The most important product of Industrias Alzuaran are standard retaining rings. Since all of them are very similar and it could be said that belong to the same family of parts, the research team took the decision of choosing more than one reference in order to develop a more universal control system. Therefore, for this company three different references were chosen, reference **"IA-04"**, reference **"5828-001"** and reference **"0863-012"**. The three references are produced in progressive blanking tools.

Reference **IA-04**

This reference is used for fixing cooling systems in the automotive industry. The main purpose is to measure the main dimensions of the parts shown in next image and the main defects shown in next images.

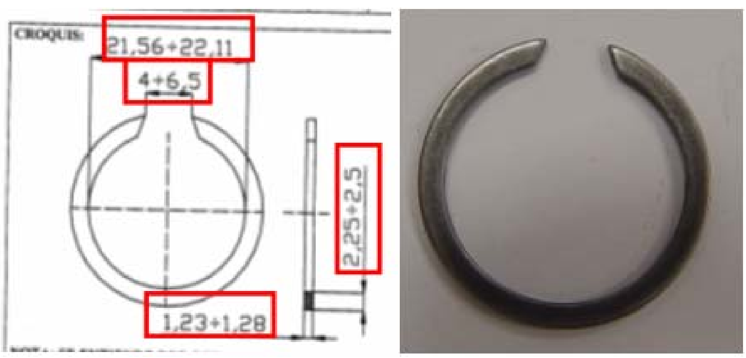


Figure 13: Reference IA04 manufactured in Industrias Alzuaran

Beside the main dimensions of the parts, the main defects to control are the ones shown below:

1. Geometry of the part: Depending on the setting of the machine some parts could be deformed during the blanking process having as a result that the final dimensions do not match with the specifications.

Figure 14: Good and bad part of the reference IA04

2. Flatness of the part: Again and depending on the setting up of the tool in the facility (in this case the position of the ram) some of the parts could loss the flatness.

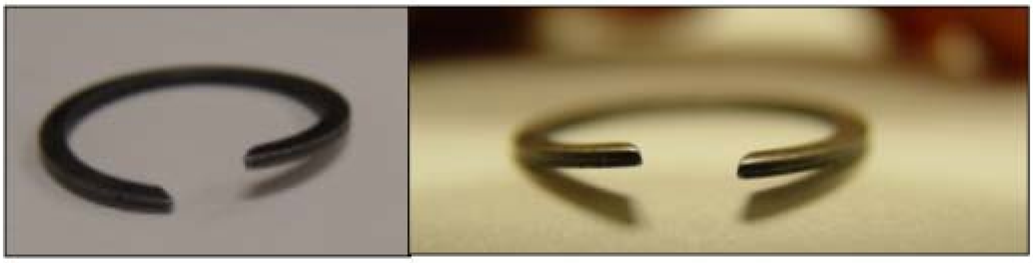


Figure 15: Good and bad part of the reference IA04

3. Dents in the surface: If the evacuation system at the machine does not work properly and some parts remains inside the tool, faulty parts are produced due to the presence of those bad evacuated parts. This could also happen if material scraps are not well evacuated.

Figure 16: Dents produced in the parts because process failure

4. Burrs in the inner or outer diameter: A normal consequence in blanking processes is the growing of the burr in the contours of the parts due to the wearing of the blanking tools. When the burrs get a critical size the blanking tools must be refilled in order to restart the production.

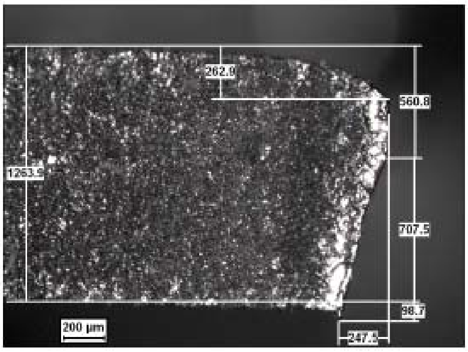


Figure 17: Burr in the corner of the reference IA04

<u>Reference **0863-012**</u>

The reference 0863-012 is used for fixing the steering wheel systems in the automotive industry. The main dimensions of the part that should be measured are shown next:

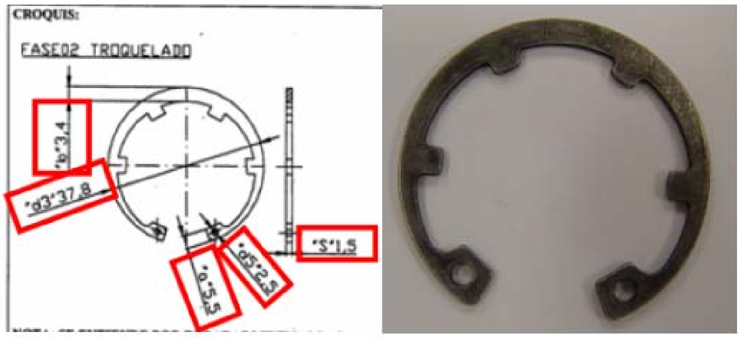


Figure 18: Reference 0863-012 manufactured in Industrias Alzuaran

At the same time the most important defects that should be controlled in the parts are shown below:

1. Geometry of the part: The same problem as in the previous reference.

Figure 19: Good and bad part of the reference 0863-012

2. Flatness of the part: The same problem as in the previous reference.

Figure 20: Good and bad part of the reference 0863-012

3. Dents in the surface: The same problem as in the previous reference.

Figure 21: Good and bad part of the reference 0863-012

And finally the growing of the burrs must also be controlled at the present reference.

<u>Reference **5828-001**</u>
Reference 5828-001 also belongs to the automotive industry and is also used, as in the case of reference 0863-012, to fix the steering wheel systems. For this reference the main dimensions to be controlled are shown in next figure.

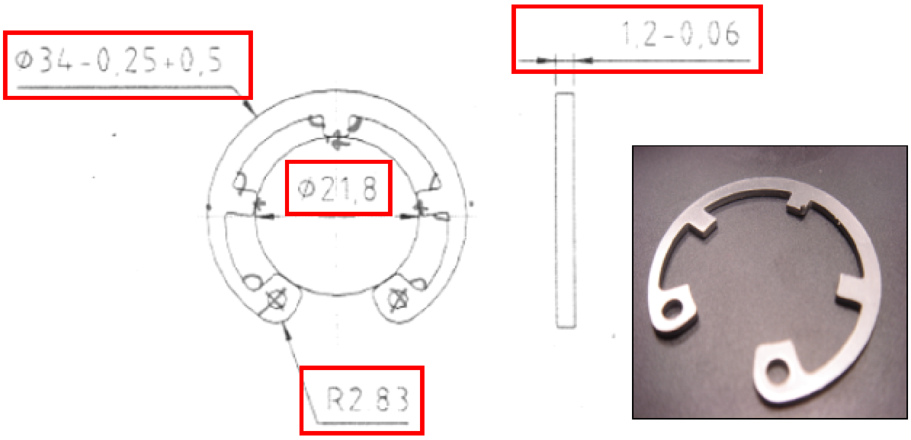


Figure 22: Reference 5828-001 manufactured in Industrias Alzuaran

The main defects to control at the present reference are very similar to the ones of the previous references (geometry of the part, flatness of the part, dents in the part, burrs at the part), but specially one defect, the most critical one has to be considered. This defect, named as pikuta, is shown in the next figure.

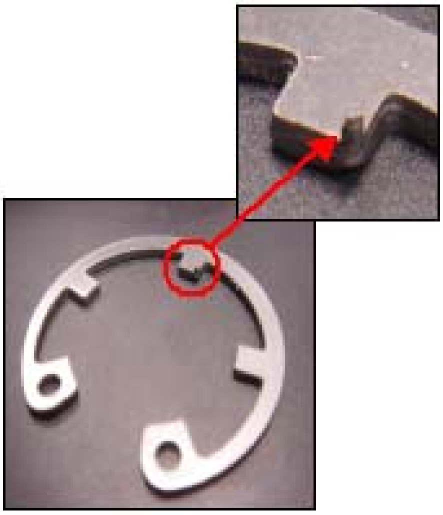


Figure 23: "Pikuta", most critical defect in the parts produced at Alzuaran

As it can be seen in the previous figure, the Pikuta is a localised big burr that appears in the parts when a punch micro crack happens. This defect can happen in all the references produced in Industrias Alzuaran since all them are produced by blanking processes.

3.1.2.2 Design and manufacturing of the mechanical prototypes.

Once the references to be controlled and the defects to be detected in each reference were chosen, next step was to develop the tools where later all the control system would be implemented. In this section the manufacturing processes for the production of the previous references are described.

3.1.2.2.1 Industrias Garita

The process for the manufacturing of this reference is quite complex. For the manufacturing of this reference, both drawing and blanking operations are combined in a progressive tool composed of 21 stations in which the part is being formed until the final shape is achieved. All the stages in the forming process are described next:

1. A spider cutting is performed in order to allow the material flow into the die in the next stations.
2. Free station
3. First drawing operation. In this operation the material is deformed until reached the height necessary.
4. Free station
5. Second drawing operation. As it is done in the 3 stage, the material is deformed until it reaches a second height.
6. Third drawing operation. This operation is needed to reach a third height in the part.

7. Free station
8. Fourth drawing operation. As in the previous operation, this one is needed to reach the fourth height.
9. Fifth drawing operation. This is the last operation which objective is to enlarge the height of the part. In this stage, the part presents its maximum height.
10. Cutting of the lower diameter of the part. In this stage, the diameter which is located at the bottom of the part, is cut, so that the expansion operations can be done.
11. Calibration of the lower diameter of the part. In this stage, it is done a calibration of the lower diameter so that the measurements of the diameter are always the same.
12. Free station
13. Free station
14. First expansion. The expansion of the diameter it is done in different stages so that it can be reduce the deformation per stage. In this stage it is done the first expansion.
15. Second expansion. In this stage it is done the second expansion with a second punch.
16. Third expansion. This is the last operation of the expansion of the diameter, in this stage is reach the maximum diameter.
17. Free station
18. Free station
19. Cone forming. In this stage, the part is deformed by a punch which has a cone form. This punch’s objective is to enlarge the diameter, but not in all the height but only in the first 2or 3 mm.
20. Free station
21. Final blanking. This operation is the one that separate the part form the blank.

The most important steps of the manufacturing process are shown in the next picture. The most critical ones are stations 14, 15 and 16 where three consecutive expansion operations take place.

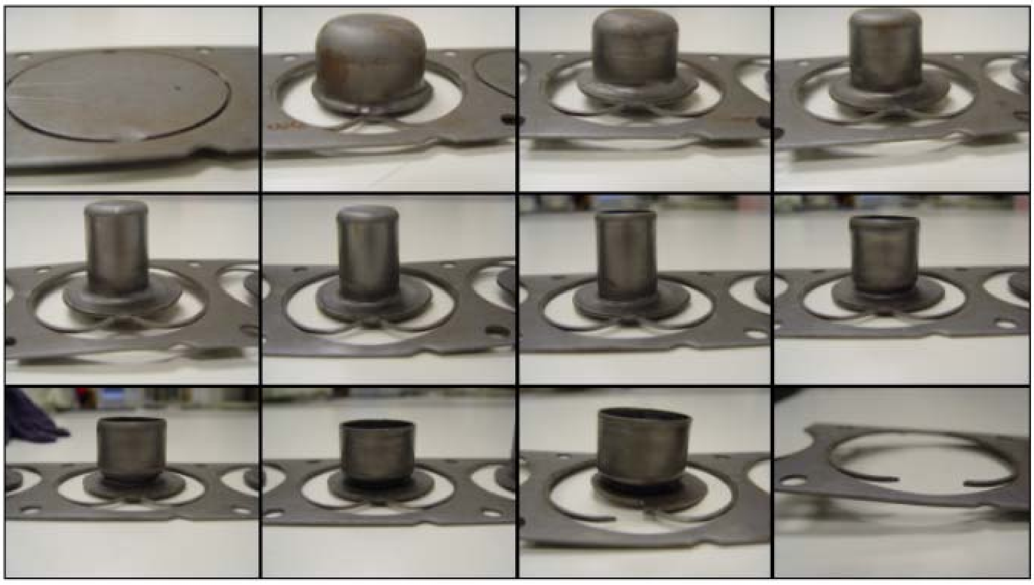


Figure 24: Manufacturing process steps of the reference Synemblock

Next an image of the tool used to produced the reference Synemblock is shown. In the figure it can be seen the complexity of the tool and all the necessary steps for the production of the parts.

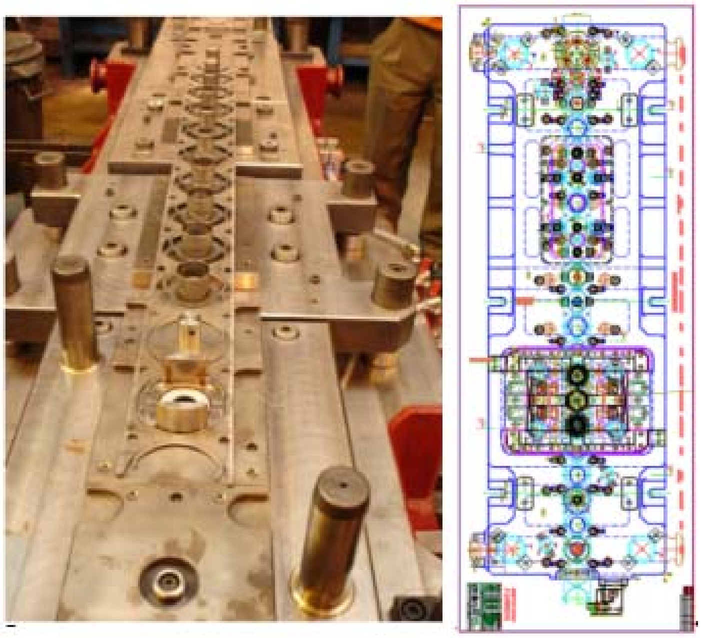


Figure 25: Drawing and picture of the tooling used to manufacture the Synemblock

3.1.2.2.2 Industrias Alzuaran

As it was stated in the previous section, three different references belonging to the same family of parts were chosen at Industrias Alzuaran. Next the manufacturing process for these references will be described.

Reference **IA 04**

In the following lines there is an explanation of the manufacturing process of the reference **IA04**. The part is produced in a progressive blanking tool composed of four stations. The forming stages are explained next:

1. –Two punches shears the metal sheet generating two holes. These holes are used for positioning the strip within the progressive tool.

Figure 26: First stage of the manufacturing process of the IA-04.

2. –In the second station, a second punch shears another area of material generating the shape shown in the picture. This shape corresponds to the central geometry of both final parts.

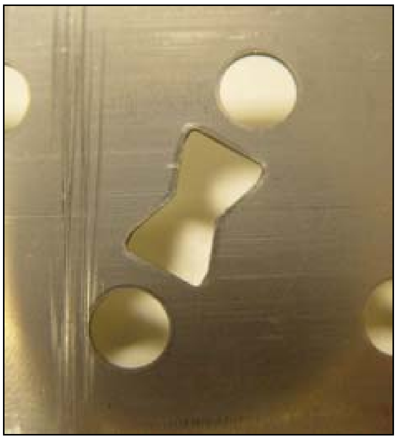


Figure 27: Second stage of the manufacturing process of the IA04

3. –In the third and fourth station, two punches (one in each station) shears the material in two diameters (external and internal final diameter of the part) generating a part that has a ring form as it can be seen in the figure 30.

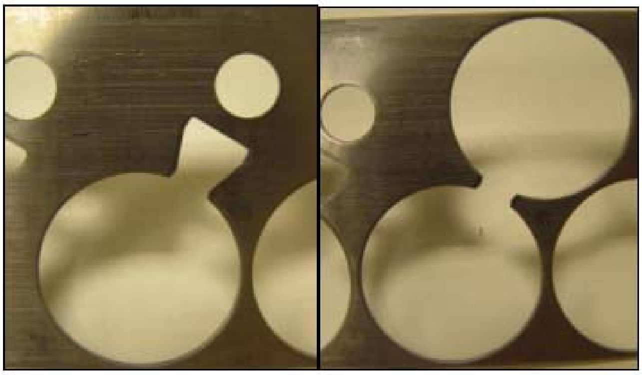


Figure 28: Third and fourth stage of the manufacturing process of the IA04

4. - The piece obtained in this process is the one shown in the next picture.

Figure 29: Final geometry of the part and strip

The tooling used to manufacture this reference is the one shown below.

Figure 30: Tooling to manufacture the reference IA04

Reference **0863-012**

For the second reference, **0638-012**, the manufacturing process is the one described below. This part is formed in the same mechanical press using another progressive tool. The forming process is achieved in four stages. These stages are explained next:

1. As in the previous case and very commonly in this type of processes, in the first station there are two punches that create two holes for the positioning of the strip in the tool.

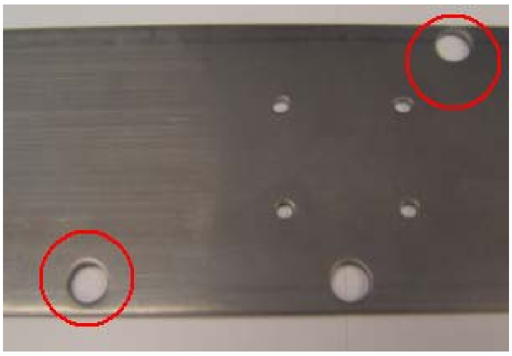


Figure 31: First station of the manufacturing process

2. In the second station, there are four punches that create the small holes in both parts at the same time. This geometry can be seen in the figure.

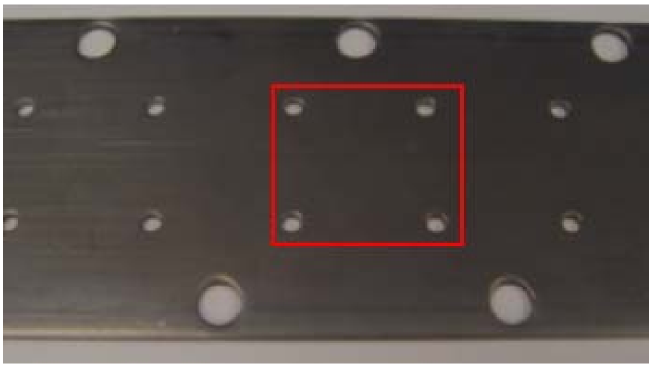


Figure 32: Second station of the manufacturing process

3. Four pins pass through the four holes to verify that there is no punch breakage in the former station.

4. In the last two stations two punches (one in each station) shears the material in two diameters (external and internal final diameter of the part) generating a part that has a ring form as it can be seen in the next figure.

Figure 33: Final stations of the process

The piece obtained in this process is the one shown in the next picture

Figure 34: Final geometry of the part

And the tooling used to manufacture this reference is the one shown below.

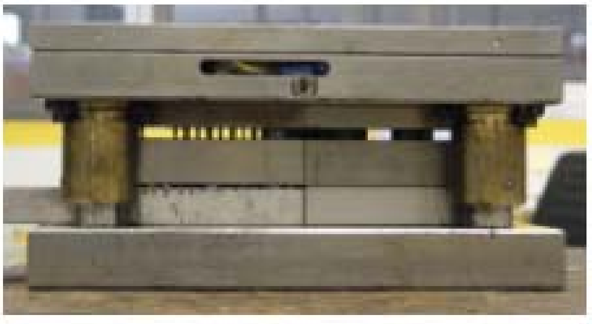


Figure 35: Tooling to manufacture the reference 0863-012

Reference **5828-001**

And finally the third reference, **5828-001**, is also formed in a progressive tool very similar to the one used for the second reference. Therefore the entire forming process is composed of four stations:

1. Cutting of the guiding holes
2. Cutting of the central small holes at the ears of the parts
3. Checking of the correct cutting of the small holes
4. Final cutting of the parts and separation from the strip material.

3.1.2.3 Set up of the prototype at SMEP7 and SMPP 8 site.

After having chosen the references that will be controlled and having prepared the tools where the references will be produced (taking into account the future installation of the sensor based monitoring system and of the artificial vision system), next step was to set up all these tools in the production facilities where the part would be produced. In the next section, the production facilities where all the experiments and trials have been performed during the project are explained.

Setting up at **Industrias Garita**

The press or forming facility used for the production of the reference Synemblock is a 400 tons press with a big table size. The production rate is more or less 30 strokes per minute and one part per stroke is produced. The raw material is supplied in coils and there is a straightener and a sheet feeder in the lateral of the press. Nowadays the extraction of the part is made by pressurize air and the parts fall down directly to a box where later are checked for the detection of possible defects. The operator of the machine is in charge of doing the quality control of the parts and therefore each 15 minutes must check the main dimensions of a predefined number of parts. In the next figure the forming facility where the reference Synemblock is produced is shown.

Figure 36: Press used during the project in Industrias Garita

At the present manufacturing facility around 20000 parts per month are produced. The main defect in the parts are the existence of tears in the upper diameter due to the excessive thinning of the material at the expansion operations. At the same time the defective percentage is around 30PPM, which means that not many defective parts are produced and at the same time, which means that the detection by means of human beings of these defective parts is very complicated.

Setting up at **Industrias Alzuaran**

The parts produced at Industrias Alzuaran are formed in a 125 tons mechanical press using a progressive blanking tool. The production rate is more or less 50 strokes per minute and two parts per stroke are produced. Therefore the production rate is more or less 100 parts per minute. The raw material, CK 67 spring steel, is fed in the progressive tool from a sheet coil using an automatic feeder.

Figure 37: Press used in the project in Industrias Alzuaran

At the present manufacturing facility around 1000000 parts per month are produced. The most produced reference is the reference **5828-001** with approximately 350000 parts per month. The other two references are not that much produced, around 150000 parts per month each reference. The main defect in the parts is the presence of Pikuta, localised big burrs that appears when small micro cracks grow in the blanking punches. The defective percentage is around 0.1%, which means that not many defective parts are produced but at the same time, the detection by means of human beings of these defective parts is very complicated.

3.1.3 Deviations from Project work programme and corrective actions

No major deviations from the work plan appeared.

3.1.4 List of deliverables

Del. no.	Deliverable name	Workpackage No.	Date due	Actual/Forecast delivery date	Estimated indicative person/month*	Used indicative person/month*	Lead contractor
D2	Mechanical prototype description (specifications and design)	1	6	6	2	2	SMEP7

3.1.5 List of milestones

Milestone no	Milestone name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
M 1.1	Mechanical prototype for blanking at SMEP7	1	6	6	SMEP7
M 1.2	Mechanical prototype for drawing at SMEP7	1	6	6	SMEP8

3.2 Workpackage 2. Development of a force and AE monitoring system

3.2.1 Workpackage objectives and starting point of work at beginning of reporting period

The objectives of the Workpackage 2 are the following ones:

- To define a common hardware and software environment for all the developments of the project, concerning:
  1. The sensors (force and AE) based monitoring system (SMEP3).
  2. The AV monitoring system (SMEP4).
  3. The control system (SMEP3, SMEP4, RTD1, RTD2).
- To acquire and set-up in the ensemble tooling – press the force and AE sensors and the PK550 monitoring system (RTD1, SMEP3 and SMEP7).
- To record the signals given by the sensors and to transfer them to the PC where the control system will be developed (RTD1). Two constraints have to be respected: the process high rate (up to 1.800 signals per minute) and the industrial environment where the system will be located at the end of the project.

The different tasks defined at the beginning of the project are the following ones:

Task 2.1: Definition of a common hardware and software environment for the project

- Gather the constraints associated to the industrialisation of the project: rate of production, industrial environment, kind and dimensions of workparts and defects encountered… (SMEP7 and SMEP8).
- Define the hardware and software means that will be used during the project, which will be able to overcome the constraints mentioned above: ensure the high-rate recording of the signal issued by the sensors and the AV system and, work in an industrial environment… (RTD1, RTD2, SMEP3, SMEP4).
- Define the measurement, data processing and analyse chains for the project (RTD1, RTD2, SMEP3, SMEP4).

Task 2.2: Acquisition & set-up of the elements for the sensors based monitoring system

- Having into account the design of the prototype (task 1.2), the sensors that are more appropriate for the detection of defects in the workpart will be chosen and bought (two force and two AE sensors are foreseen).
- The sensors will be placed in the ensemble tooling – press (probably, the force sensors will be mounted on the press, whereas the AE sensors will be placed in the tooling; FEM simulation will be necessary to identify the best placements). An initial tuning-up will be necessary (SMEP3 and RTD1).
- The sensors based monitoring system (probably a commercial Brankamp PK550) will be placed near the prototype. The sensors will be connected, and tests will be made until acquire good quality signals to validate the correct installation (SMEP3, SMEP7, RTD1).

Task 2.3: Definition of the tests and initial validation of the sensors based monitoring system

- Preliminary production tests, in order to analyse the signals given by the occurrence of different types of defects: waste penetration, tooling wear and breakage, tears and cracks in the workparts, excessive burrs,… (SMEP7, RTD1)
- Define the tests that will be needed in order to gather different signals, associated to the occurrence of different defects in the part, and the schedule foreseen for those tests (SMEP7, RTD1).

3.2.2 Progress towards objectives

The proposed schedule for the tasks described in the previous section is the one shown in the next picture:

Description of workpackages, tasks and specific reports	Year 1	2	3	4	5	6
WP 2: Development of a force and AE monitoring system						
Task 2.1: Definition of a common hardware and software environment for the project		X	X	X		
Task 2.2: Acquisition & set-up of the elements for the sensors based monitoring system			X	X	X	X
Task 2.3: Definition of the tests and initial validation of the sensors monitoring system					X	X

Figure 38: Schedule of the second workpackage

The work done and the most important results achieved in Workpackage 2 are described in the next lines of the present report.

3.2.2.1 Definition of a common hardware and software

In order to get a good definition of the common hardware and software system, the main condition has been that all the chosen systems must be able to communicate one each others because large amount of information will be share by them. Anyway the first study carried out has been to analyse the parts to be studied, geometry, size, defects to check..... as well as the conditions for their production, such as production rate, type of machine where are produced, tools, etc......

With this first analysis, the minimum requirements of the system have been established and the next step has been a review of the commercial software available in the market nowadays. Taking into account these softwares, their main characteristics, the possibility of communicate one each others and the minimum requirements for the system, a decision of the software to be used in the different systems has been done. For the signal acquisition system the system proposed by Brankamp was chosen, for the control system the software chosen is the Expert System developed in the laboratories of the NASA time ago called CLIPS and for the Artificial Vision System the software chosen are the vision libraries Open CV.

Once the softwares were chosen the final step was to choose the hardware needed to run them. Here for the signal acquisition system the hardware is the one developed by Brankamp and that is nowadays commercialised by this company. On the other hand, for both the control and the artificial vision system a common CPU was chosen. Finally this CPU will only be used to run the control system but it will also be used for the set-up of the artificial vision system. For this system more necessary components such as the cameras, the lenses or the illumination have been chosen. Therefore, in this part of the project all the necessary components to develop the system have been chosen.

In the next figure the final architecture of the control system is shown:

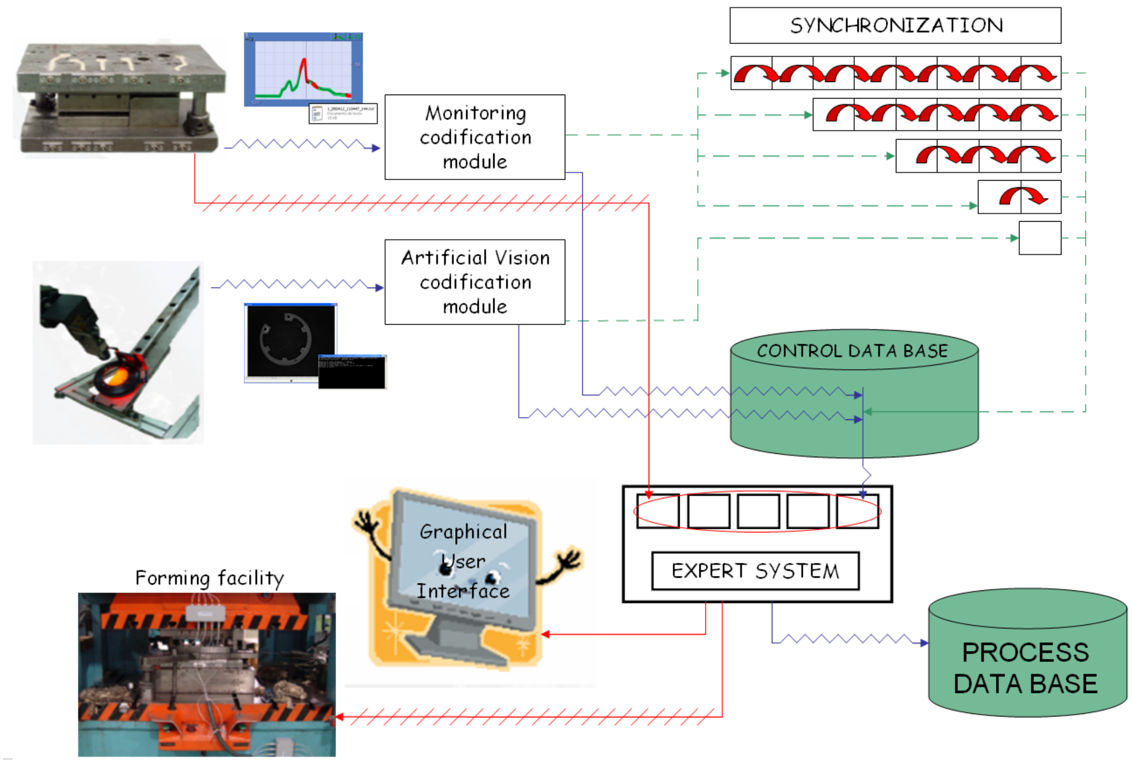


Figure 39: Information management during the control process.

3.2.2.2 Definition of the sensors and their placement in the tools

In this part of the document the type and number of sensors and their placement in the tools will be explained. This work is done for each reference.

3.2.2.2.1 Industrias Garita

Type of sensors:

In the tooling used to manufacture the reference **Synemblock**, 5 force sensors are placed. The type of sensors that is going to be installed is shown in the next figure.

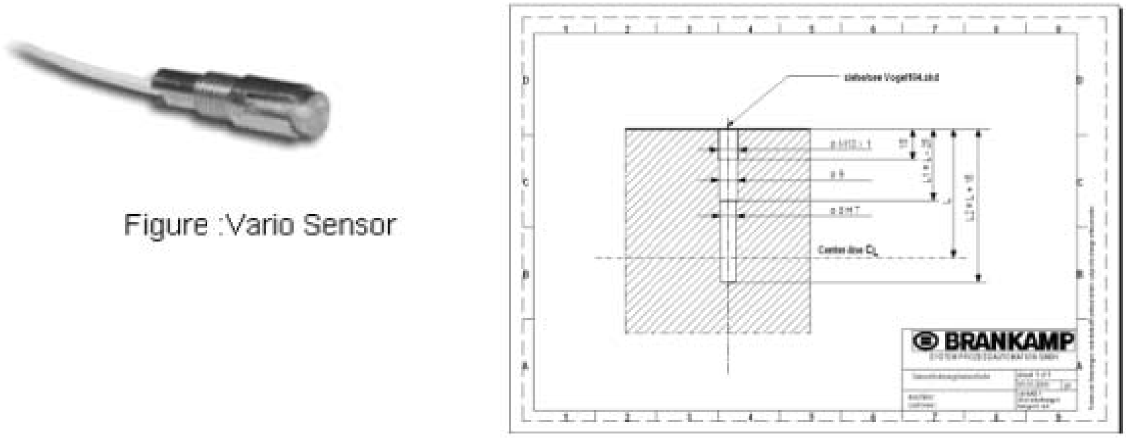


Figure 40: Force sensor used in the first tooling

This type of sensor is a piezoelectric sensor for indirect force measurement in machine structures, tools, etc. This type of sensor is able to detect tensile and compresive forces.

<u>Placement in the tooling:</u>
These sensors are going to be placed in five different work stations of the tooling. The first sensor will be placed in the station 10. In this station the cutting of the lower diameter is done.

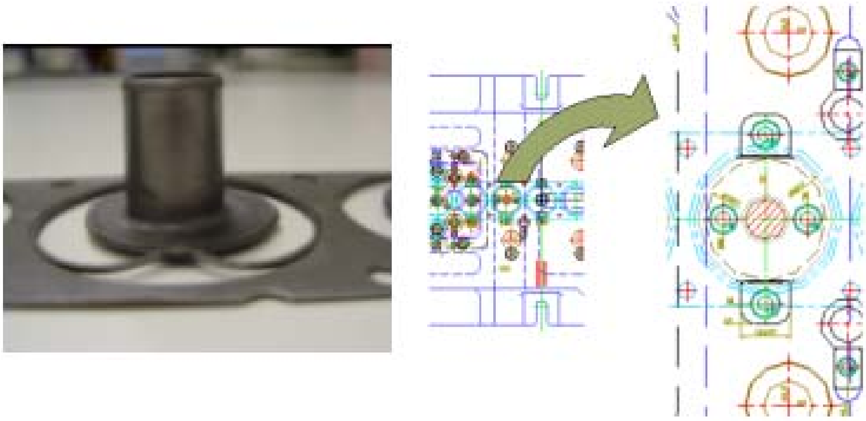


Figure 41: Station 10, first force sensor

The second sensor will be place in the station 14. In this station the first expansion is done.

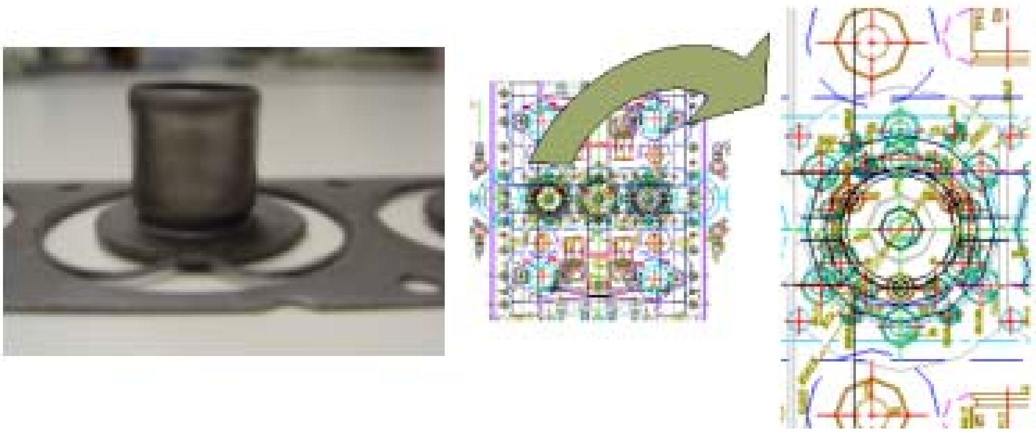


Figure 42: Station 14, second force sensor

The third sensor will be placed in the station 15. In this station the second expansion is done.

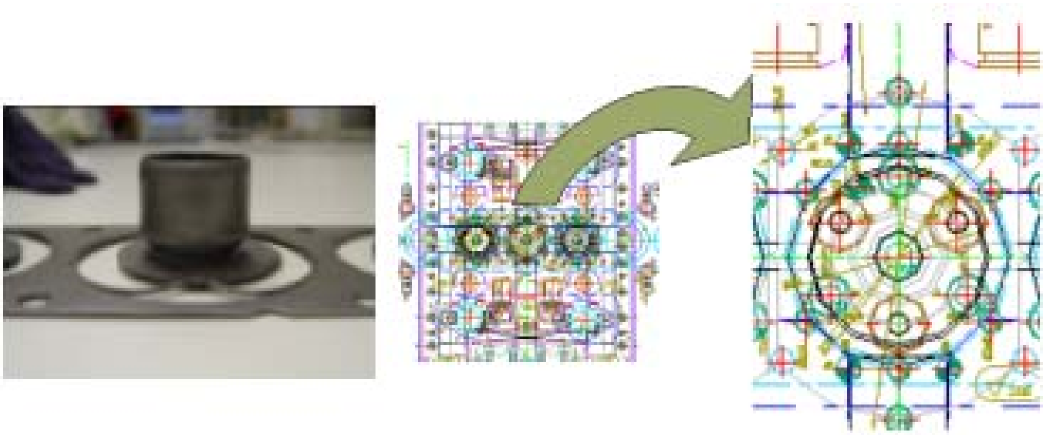


Figure 43: Station 15, third force sensor

The fourth sensor will be placed in the station 16. In this station the third expansion is done.

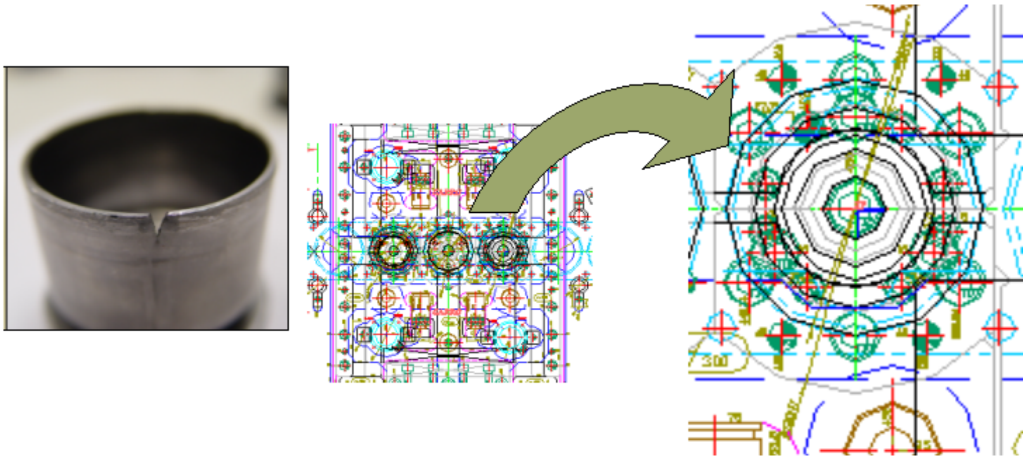


Figure 44: Station 16, fourth force sensor

The fifth sensor will be placed in the station 21. In this station the final cutting is done.

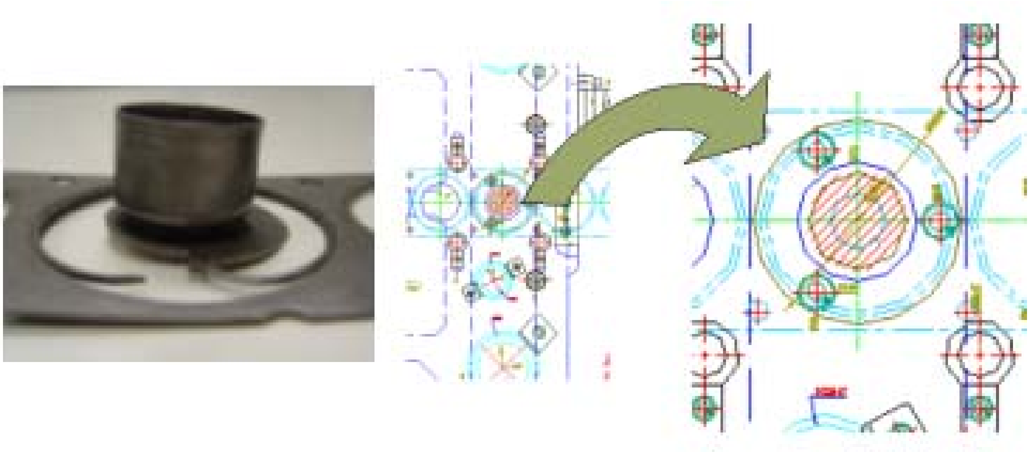


Figure 45: Station 21, fifth force sensor

3.2.2.2.2 Industrias Alzuaran

Type of sensors:

Here, the type of sensors that are going to be used for the references at Industrias Alzuaran, reference **IA-04,** reference **0863-012** and reference **5828-001** are explained next.

- Force sensors:

This type of sensor is a piezoelectric sensor for indirect force measurement in machine structures, tools, etc. This type of sensor is able to detect tensile and compressive forces.

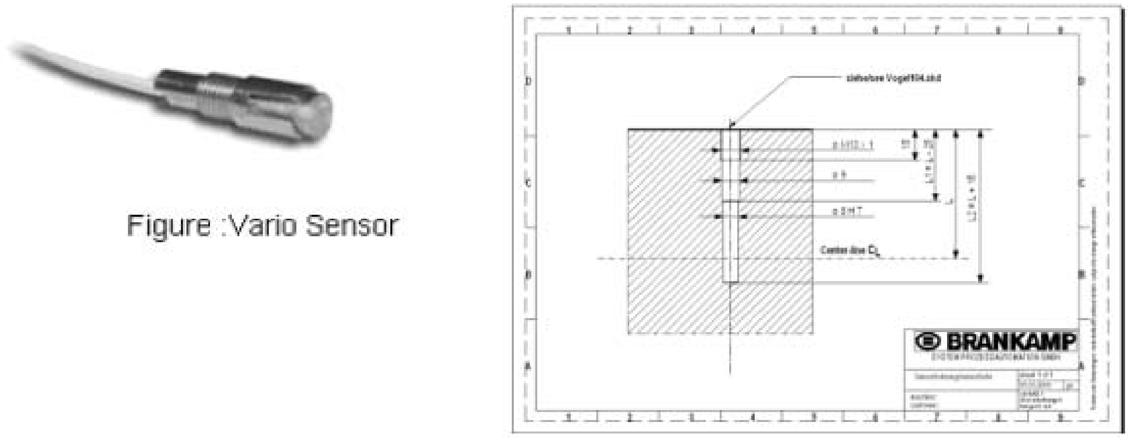


Figure 46: Force sensor used in the second tooling (IA04)

- Acoustic emission sensor:

This type of sensor is an acoustic sensor for detection of tool breakage in the LF range up to 100 kHz. It is equipped with a partly free vibrating ceramic piezo element. The sensor will be mounted with a M8 screw to the surface of the tool.

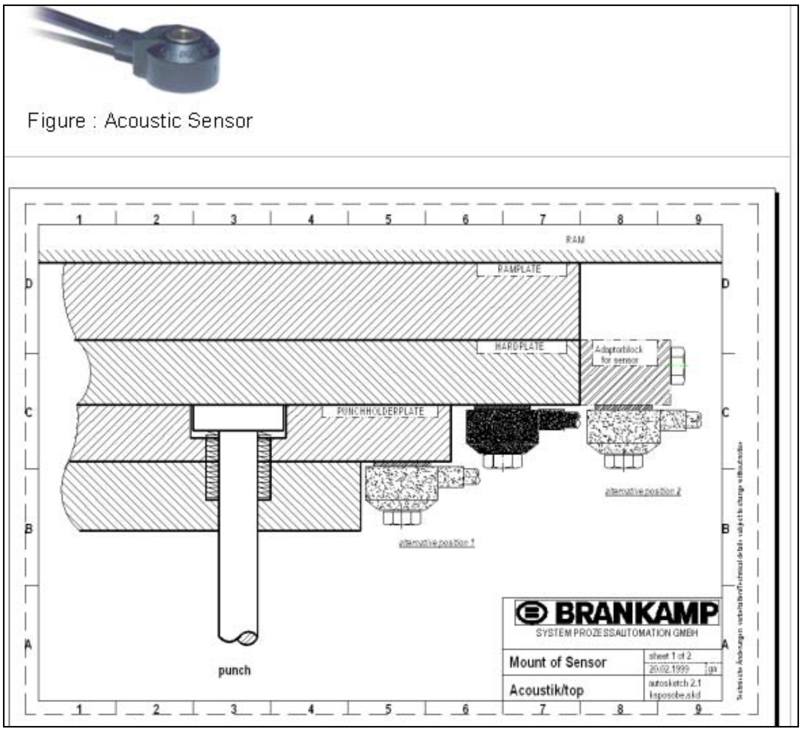


Figure 47: Acoustic emission sensor for the second tooling (IA04)

- Ultra emission sensor:

This type of sensor is an Ultra Emission sensor. This sensor for slug detection is equipped with a ceramic piezo element. The sensor will be mounted to the stripper plate.

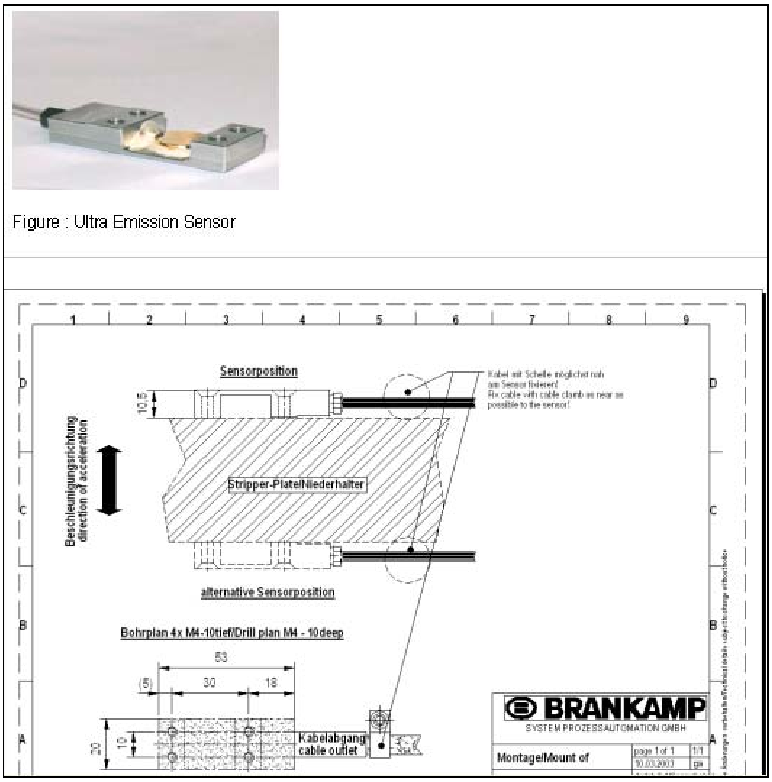


Figure 48: Ultra emission sensor for the third tooling (0863-012)

Placement in the tooling:
In this section, the placement of the sensors in the different tools (for each reference) is explained. The installation of the sensors will be in both, upper and lower side of the tooling.

Reference **IA-04**
In the upper tool 5 force sensors and two acoustic emission sensor will be installed. The position of the sensors can be seen in the next two figures.

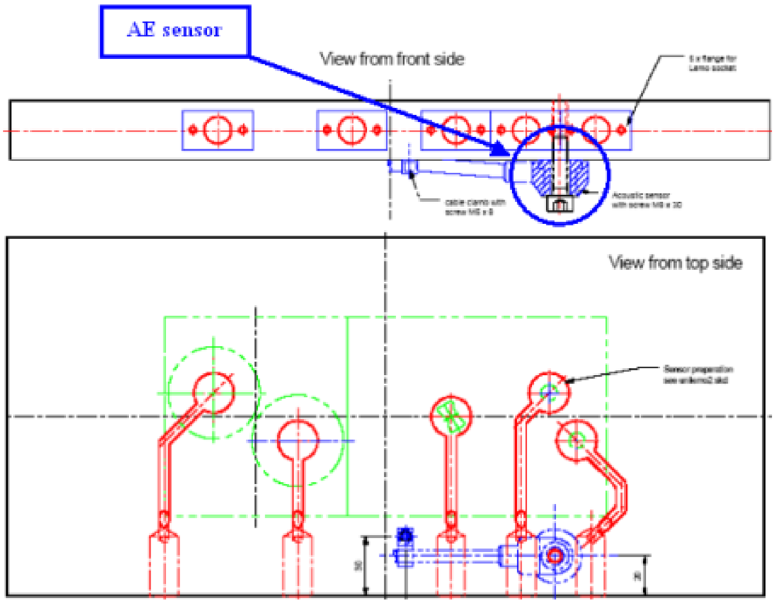


Figure 49: Upper part of the tooling for the reference IA04

In the lower tool another 5 force sensors will be installed.

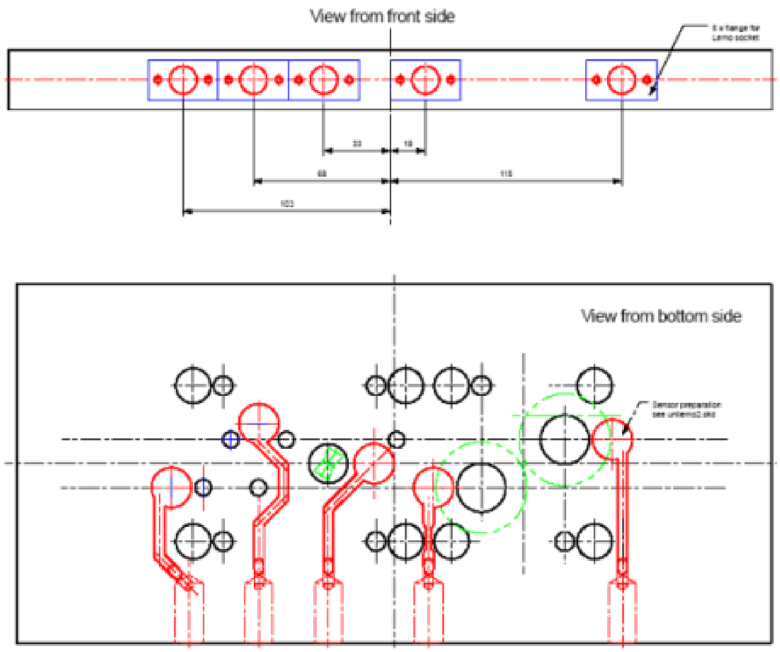


Figure 50: Lower part of the tooling for the reference IA04

Next a picture of the tool after the installation of the sensors is given:

Figure 51: Real image of the tool for the production of the reference IA 04 after sensors installation

And in next figure, a real image of the interior of the tool and the position where the sensors were placed is given. As it can be seen, the sensors were placed close to the punches and dies where the manufacturing process takes place.

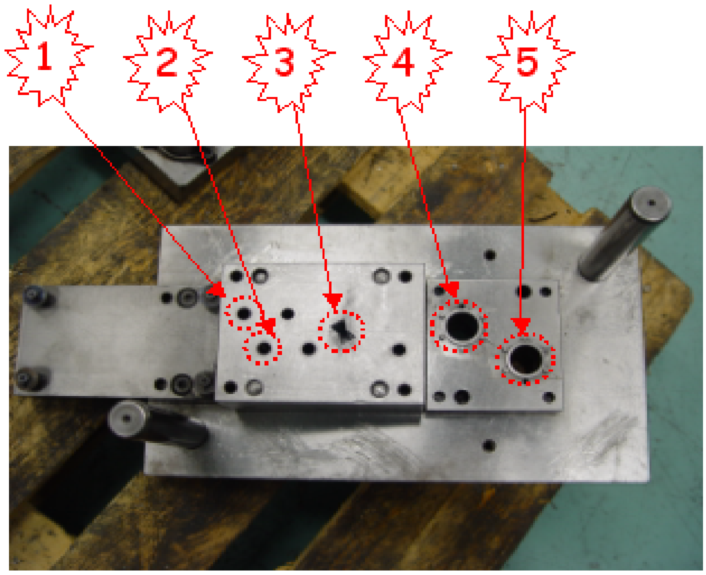


Figure 52: Position of the sensors in the tool for the production of the reference IA 04

<u>Reference **0863-012**</u>
In the upper tool, 3 force sensors, an acoustic emission sensor and one ultra emission sensor will be installed, as it can be seen in the next figure.

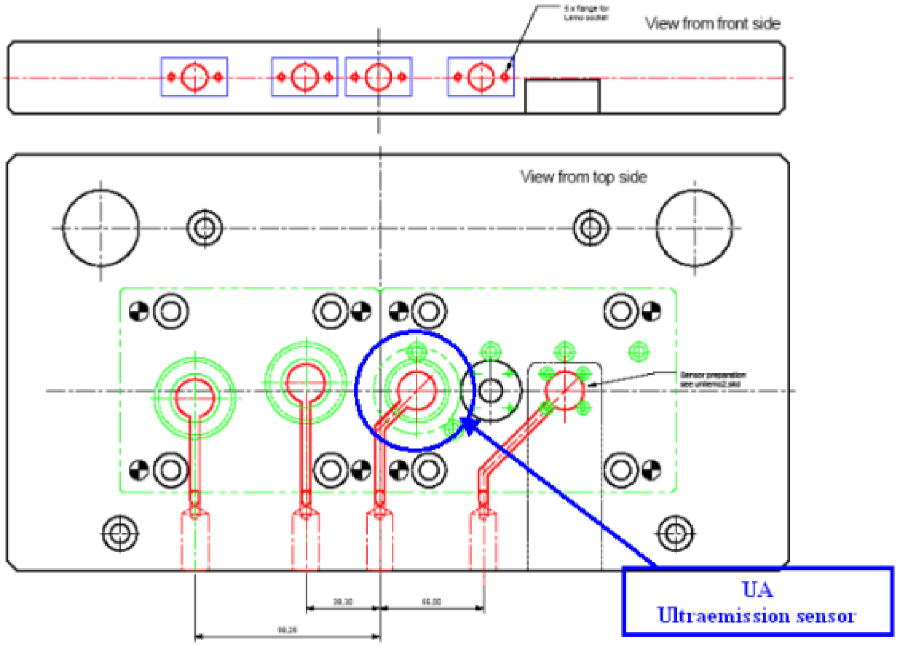


Figure 53: Upper side of the tooling for the reference 0863-012

In the lower tooling another 3 force sensors will be installed.

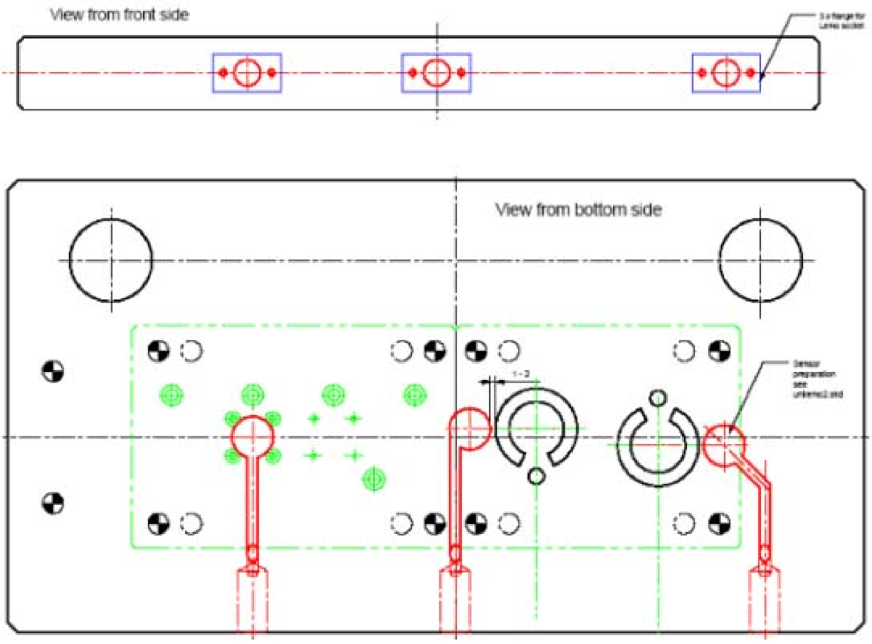


Figure 54: Lower part of the tooling for the reference 0863-012

Next a real image of the tool and the position where the sensors were installed is shown.

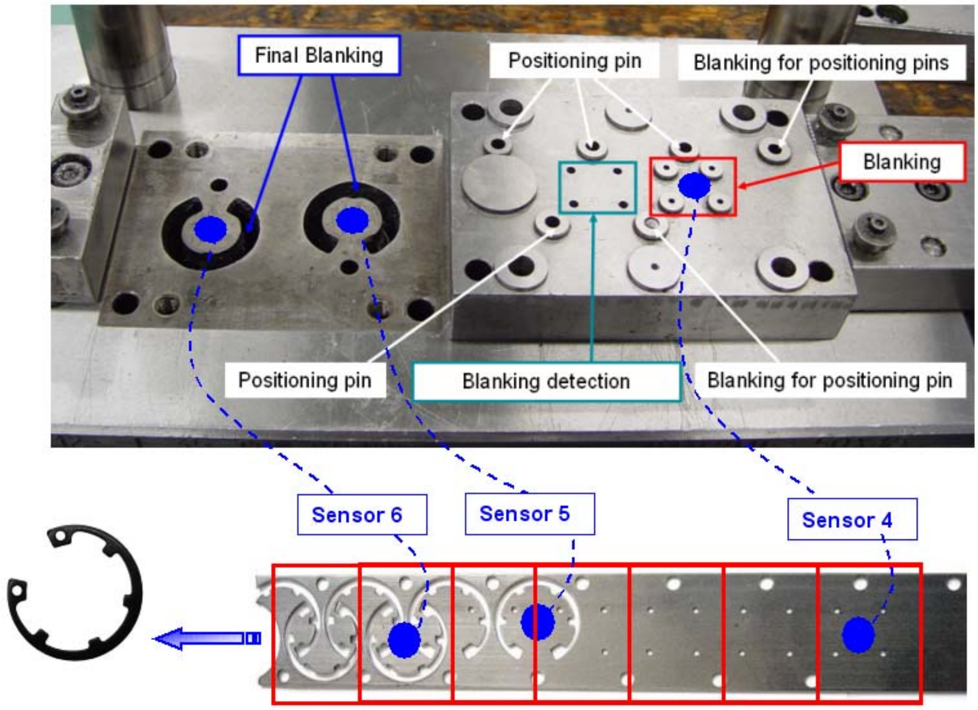


Figure 55: Position of the sensors in the tool for the production of the reference 0863-012

<u>Reference **5828-001**</u>

And finally for the third reference at Industrias Alzuaran and since the manufacturing process of this third reference is very similar to the manufacturing process of the reference 0863-012, a very similar installation to the one shown at the previous image was made. In this third reference three force sensors were installed inside the tool and two acoustic emission sensors were attached to the tool.

3.2.2.3 Initial validation of the sensors based monitoring system

After installing the sensors in the tools, several trials were made for recording signals, force and acoustical curves from the process. The way the Brankamp monitoring system works is based on the placement of two envelope curves that are created after a training period. There is a first period when the Brankamp monitoring system learns which the curves of the right process performance are and after this, it generates two envelope curves. Later, when the parts are being produced if the stroke curve is out of the envelope curves the system stops the machine. This is shown in the next figure.

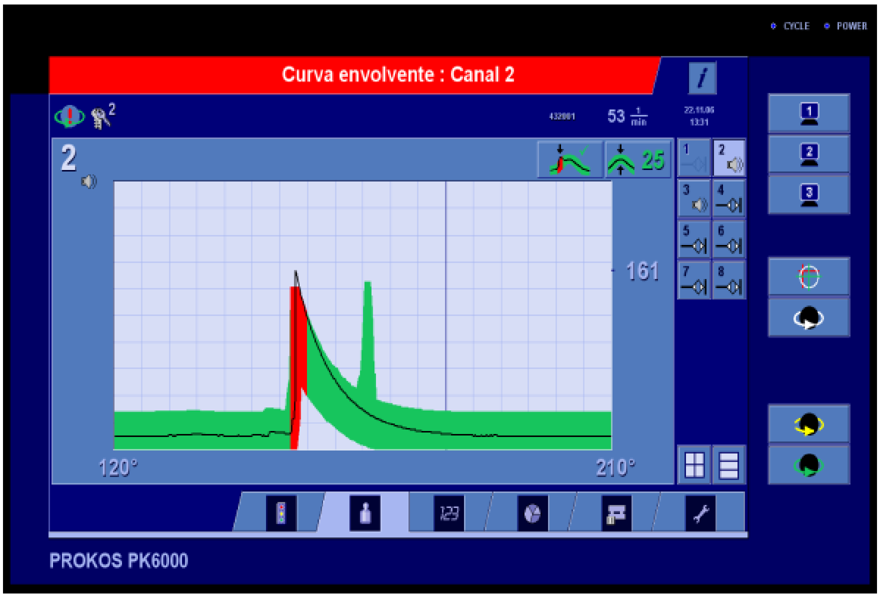


Figure 56: Process failure detection with acoustic emission channel

One of the purposes of the project is to create corrective actions when the process is not stable, when some process failure happens or when the quality of the parts is not good enough. In order to do this, the control system that will be installed in a PC must get as much information as possible from the Brankamp monitoring system. This will be achieved via a RS232 serial connection between the Brankamp monitoring system and the PC where the control system will be installed. The information will be sent in txt format as is shown in the next figure. After getting the txt file, the control system will be able to calculate the principal variables of the curves in order to evaluate the possible prediction of future process failures (this will be more deeply explained in workpackage 5).

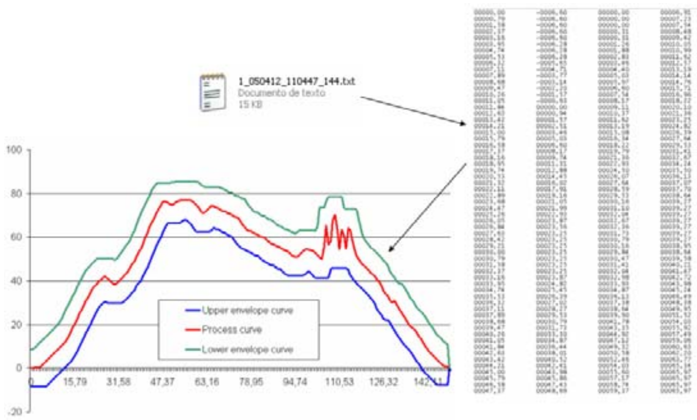


Figure 57: Brankamp txt file's information and its representation.

During this second workpackage the research team was able to communicate the Brankamp monitoring system with a PC and was able to download the curves. In workpackage four, a more detailed report about all the trails and conclusions that the research team got when using the Brankamp system are explained.

3.2.3 Deviations from Project work programme and corrective actions

No major deviations from the work plan appeared.

3.2.4 List of deliverables

Del. no.	Deliverable name	Workpackage No.	Date due	Actual/Forecast delivery date	Estimated indicative person/month*	Used indicative person/month*	Lead contractor
D1	Software and hardware environment definition	2	2	2	3	3	SMEP3
D3	Description of the sensors (force and AE) based system architecture	2	6	6	2	2	SMEP3

3.2.5 List of milestones

Milestone no	Milestone name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
M 2.1	Definition and description of the hardware and software	2	4	4	SMEP3
M 2.2	Sensors based monitoring system mounted and installed in the ensemble tooling – press	2	8	8	SMEP3
M 2.3	Description of the tests at the SMEP7 site	2	8	8	SMEP3

3.3 Workpackage 3. Development of an AV monitoring system

3.3.1 Workpackage objectives and starting point of work at beginning of reporting period

The objectives of the Workpackage 3 are the following ones:

- To develop an AV system for the analysis of workpart quality, able to detect dimensional accuracy and excessive burrs in blanking, scratches and cracks in drawing, in a fast way (at least 1.800 inspections per minute for blanking), and easy to adapt to a new workpart (SMEP4).
- To install the AV system on a PC next to the press at the SMEP7 site (SMEP4, RTD2).
- To modify the settings and illumination of the AV system and to develop the algorithms for the detection of defects in the workparts (RTD2, SMEP4)
- To validate the AV system in a real time system, in an industrial environment, but using the tooling specifically designed for the research tasks of the project (SMEP4, SMEP7, RTD2).

The different tasks defined at the beginning of the project are the following ones:

Task 3.1: Acquisition and set-up of the elements for the AV based system:

- Having into account the specific cases selected in the task 1.1, the commercial elements needed for the AV system will be chosen and bought, probably an OC-PSS-40 system (SMEP7).
- Installation of the AV system on the same PC as workpackage 2, close to the press and tooling, adaptation of the press-tooling ensemble to place the AV system, illumination set-up (SMEP4, SMEP7, RTD2).
- The system has to be adapted to the parts produced in the experimental tooling, in order to detect the defects associated to both workparts, but having into account that an easy change procedure to a new workpart has to be foreseen. Illumination conditions and system settings will be analysed, AV algorithms will be tested to ensure proper defect detection (SMEP4, SMEP7, RTD1, RTD2).

Task 3.2: Definition of the tests and initial validation of the AV based monitoring system

- Tuning up for the detection of dimensional accuracy, excessive burrs, scratches and cracks in the blanking and stamping workparts selected in the task 1.1. Artificial Intelligent techniques, like neural networks, will be used to detect defects like cracks and wrinkles (SMEP4, SMEP7, RTD2)
- Adjustment of the AV system in order to be able to work fast (at least 1.800 inspections per minute), and in an industrial environment: dust and dark (SMEP4, SMEP7, RTD2).
- Tests, results and conclusions (SMEP4, SMEP7, RTD2).

3.3.2 Progress towards objectives

The proposed schedule for the tasks described in the previous section is the one shown in the next picture:

Description of workpackages, tasks and specific reports	Year 1											
	1	2	3	4	5	6	7	8	9	10	11	12
WP 3: Development of an AV monitoring system												
Task 3.1: Acquisition and set-up of the elements for the AV based system		X	X	X	X	X	X					
Task 3.2: Definition of the tests and initial validation of the AV monitoring system					X	X	X	X				

Figure 58: Schedule of the third workpackage

The work done and the most important results achieved in Workpackage 3 are described in the next lines of the present report.

3.3.2.1 Acquisition and set-up of the elements for the AV based system

3.3.2.1.1 Artificial Vision System Benchmarking

In order to acquire knowledge and experience, visits to other companies have been made. The companies visited are the following ones:

- <u>Fagor Ederlan</u>: Works in the automation sector manufacturing different parts like suspensions, brake, motors and transmission systems. In its manufacturing plants there are different types of artificial vision devices that work in common with robotic devices. This company presents the similar problematic of dirty parts that the one that presents this project.
- <u>Tuboplast:</u> Manufactures plastic and metal plastic tubes for the cosmetic industry. This company has several artificial vision devices. The problematic that Tuboplast presents in common with this project is the frequency of analysis of the parts.
- <u>Cegasa:</u> Manufacture different types of batteries. Cegasa has some artificial vision devices in order to make some control of the batteries. In this company, matricidal and intelligent cameras are used.
- <u>Infaimon:</u> This is the company which is going to sell the material of the artificial vision to this project.
- <u>Mondragón Sistemas</u>: This is a company that develops projects “key on hand”. The artificial vision is not very evolved. They have a commercial device of compact vision.

The conclusions of these visits are the following ones:

- It is impossible for humans to make a 100% of revision and detecting all the defective pieces.
- It is possible to take pictures in the air but it depends on the defects wanted to detect and on the tolerances.
- The utility of LED illumination because of their good performance, large period of life and low maintenance.
- The utility of FPGAs for accelerating the algorithms.
- The necessity of using a small laser as a trigger for the shutting of the camera

3.3.2.1.2 Artificial vision device election and acquisition

The main components for the development of an artificial vision system are the cameras, the lenses and the illuminations although other components such as the triggers or the computer for the image treatment must be selected.

After doing some initial evaluations of the parts taking into account the different dimensions that should be measured, it was decided that at least two cameras are needed. One of the cameras will be placed in a top position and will make an upper picture of the part and the other camera will be placed in a lateral generating the lateral picture of the part. An example of one of the parts manufactured in Industrias Alzuaran is given in the next figure.

Figure 59: Upper and lateral picture of the reference 0863-012.

For the upper picture it was clear from the beginning that the right decision was to use a matricidal camera. After talking with some companies specialised on vision systems, they suggested to work with a 1280*1024 pixels matricidal camera. At the same time, and because the depth of view necessary for this application is very low, the thickness of part, they also suggested to use a normal lens. For the illumination a LED illumination was chosen after comparing their results with other kind of illumination such as fluorescent or incandescent illumination.

With all this characteristic, the quality of the upper image can be seen in the left side of the previous figure and the resolution is close to 50 microns, enough to detect any defect in the produced parts.

A budget for the material needed for this upper view of the part is shown in the next table.

NOW	Price (€)
uEye USB 2.0 cameras - SXGA (1,3 Megapixels) with CCD sensors	
UI-2240-M 1280x1024 1/2" **CCD** 15 monochrome 8 Bit async. Progressive	1428
Angled cable with Trigger & Strobe for industrial use	89,82
The cable is equipped with a 90° angled micro Sub-D connector with screws. The cable is split in two wires. A screened USB 2.0 cable with a USB type A connector and a four wire cable with open ends for trigger and digital out. The cable conditional suitable with drag chains and it is available in different length.	
CCS-LFL-4012 Back-light inspec. Silhouette Rojo, 50 x 95 mm	363,79
12 v for Back-light CCS-LFL-4012	66,67
OPT-GMn21214mcn Óptica 12mm F1.4 para camara rosca c 2/3"	128,8
NER-010-600200 DF-150-3 Dark Field Illuminat. Rojo, 75°, Continous	975,81
12 v Dark Field NER-010-600200 DF-150-3	71,67
Photocell	
Total:	**3124,56**
JUNE	
Conveyor belt	2500
Mechanical device for the artificial vision system	1000
Computer for treatment of images	1800
Artificial system device (2 cameras+2lenses+illumination dark field)	4340
Total:	**9640**
NOVEMBER	
2 FPGA ADP-WRC-II 2V6000	**17000**
TOTAL:	**29764,56**

Figure 60: Description of the components of the artificial vision system.

The lateral view for this kind of parts is much more complicate. The first aim was to use a linear camera and get a high resolution. For example, using a linear camera of a1000 pixels, the resolution should be around 2 microns, which is enough to distinguished if the burr is getting problematic or not. After asking to many artificial vision system suppliers, it was found a big problem for the use of this camera in this application. The problem is that the lenses for this kind of cameras, linear cameras do not have a very big depth of view. This means that the camera will have a very good resolution in the plane where it is focused, but when moving perpendicularly to this plane the quality of the image is very bad. This fact can be seen in the right side of the previous figure, where the image of the part is completely fuzzy.

Because of this reason it was decided to work with matricidal cameras and with lenses prepared for this type of cameras. Specifically, telecentric lenses will be used with matricidal cameras. In this way the completely picture of the part will be on focus but on the other hand the resolution will be much lower. This means that one of the questions that will have to be checked is if it will be possible to measure the burr of the part.

3.3.2.1.3 Development of the algorithms

Next there is a briefly explanation of the algorithms that will be used to evaluate the quality of the part. The complete design of the algorithms can be found in the document “NTT-06-007-tra Project State at July 7th 2006 - the two parts”.

Reference **synemblock**:

The dimensions and tolerances to control for this reference are the ones described below:

- The dimension A must be in this range, 25,85 and 26,2mm.
- The tolerance B indicates that the concentricity between the diameters must be in an error of 0,3mm.
- The dimension C must be in this range, 2,7 and 2.75mm.
- The dimension D must be in this range,33 and 33,25mm.
- The dimension E must be in this range, 38 and 37,6mm
- See if it has cracks

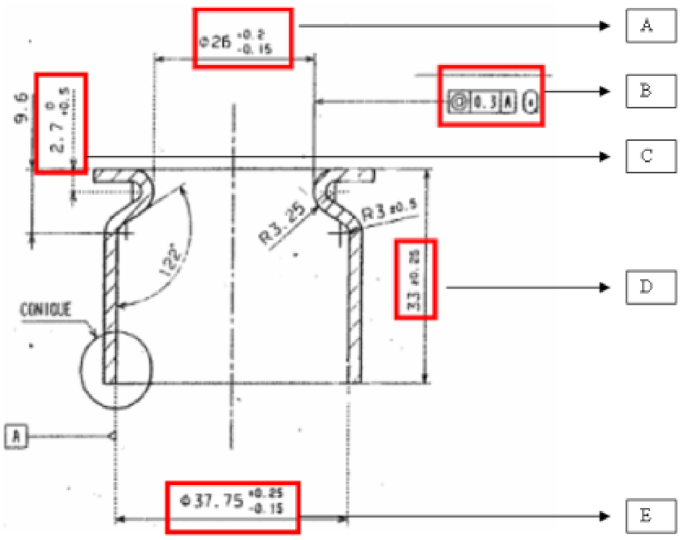


Figure 61: Tolerances to control in the reference Synemblock

The way the algorithms evaluate the reference Synemblock is explained in the next diagram:

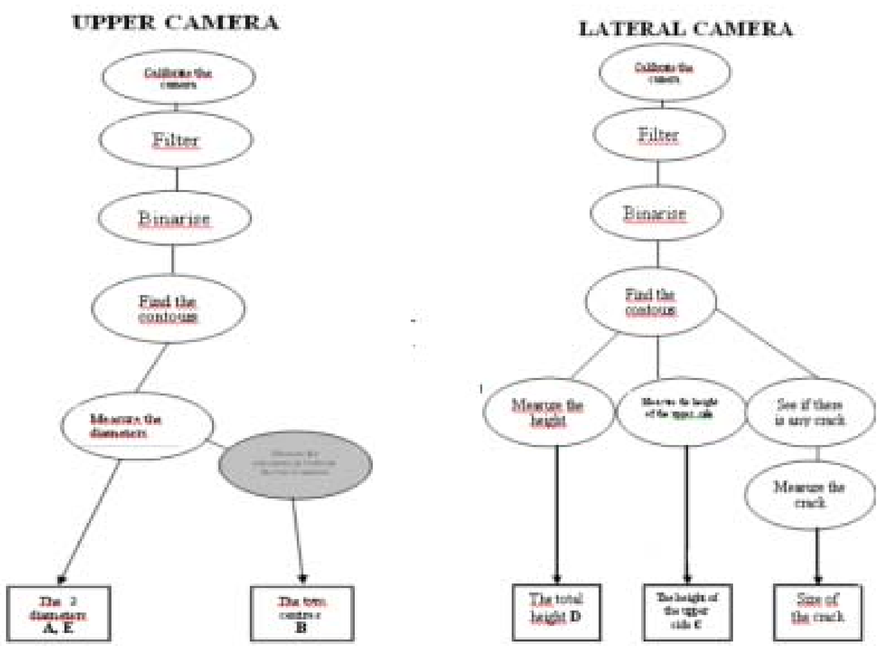


Figure 62: Algorithms for the upper and lateral camera for the reference Synemblock

<u>Reference **IA-A04:**</u>

The dimensions and tolerances to control for this reference are the ones described below:

- The dimension A must be in this range 21,56 and 22,11mm.
- The dimension B must be in this range 4 and 6,5mm.
- The dimension C must be in this range 2,25 and 2,5mm
- The dimension D must be in this range 1,23 and 1,28mm
- See if it is plane
- See if it has a localized burr

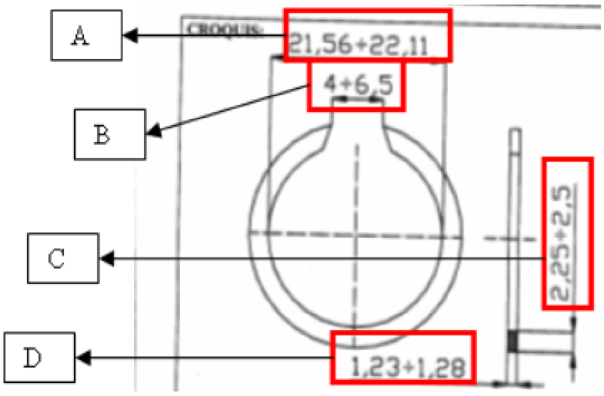


Figure 63: Tolerances to control in the reference IA04

The way the algorithms evaluate the reference IA 04 is explained in the next diagram:

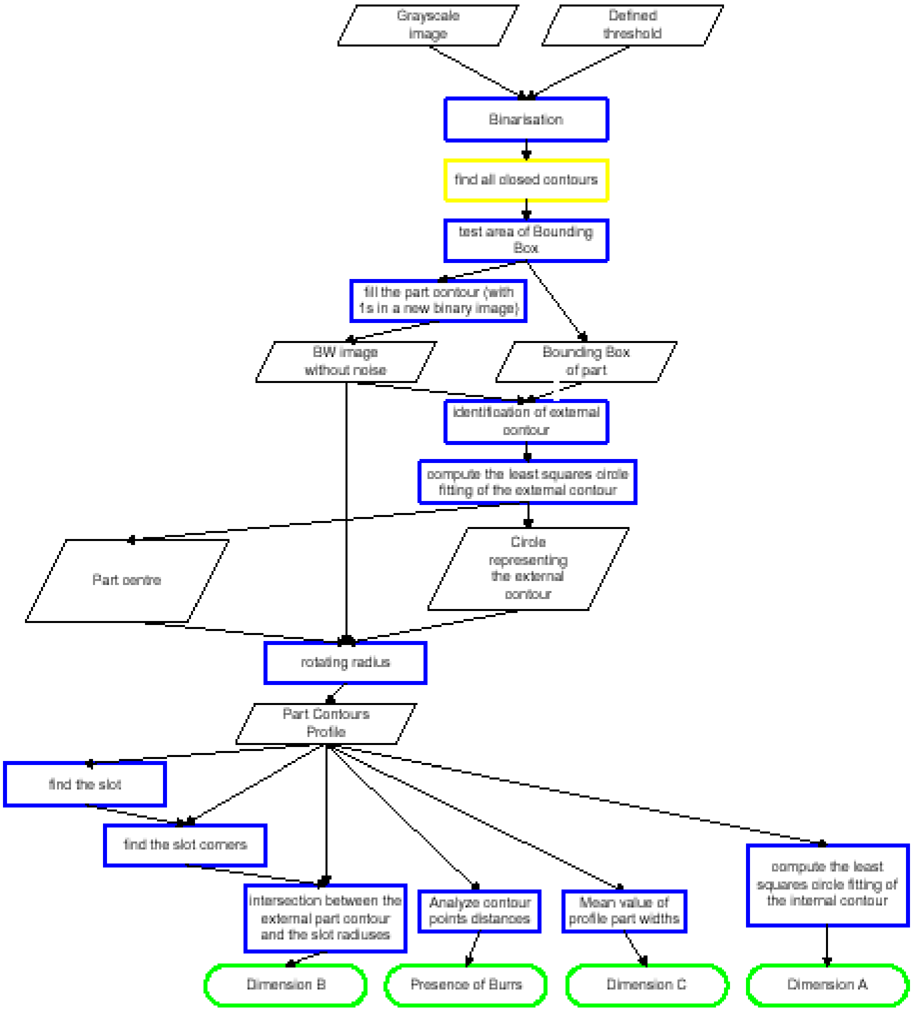


Figure 64: Algorithms for the upper and lateral camera for the reference IA04

<u>Reference **0863-012:**</u>
The dimensions and tolerances to control for this reference are the ones described below:

- The dimension A (b) must be approximately 3,4mm.
- The dimension B (d3) must in this range 38,30 and 37.55mm
- The dimension C (a) must 5,5mm as maximum.
- The dimension D (d5) must be in this range 1,23 and 1,28mm
- The dimension E (s) must be in this range 1,5 and 1,495mm
- See if it is plane
- See if it has a localized burr

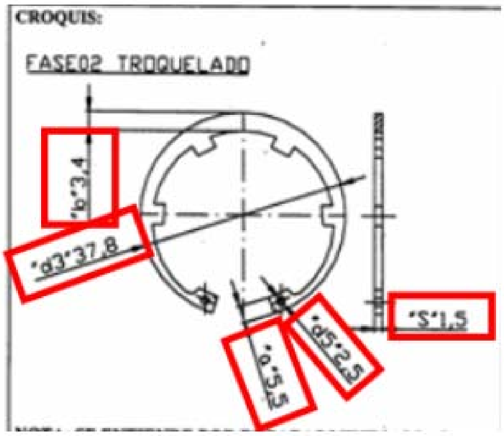


Figure 65: Tolerances to control in the reference 0863-012

The way the algorithms evaluate the reference 0863-012 is explained in the next diagram:

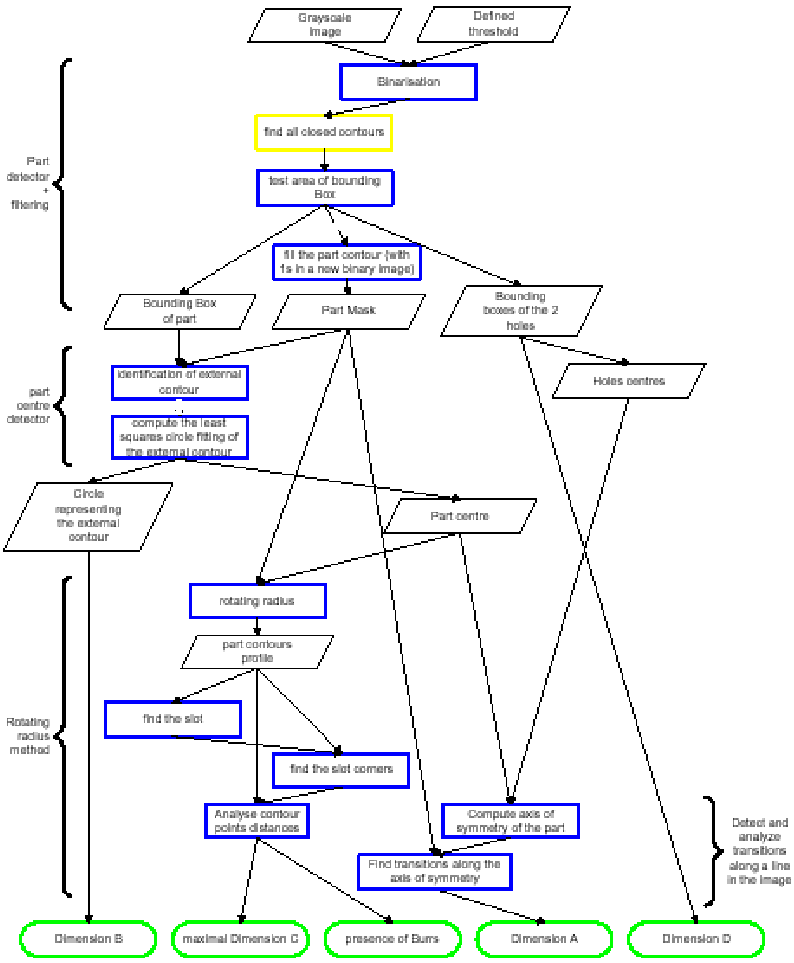


Figure 66: Algorithms for the upper and lateral camera for the reference 0863-012

And finally the algorithms applied to the reference **5828-001** are more or less the same as the algorithms applied to the reference 0863-012.

3.3.2.1.4 Development of the mechanical device

Although the initial idea of the project was to develop a common artificial vision system for all the references, after making a deeper evaluation it was stated that different cameras, lenses and illuminations were needed depending on the type of parts to be evaluated. At the same time, the mechanical device which is in charge of taking the parts from the press, placing them in front of the cameras to take the pictures and releasing them from the artificial vision device will also be different depending on the parts to be studied.

Therefore, in order to install the cameras and the illumination, which are the main parts of the artificial vision device, two mechanical devices have been designed and tested. These mechanical devices have the flexibility of installing the cameras in many positions, because during the set up, changes in the camera's positions will be necessary. The mechanical devices also control the positions of the parts that leave the machine. This is a critical point due to the importance of taking always the same photo of the different parts of a same reference. In the following lines the mechanical devices for each company are explained.

<u>Industrias Garita</u>
<u>First prototype:</u>
The initial idea of the research team was to develop a mechanical device that makes the parts rotate and during their rotation several pictures were made and evaluated. In order to get this, a first prototype was created and tested. This first prototype develop for the reference Synemblock is shown in the next images.

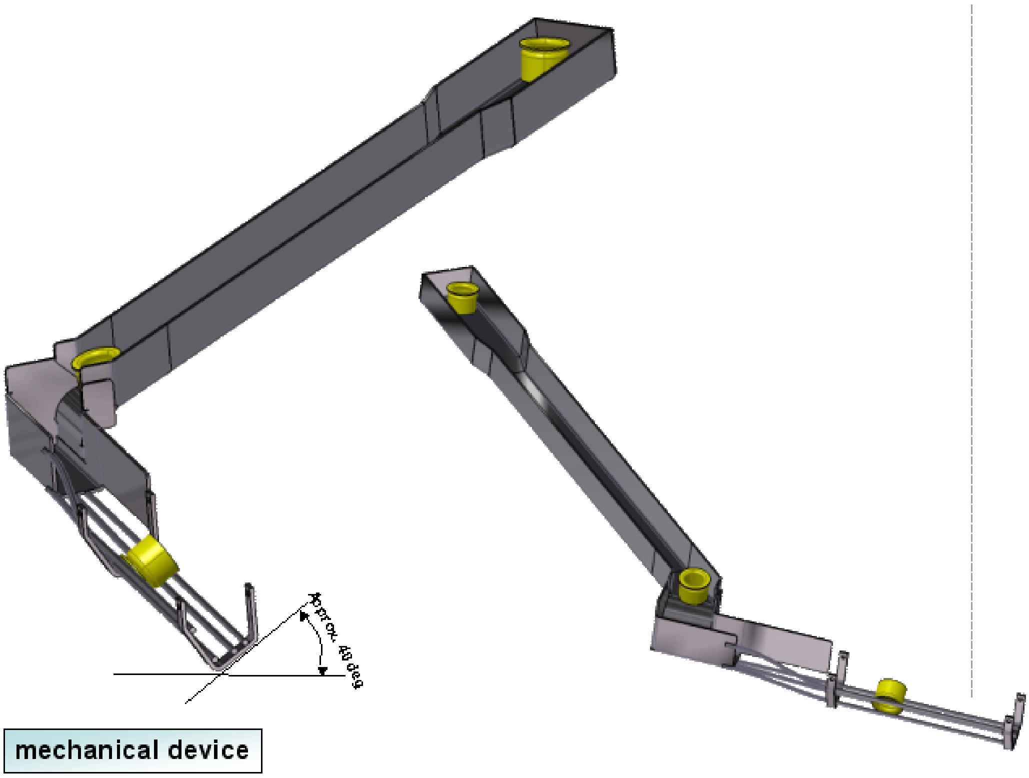


Figure 67: Design of the mechanical device for the reference Synemblock

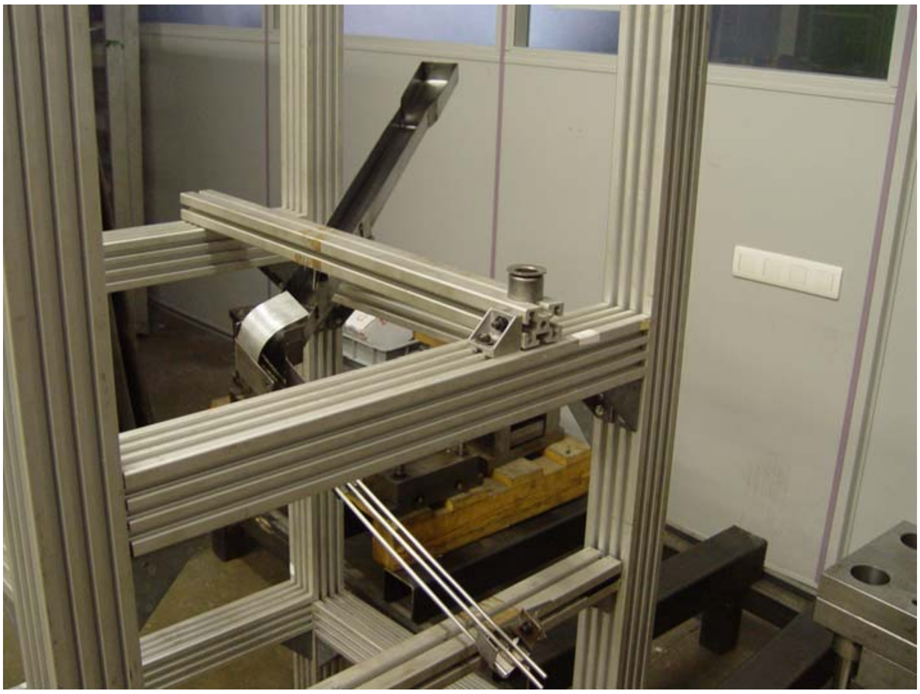


Figure 68: Picture of the first mechanical device for Industrias Garita´s part

With this first prototype several pictures of the parts during rotation were taken and the research team realised that the rotation of the parts was not able to be controlled and therefore the quality of the pictures was not good enough. Next a few pictures of the reference Synemblock taken at this prototype are shown.

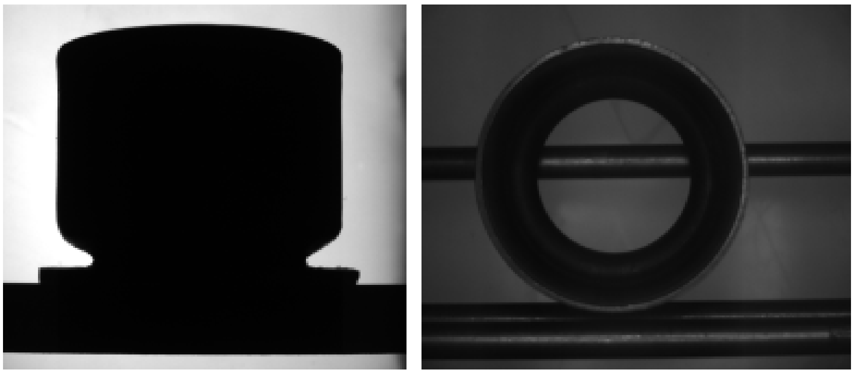


Figure 69: Lateral and upper picture of the Synemblock taken in the first prototype

After the pictures two consequences were very clear. First the lateral camera needed more resolution if small tears wanted to be detected in the upper diameter. At the same time, the strategy used for this lateral camera was to take more than one picture (in this case three pictures) in order to check all the lateral contour. This strategy had a problem by its own, and is that if the rotation of the part is not controlled bad quality pictures could be taken and at the end the lateral contour would not be well develop. At the same time for the upper picture, if the part was not rotating properly and therefore the centre of the part was not properly aligned with the camera, the diameters and the concentricity between them were not correctly measured and the dimensions were not right.

All these problems that appeared during the trials with this first prototype made the research team to change the idea and to develop a new mechanical device for the reference Synemblock.

Second and final prototype:

The purposes of the research team for the second prototype were two. First to introduce a linear camera instead of a matricidal camera for the lateral picture. With this introduction a much better resolution can be achieved and defects that could not be detected with the matricidal camera are now detectable. At the same time this new strategy needs a rotational movement of the part to be studied. In order to get this, the part is rotated but in a controllable way meanwhile the lateral linear camera takes the images. In the next figure the second artificial vision prototype for the reference Synemblock is shown.

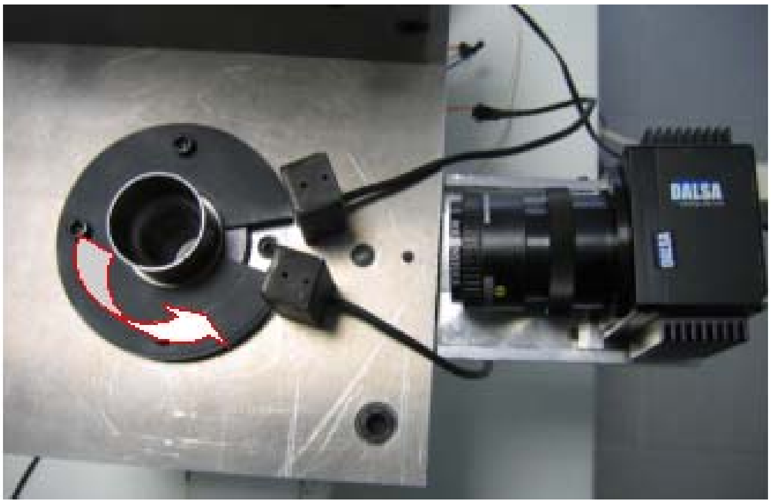


Figure 70: Figure if the second mechanical prototype developed for the reference Synemblock

Next both images, the upper and the lateral one, of the reference Synemblock taken with this second prototype are shown.

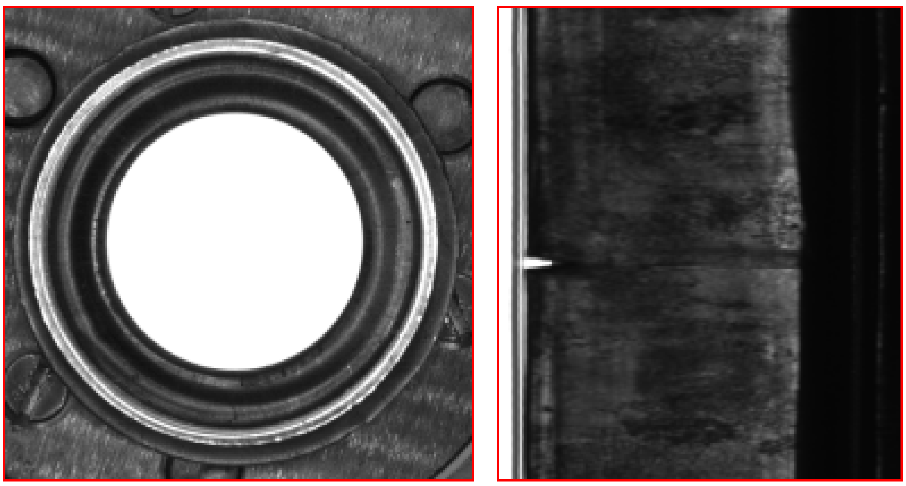


Figure 71: Upper and lateral image of the reference Synemblock at the second prototype

Since the image taken with this second prototype avoided the problems got with the first one, lack of resolution and lack of stability, it was decided to design and manufacture, following the strategy chosen for this second prototype, an industrial prototype for the evaluation of the reference Synemblock in situ in the press at Industrias Garita.

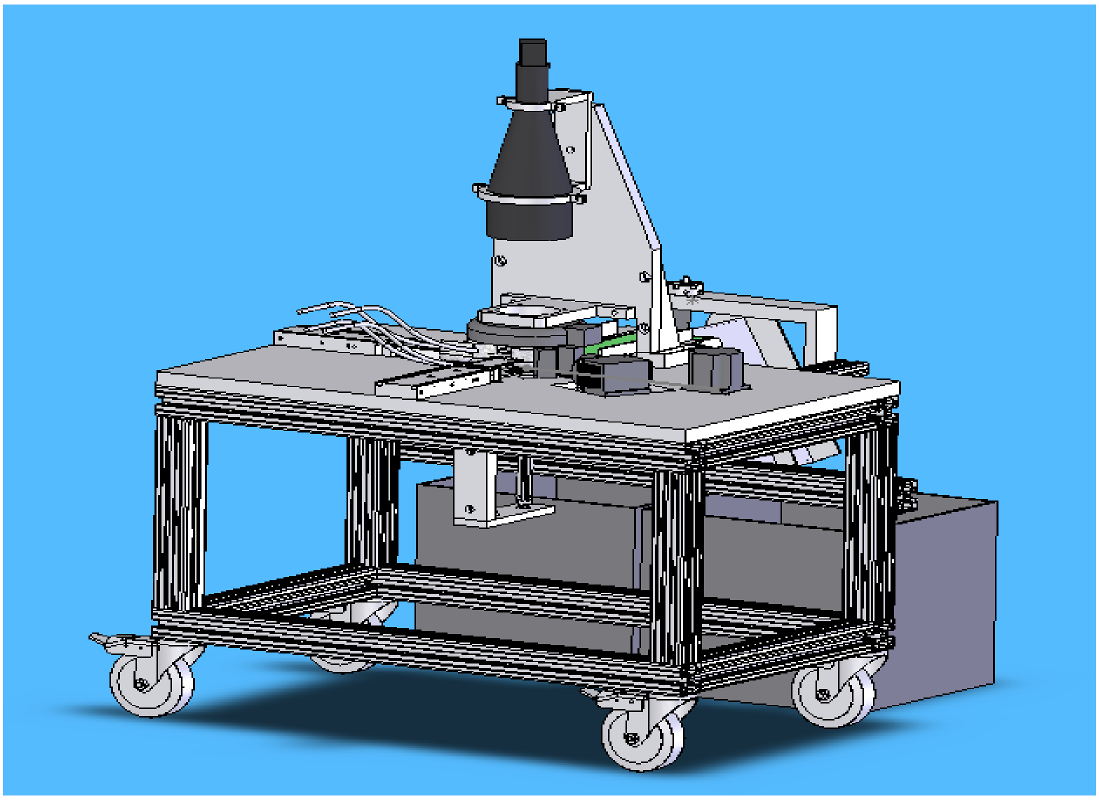


Figure 72: Final prototype developed for the reference Synemblock.

Industrias Alzuaran

Initial prototypes:

During the development of the artificial vision system for Industrias Alzuaran, up to seven different prototypes were tested. In order not describe all them, only the initial ideas and the final solution will be described at the present report.

The initial idea for the parts produced at Industrias Alzuaran was also to take pictures of them during their motion. At the beginning it seemed to be a very good idea because this artificial vision system must check 120 parts per minute, which means two parts per second. The initial approaches went towards that direction, to let the parts fall down over a ramp and to take picture of them. At this time two pictures were taken, an upper picture and a lateral picture. Although it was supposed to work well, the research team realised that the parts were not falling down parallel to the ramp and therefore the pictures were not valid. A picture of this initial prototypes is given in next figure. As it can be seen, the parts fell over the ramp and at one point of the ramp there was a trigger that shoots the cameras. After analysing the images it was concluded that they were not good enough and that parts must be stopped to take the pictures.

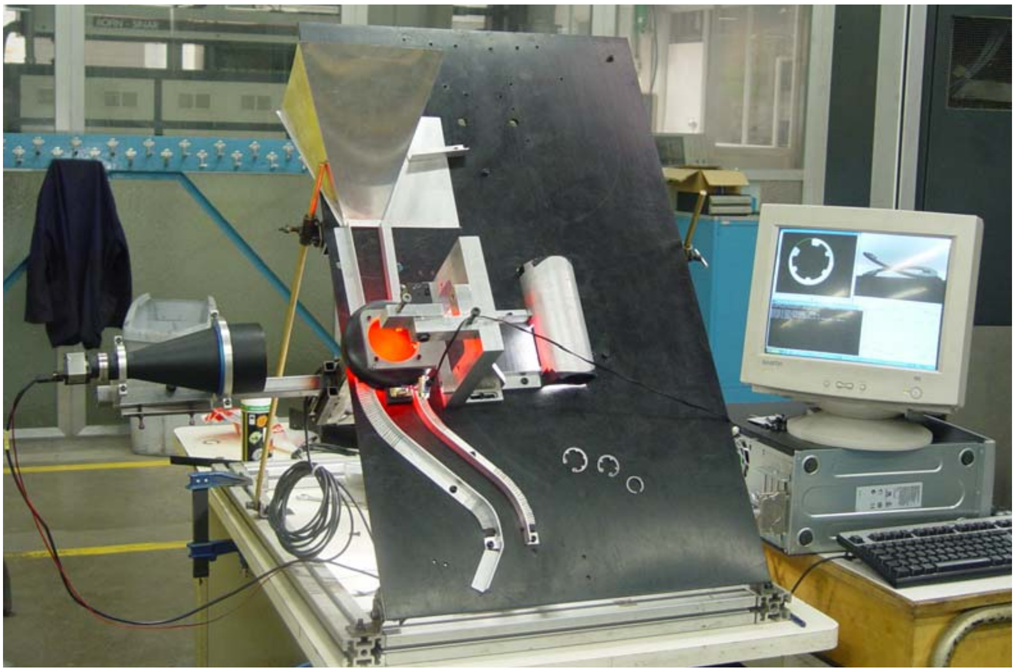


Figure 73: Initial prototype for the parts produced at Industrias Alzuaran.

Final prototypes:

After realising that the parts should be stopped when the pictures are taken, the research team implemented an electro magnet into the artificial vision prototype. The electro magnet stops the parts and then the cameras take the images. In this way the quality of the images taken is much better and now a better evaluation of the quality of the parts can be made.

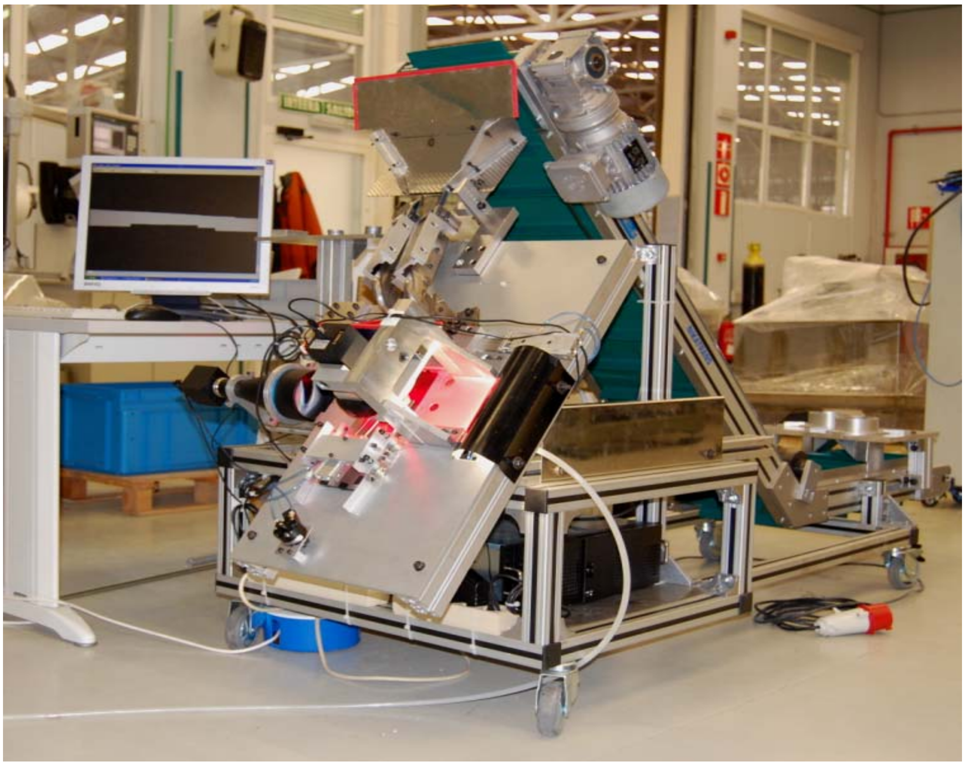


Figure 74: Final artificial vision prototype for Industrias Alzuaran

The developed system is able to check more than 100 parts per minute, which is a higher rate than the production rate at Industrias Alzuaran. Therefore another objective was fulfilled because the artificial vision system will not be the bottle neck of the manufacturing process.

Next a few images taken at this final prototype will be shown. First of all three lateral images, first and second belonging to defective parts (defect upward and downward) and third belonging to a good part.

Figure 75: Lateral images of parts produced at Industrias Alzuaran

And finally two images of upper pictures taken to parts produced at Industrial Alzuaran. It is clear how with the quality of these pictures the artificial vision system will have very good results.

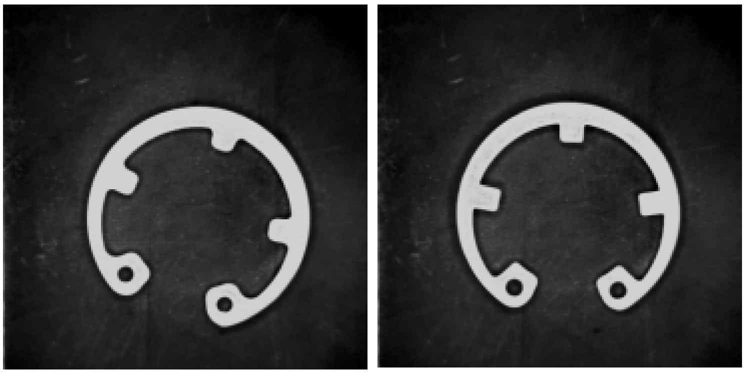


Figure 76: Upper images of parts produced at Industrias Alzuaran

3.3.2.1.5 Acceleration of the artificial vision prototype

During all the development a very clear objective was to reach a high supervision rate, in other words, a system able to evaluate as many parts per unit of time as possible. The minimum number of parts for Industrial Alzuaran is 100 parts per minute, because that is their production rate nowadays. In order to get this, several tests concerning the processing time of the images were made and noticeable results were achieved. In the next image it can be seen how most of time for the pictures analysis was consumed during the step image filtering, that deletes the noises in the image and extract the contours.

	Part Ref. 1		Part Ref. 2	
Image filtering	33 msec.	1818 parts/min.	35 msec.	1740 parts/min.
Center Calculation	0.64 msec.	93720 part/min.	0.58msec.	103440 parts/min.
Dimension Calcul.	4.4 msec.	13440 parts/min.	3.8 msec.	15540 parts/min.
Total time Calcul.	38 msec.	1580 parts/min.	39 msec.	1538 parts/min.

Figure 77: Processing time steps for parts evaluation

Therefore in order to solve this situation the research team proposed to use a new technique in artificial vision system; to use intelligent cameras that use FPGAs to perform the most consuming steps and to make only part of the treatment at the computer. This means that the cameras will be able to take the pictures, to binaries, to delete the noises and extract the contours, and later they will send the contours to the computer that will measure the dimensions of the parts. This approach can be graphically described in next figure.

Algorithms in the smart camera via VHDL on FPGA • Distortion correction. • Noise filtering by image convolution. • Binarization • Image compression before sending data to the PC.		**Algorithms in PC Open Source** • Part contour detection and analysis. • Part features extraction. • Part validity assessment.

Figure 78: Software and hardware codesign approach

With this new approach the total time can be considerable reduced (up to 100 times) and nowadays at the application developed for Industrias Alzuaran the processing time is more or less 100 milliseconds per part. In order to develop this approach, Delta Technologies have made two intelligent cameras and the intelligent cameras have been linked to the computer that makes the final treatment of the parts. An image and the principal characteristics of the intelligent camera can be seen in next figure.

Dimensions	60x60x70mm
Sensor type	Matrix CMOS – monochromatic or colour
Sensor resolution	1280x1024
Acquisition rate	40 Mpixel/s
FPGA reference	ALTERA Cyclone EP2C20
FPGA size	18 000 logical elements – 26 18x18 multipliers
Memory and possibilities	EEPROM 32ko, SYNC RAM 1Mo (600 Mo/s),FLASH 2Mo, IP NIOS ALTERA
Power consumption	8W @ 24V
Communication	USB 2.0

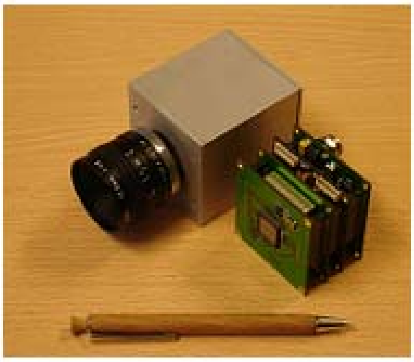


Figure 79: Developed intelligent camera and its characteristics

With this final approach the total time for the quality control of each part was reduced down to 500 milliseconds, which means that around 120 parts per minute can be tested at the developed system. Anyway it has to be stated that at the present research project the bottleneck of the artificial vision system was the mechanic, which means that although the cameras are able to treat more than 120 parts per minute, the most problematic point is how to handle that rate of parts. In this case, handling means to take the parts from the manufacturing facility, to place the parts in front of the cameras in a way good enough to get high quality images and to move the parts again to the right box (good or bad quality parts box).

At the present research project the handling of the parts was made mainly by the use of a vertical buffer that is described in the next figure. This vertical buffer allows to position all the parts coming from the machine in the same position and therefore allows to feed the parts in right position in front of the cameras to get good pictures.

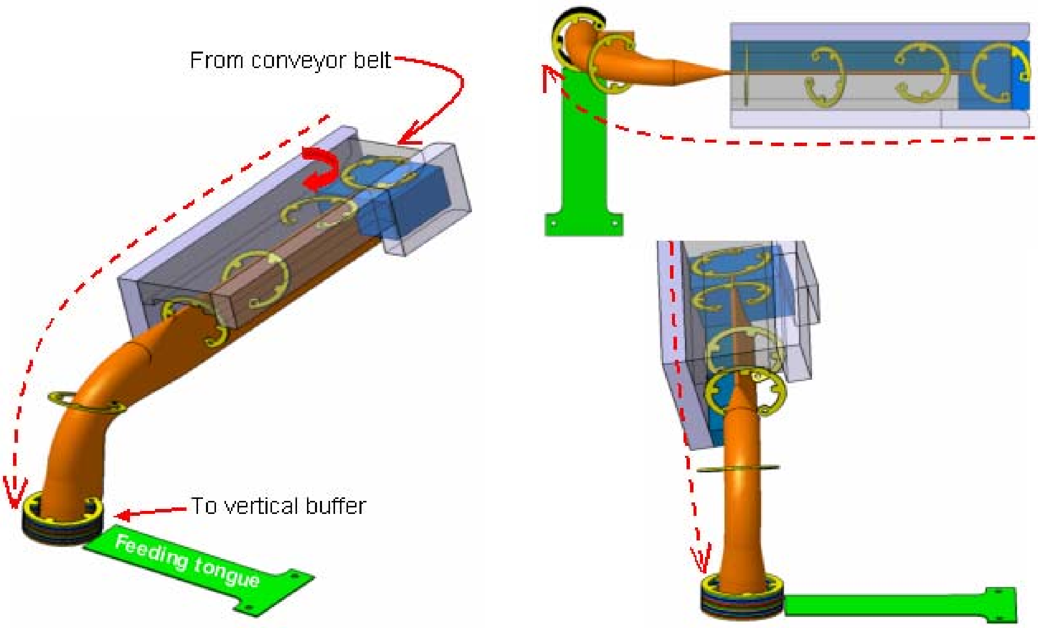


Figure 80: Vertical buffer for the artificial vision system developed for Industrias Alzuaran

3.3.2.2 Definition of the tests and initial validation of the AV based monitoring system

3.3.2.2.1 Artificial Vision System developed for Industrias Garita

As it was explained in the previous chapter, the system for Industrias Garita is composed of two cameras, one takes a picture from above and the other one, a linear camera, takes a set of pictures from the lateral meanwhile the part is rotating. Next the results of both cameras and the images after binarisation are shown.

For the upper image, the first thing that was made was a setting up of the camera. The right position of the illumination and the right parameters of the camera were chosen. In the next image a table showing the images taken at different illumination positions and with different camera parameters is shown. It was concluded that the images taken at the red area had the best quality and therefore the chosen parameters were those ones.

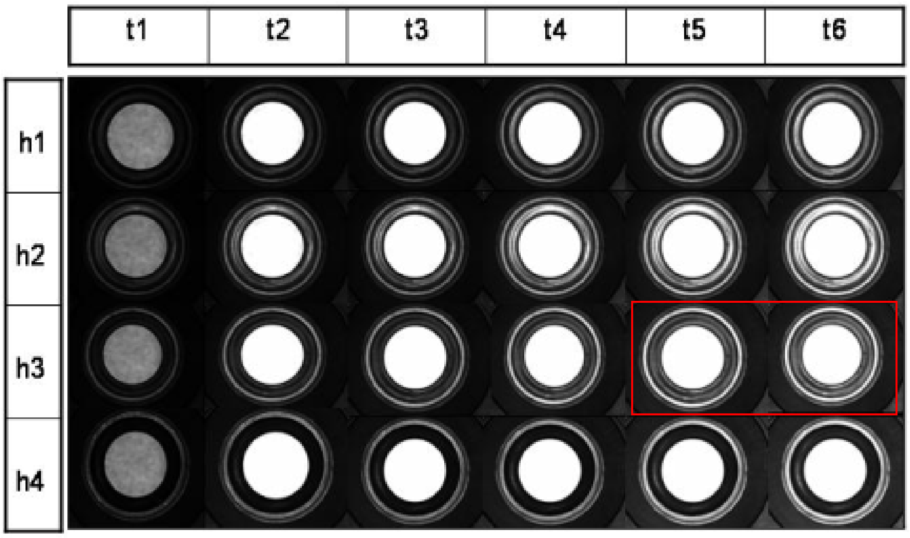


Figure 81: Tuning of the illumination and camera parameters for upper picture

Next an image taken with the previous parameters is shown. It can be seen how in the image both the lower and upper diameter are clearly identified and therefore the dimensions of both diameters and the concentricity between them is also very easy to extract from the picture.

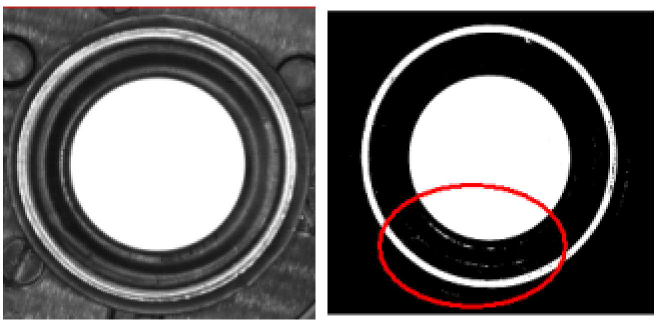


Figure 82: Final upper picture and its binarisation

The research team also made trials to detect the tears from the upper camera but this was more difficult to achieve. The reason is that if the tears want to be detected, a normal lens instead of a telecentric lens should be used. And at the same time if a telecentric lens is used the dimensions of the part do not correspond to the real ones because of the distortion of the lenses. At the same time with a matricidal camera, like the upper camera at the present application, the resolution is not high enough to detect the small tears. For all this reason the research team decided to used a telecentric lens for the upper camera and in this way to measure the diameters of the parts correctly, and to use a linear camera for the lateral picture and in this way even the smallest defects could be detected as it will be shown later.

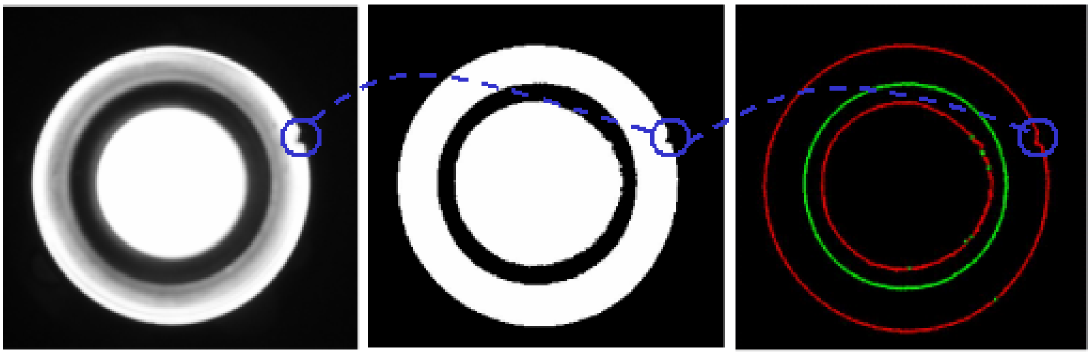


Figure 83: Detection of tears with the upper camera

For the lateral camera, a linear camera was chosen and the results were very successful. Next a set of three images is given: in these images the detection of the lateral tears is shown. Each set is composed of three images, the first is the original image, the second is the binarised image and the third is the binarised image after noise filtering.

In the first set of images is shown the detection of a big tear in the lateral of the part. It can be seen how the contrast in the tear is high enough at the original image and how after binarising and filtering the noise the tear is very easily detected.

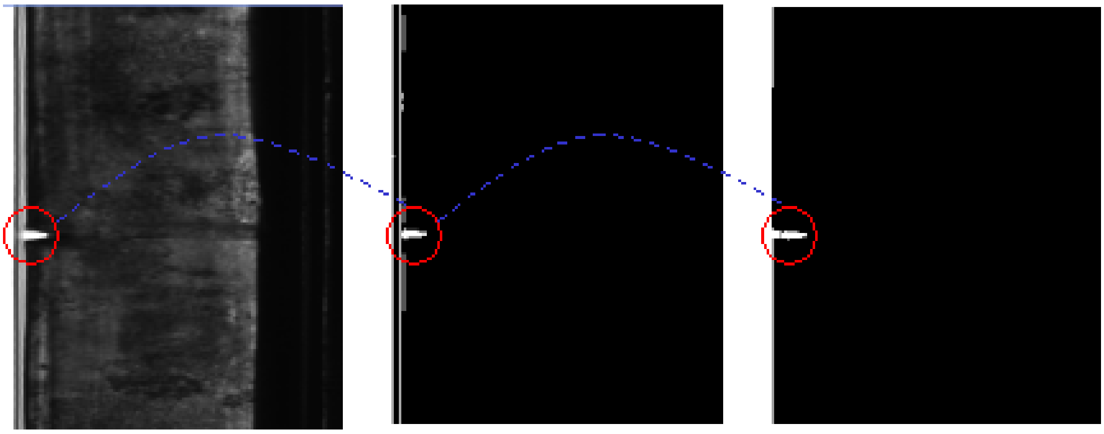


Figure 84: Detection of a big tear with the lateral linear camera

Next the same trial but with a smaller tear was made. In the pictures it can be seen how even the smallest tears are detected with this system. The key is that with the use of a linear camera much higher resolution is achieved.

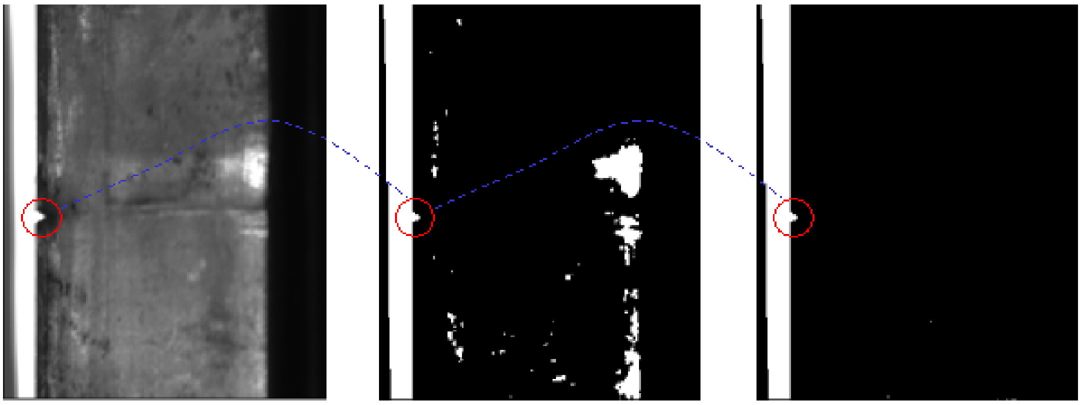


Figure 85: Detection of a small tear with the lateral linear camera

And finally the research team made a trial with parts that although are considered as good quality parts by Industrias Garita, they have really small tears in the upper diameter, what could be considered as the beginning of the tears. In next set of images it can be seen how the vision system is able to detect these small tears and therefore it is able to detect even the beginning of tearing.

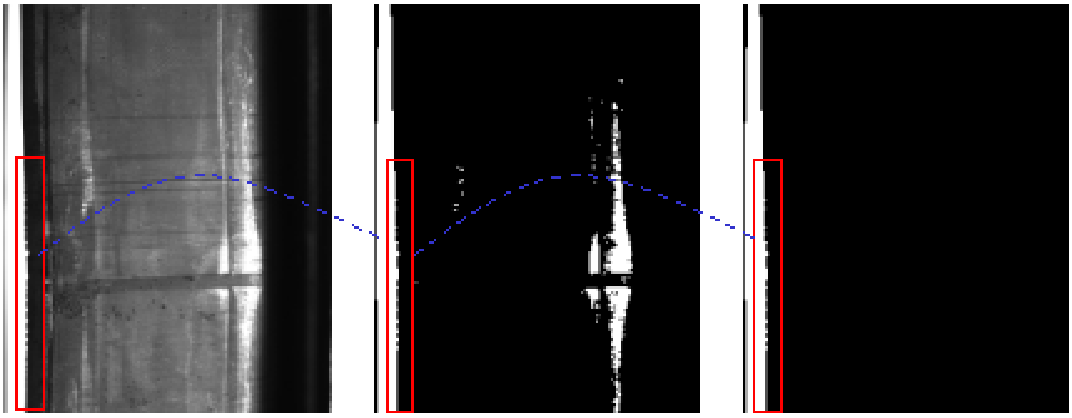


Figure 86: Detection of beginning of tearing in the parts.

3.3.2.2.2 Artificial Vision System developed for Industrias Alzuaran

After developing the artificial vision system and implementing the intelligent cameras into the same, several test were made in order to evaluate its efficiency. First of all, a set up was made in order to improve the quality of the images taken by the intelligent cameras. Although the setting up will not be described, just comment that during the same the parameters of the cameras and the position of the illuminations were tuned. After all this stage, the quality of the pictures is the next one:

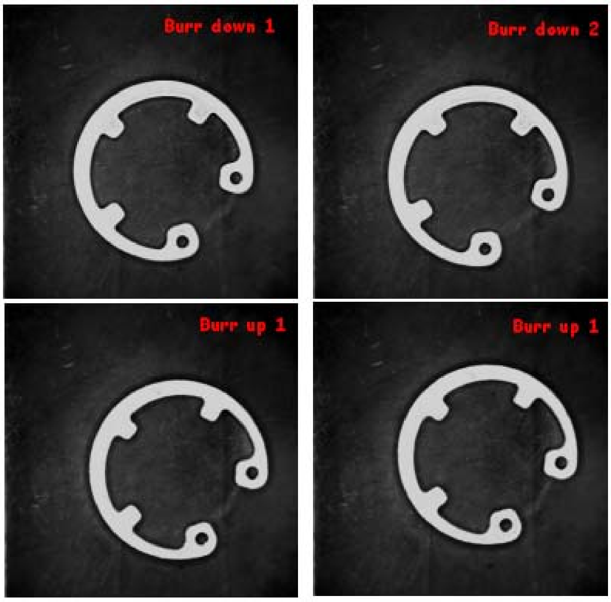


Figure 87: Pictures taken by the intelligent upper camera.

In the images it can be seen how the contrast with the surface (black Teflon) is very high and therefore after binarisation the contours of the parts can be very easily extracted. Next a few images of the intelligent lateral camera are shown:

Figure 88: Pictures taken by the lateral intelligent camera

Here again it can be seen how the contrast of the part with the background is very high and therefore after binarisation the contours of the parts can be easily extracted.

After getting the images with a good quality, next step was to test the algorithms that had been developed to measure the dimensions of the parts and to detect the presence of defects in the parts. In the next figure the results of the algorithms developed for this application are shown. In the first picture the original image is shown. It can be seen how the contrast between the part and the background is perfect. The next figure is the image binarised where the part is white and the background is black. After that a process of noise filtering is carried out and at the end the contours of the part are extracted. These contours are painted in red. With that contour the algorithms measure the main dimensions of the part and those are displayed in the Graphical User Interface developed for this application.

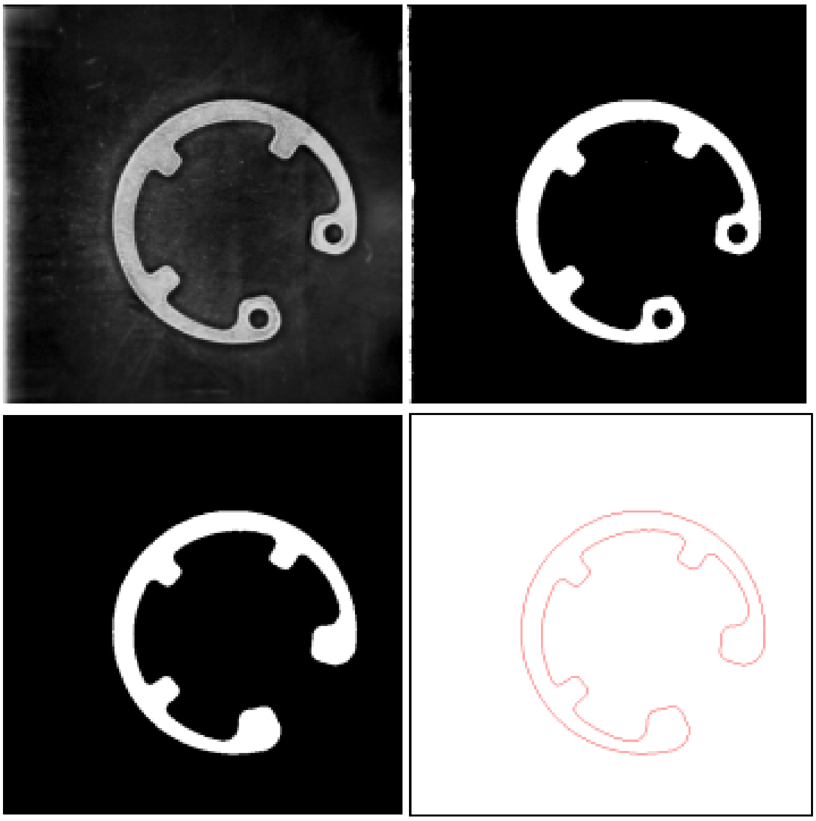


Figure 89: Upper image treatment of the reference 5828-001

Next the results of the algorithm for the lateral picture are shown. Next image shows the results of a good part without pikuta (huge localised burr).

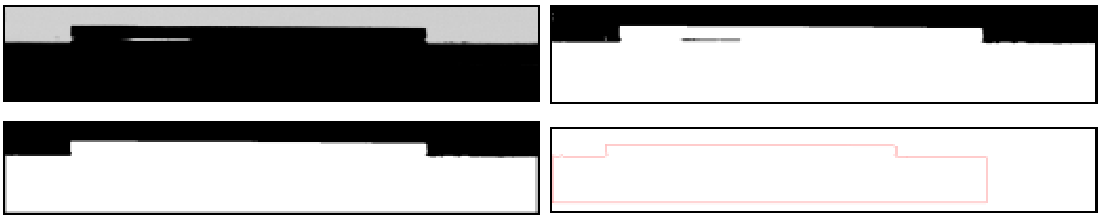


Figure 90: Lateral image treatment of the reference 5828-001 (good quality part)

And finally the treatment of the lateral picture of a part big pikuta is shown in the next image. It can be clearly seen how the pikuta is shown by the camera and how at the end, in the contours, the pikuta is detected as a peak in the lower side of the part.

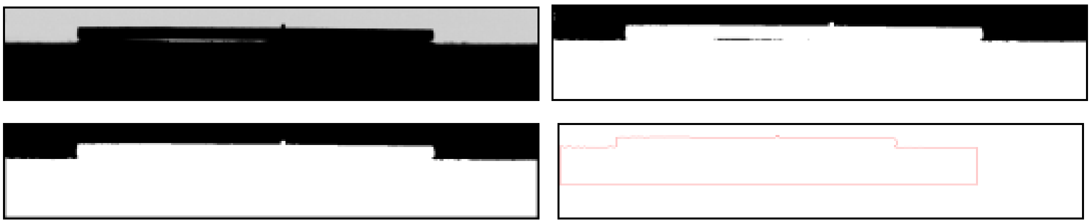


Figure 91: Lateral image treatment of the reference 5828-001 (part with pikuta)

Finally an image where the graphical user interface of the artificial vision system is shown. In the figure, it is shown how the user is informed about the quality of the upper picture and about the quality of the lateral picture.

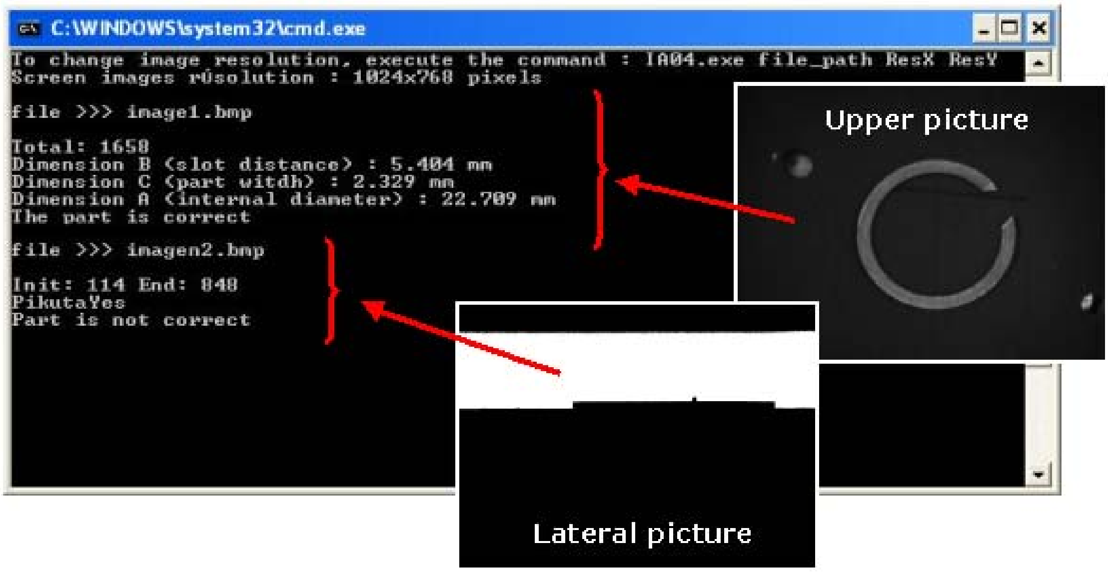


Figure 92: Graphical User Interface of the developed artificial vision system

3.3.3 Deviations from Project work programme and corrective actions

The present workpackage has been the biggest bottle neck of the project. Although the monitoring system based on sensors at the facility was very fast developed and results from the manufacturing facility were achieve from the early stage of the project, the development of the artificial vision system was not that easy at all, and since it took a lot of time during the project, the results about the quality of the parts were achieved at the end of the project.

Anyway the final result has been really satisfactory and the quality of the produced parts can nowadays be monitored very efficiently.

3.3.4 List of deliverables

Del. no.	Deliverable name	Workpackage No.	Date due	Actual/Forecast delivery date	Estimated indicative person/month*	Used indicative person/month*	Lead contractor
D4	Description of the AV based system architecture	3	9	9	2	2	SMEP4
D5	Mechanical prototype	3	9	9	4	4	RTD1
D6	Preliminary tests on the monitoring systems: design of experiments, results and conclusions	3	9	9	3	3	RTD1

3.3.5 List of milestones

Milestone no	Milestone name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
M 3.1	AV based monitoring system detecting dimensional accuracy and excessive burrs in blanking workparts	3	7	7	SMEP4
M 3.2	AV based monitoring system detecting scratches in blanking and drawing workparts	3	7	9	SMEP4
M 3.3	AV monitoring system working close to the mechanical prototype, real-time, detecting the occurrence of excessive burr, scratches and cracks	3	8	13	SMEP4

3.4 Workpackage 4. Integration and recording of critical cases

3.4.1 Workpackage objectives and starting point of work at beginning of reporting period

The objectives of the Workpackage 4 are the following ones:

- To integrate the sensors based monitoring system and the AV based monitoring system on the same programming environment, working close to the press at SMEP7 site, and to ensure the communications between the two monitoring programs (SMEP3, SMEP4, RTD1, RTD2).
- To acquire the results of critical cases (SMEP3, SMEP4, SMEP7, RTD1, RTD2) related to the occurrence of:
  1. Tooling breakages.
  2. Tooling excessive wear.
  3. Waste penetration.
  4. Tears in drawing parts.
  5. Cracks in drawing parts.
  6. Scratches in blanking or drawing parts.
  7. Dimensional and geometrical errors in the workparts.
  8. Excessive burr in blanking workparts.

In each of these cases the following has to be collected:

The results of the sensors based monitoring system.

The results of the AV based monitoring system.

The workpart.

The different tasks defined at the beginning of the project are the following ones:

<u>Task 4.1: Integration of the two monitoring systems in the same environment</u>:

- Install the AV monitoring system in the same PC where the sensors based monitoring system is (SMEP3, SMEP4, RTD2).
- Verify the correct working of the two systems separately (SMEP3, SMEP4, RTD1, RTD2).
- Verify the correct working of the two systems altogether: possibility of taking at least 1.800 inspections per minute, compatibility, reliability… (SMEP3, SMEP4, RTD1, RTD2).

<u>Task 4.2: Recording on press of critical cases (at SMEP7):</u>

- Prepare (SMEP7, RTD1, RTD2) a set of continuous tests in order to be able to get good workparts and workparts with defects (tooling breakages, tooling excessive wear, waste penetration, tears in drawing parts, cracks in drawing parts, scratches in blanking or drawing parts, dimensional and geometrical errors in the workparts and excessive burr in blanking workparts).
- Record (RTD1) several cases with the occurrence of defects (at least 5 for each type of defect).

- Record (RTD1) representative signals and images of good workparts (at least 1.800 tests for each workpart).

3.4.2 Progress towards objectives

The proposed schedule for the tasks described in the previous section is the one shown in the next picture:

Description of workpackages, tasks and specific reports	Year 1: 1	2	3	4	5	6	7	8	9	10	11	12
WP 4: Integration and recording of critical cases												
Task 4.1: Integration of the two monitoring systems in the same environment						X	X	X	X	X		
Task 4.2: Recording on press of critical cases (at SMEP7)								X	X	X	X	X

Figure 93: Schedule of the fourth workpackage

The work done and the most important results achieved in Workpackage 4 are described in the next lines of the present report.

3.4.2.1 Integration of the two monitoring systems in the same environment

Before showing the results from the monitoring and from the artificial vision system an explanation of the communication between them will be given schematically. The main purpose when designing the control system and the way the information will be treated is double: not to loose any information and to get the shortest treatment time. After several discussions, the final decision about the necessary information coming from the monitoring system and from the artificial vision system was taken. As it is shown in the next figure, the information coming from the monitoring system will be the curves from the different channels. These curves will be transferred from the monitoring system to the PC where the control system will be installed via txt files. An image of one txt file containing a curve from the Brankamp monitoring system and the representation of the curve is given in the next figure.

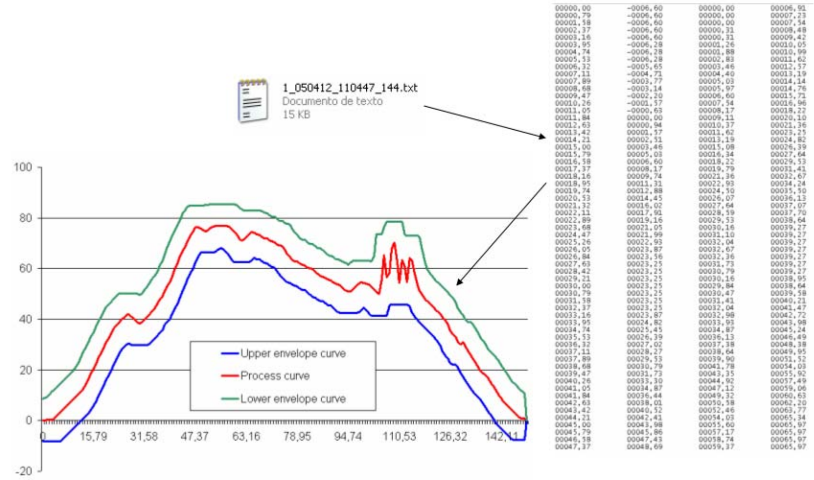


Figure 94: Txt file's information and its representation.

At the same time, the Brankamp monitoring system will send also to the control system digital signals for stopping the machine in case something strange happens in the process. From the artificial vision system, the information that will be sent to the control system is a picture and an txt file with the main dimensions of the part (this is shown later in this deliverable).

All the previous data transferring can schematically be seen in the next figure. In this figure, both the monitoring and the artificial vision systems are placed in the top left part. From these systems the information explained earlier is transferred to the control system following the next way.

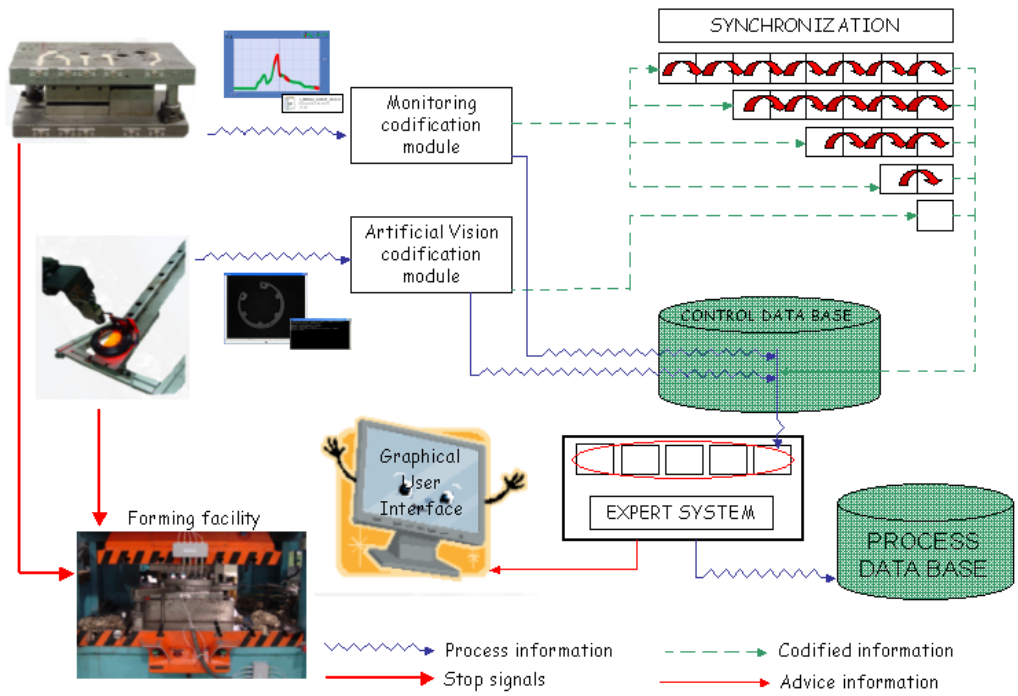


Figure 95: Information management during the control process

First of all, and to avoid transferring the data continuously, there will be two codification modules, one for the monitoring system and another one for the artificial vision system. In these codification modules, the txt and the jpg files will be linked to a code. Therefore the input to these modules is a txt or jpg file and the output is the same file, transferred to a control data base and a code that will be transferred to the synchronization module. In the synchronization module, all the force and acoustic emission curves are gathered and linked to the part that belong to. Finally all these curves are also linked to the picture and data dimensions belonging to the same part and coming from the artificial vision system. Therefore, at the end of the synchronization module, all the information belonging to one part has been gathered and linked to the right part.

As it can be seen in the previous figure, the discontinuous lines represent the codes generated in the codification modules, the zig-zag lines represent the information coming from the monitoring and the artificial vision system and the lines cut by others almost perpendicular small lines represent the digital inputs and outputs from the control system.
After linking all the information to the right part, and using the codified signals, the real information, txt and jpg files are called from the control data base and transferred to the expert system. Once the expert system gets the right information belonging to the part being processed, it will take decisions about what to do in case something strange is detected in the information. The outputs of the expert system are the advices for the operator about what he/she should do to improve the behaviour of the process, via a graphical user interface, and digital signals directly connected to the PLC of the machine in case it should be stopped. At the same time there will exist the possibility of recording the txt and jpg files for doing statistical calculus that will help to understand better the process. In order to record this information another data base, the process data base, will be developed.

Looking at this scheme, there will exist three main ways of work. The first case is when the Brankamp detects something strange in any of the curves and stops the machine. In that case the expert system will get the last curves and will try to find the defect and the reason why the defect has happened. With this information the expert system will advise the operator about how to solve the problem.

The second case will happen when the artificial vision system detects something wrong in the part. In this case, the expert system will stop the machine, will try to find in the curves of the Brankamp system the reason why the defect has happened. In this way, the expert system will try to improve the behaviour of the Brankamp monitoring system that was not able to detect that something wrong happened.

And the third case is when both the Brankamp monitoring and the artificial vision system do not detect any defects in the process and the part. In this case the machine will not be stopped, but the control system will get information about the evolution of both the process and the part and will try to find trends that show future problems in the quality of the part. The main idea of this third case is to try to make preventive actions and in this way avoid defects before happening.

3.4.2.2 Recording on press of the critical cases (at SMEP7)

3.4.2.2.1 Brankamp monitoring system results

At the end of the first year, the Brankamp monitoring system has already been installed and tested in the tools at Industrias Alzuaran. The main idea when Brankamp designed the monitoring system for these tools was to use as many sensors as possible in order to evaluate which the best position for them in the tool is. For that, a unit PK550 with 8 channels was installed in Industrias Alzuaran and the tools for manufacturing the references IA04 and 0863-012 were modified for placing the sensors. Next a brief explanation of the conclusions for both references is given.

Reference **0863-012**

The first trials to compare the sensors placed in the upper and lower tool were made in this reference. In this case this reference can be divided into three different operations. The first of them cuts the holes for the positioning of the strip (blanking positioning). The second operation cuts the four small holes belonging to both parts (holes blanking) and the last operation cuts the final parts (final blanking).

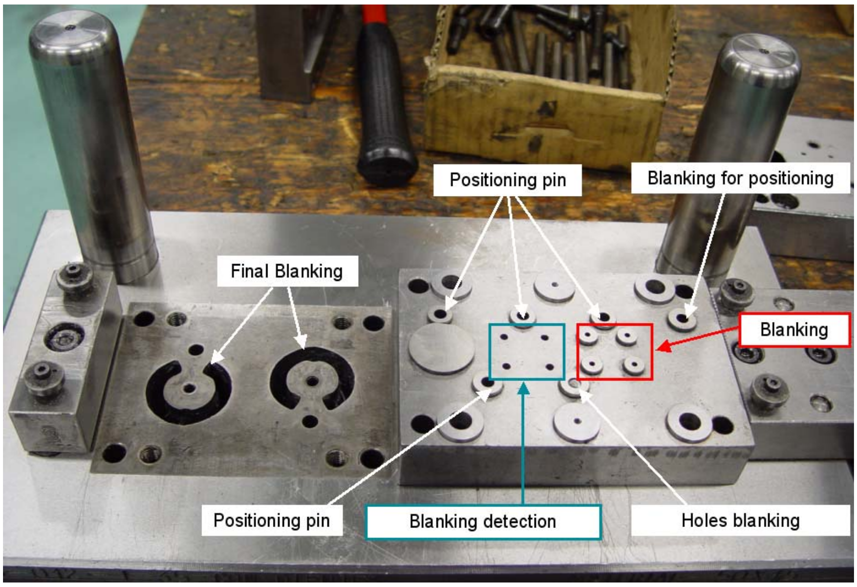


Figure 96: Operations in the tool reference 0863-012

In order to compare the position of the sensors, the signals coming from the first upper sensor, from the first lower sensor and from the conrod were compared. This can be seen in the next figure.

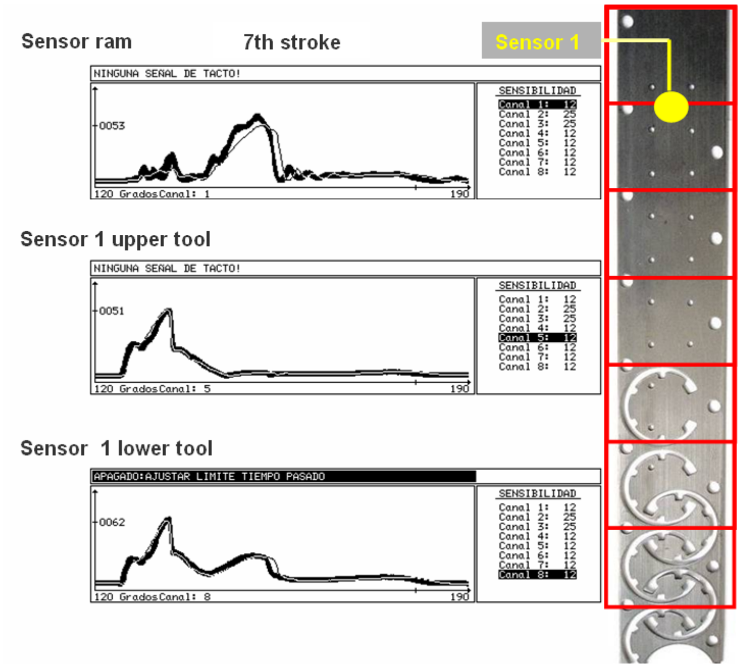


Figure 97: Comparison between signals from sensors placed in the connection rod, the upper tool and the lower tool

The first curve represents the forces applied to the connection rod of the machine during the cutting of the material. This curve shows perfectly how the vibrations that the cutting of the material generates affect to the machine and how the curve is not flat/stable at the beginning and at the end as it should be. This fact is because the curve is the sum up of the forces of the different stations, which in some cases happens at different times because for example the length of the punches can be different and the cutting of the material in each station occurs at different time. Therefore the curve is much more instable and this could generate false stops or decrease the chance for working with higher accuracy. At the same time, the sum up of all the signals makes the machine to vibrate and the smaller signals in the left and right are because of this.

The second and third curve represents the signals coming from two sensors placed one in front of the other, one in the upper tool and the other one in the lower tool. It can be seen that the signals are almost identical although the first one is “cleaner”. This fact makes the upper curve better for monitoring the process. The reason why the upper curve is cleaner and better is that the sensor in the upper tool is directly placed above the punch. This is impossible to do in the lower tool because the die is in the lower tool, the parts are falling through and therefore the sensors must be placed in a lateral.

This reason is why Brankamp has decided that the sensors should be installed in the upper tool. This will offer cleaner curves and therefore the quality of the monitoring process will be higher. In the next deliverables more reasons for placing the sensors in the upper tool are given. Within them, the most important is that when some defect happens it can be seen better in the upper tool curves than in the lower tool curves.

On the other hand, there is only one drawback when installing the sensors in the upper tool, and is that the ram is continuously moving and the design to connect the sensors and the amplifier box is more complicate.

<u>Reference</u> **IA04**

As it was explained in previous deliverables, this tool produces two parts per stroke and needs 3 operations to manufacture each part. All this can be seen in the figure, where it can be seen the three operations (1st, 2nd and 3rd punch) and the two lanes for producing both parts.

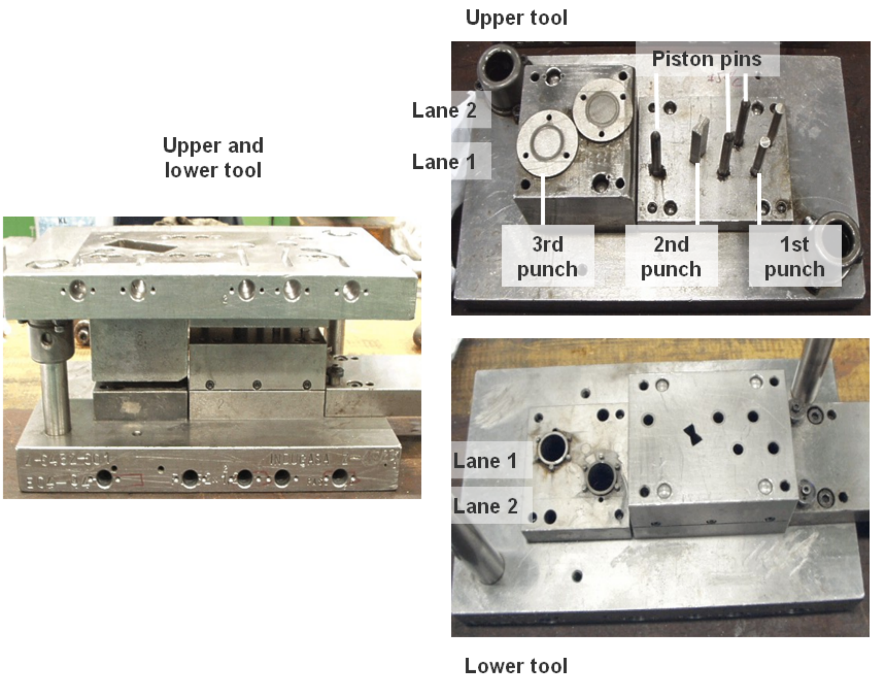


Figure 98: Picture of the ref IA04 tool

Brankamp proposed to install ten sensors in the tool for manufacturing the reference IA04. Five of the sensors were placed in the lower tool and the other five sensors were placed in the upper tool. The sensors in the upper and lower tool are placed ones in front of the others when the tool is closed. With this special distribution, Brankamp wants to check again whether there is any coincidence in the curves. Therefore, for the first station there will be one sensor in the upper tool and another one in the lower tool and both curves will be compared later.

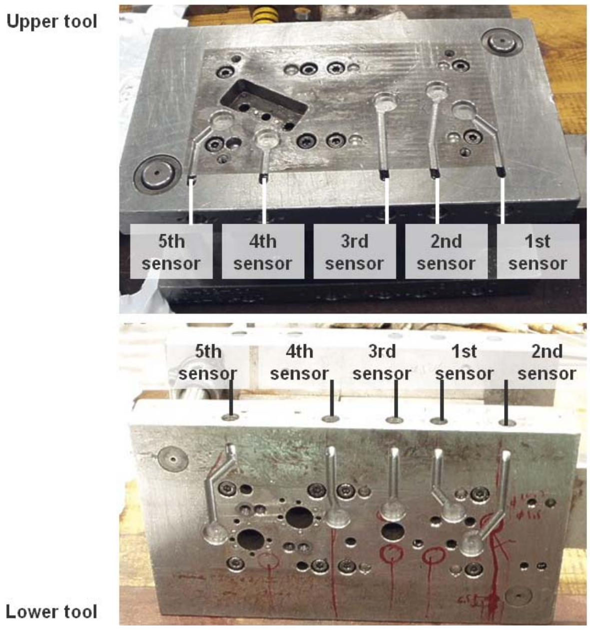


Figure 99: Position of the ten sensors in the ref IA04 tool

Another fear that Brankamp had when installing the sensors in the upper tool was about the dynamic of the machine. Brankamp wanted to check if the signals coming from the upper sensors were influenced by the continuously movement of the machine. In order to check this and to find any coincidence between the upper and lower curves, a comparison between the upper sensors and the lower sensors was carried out. In the next figures it can be seen that the dynamic of the machine does not affect the shape of the curves and there is not strange shapes in the upper curves. At the same time, from these curves it can be seen that there is not a pattern between the upper and lower curves.

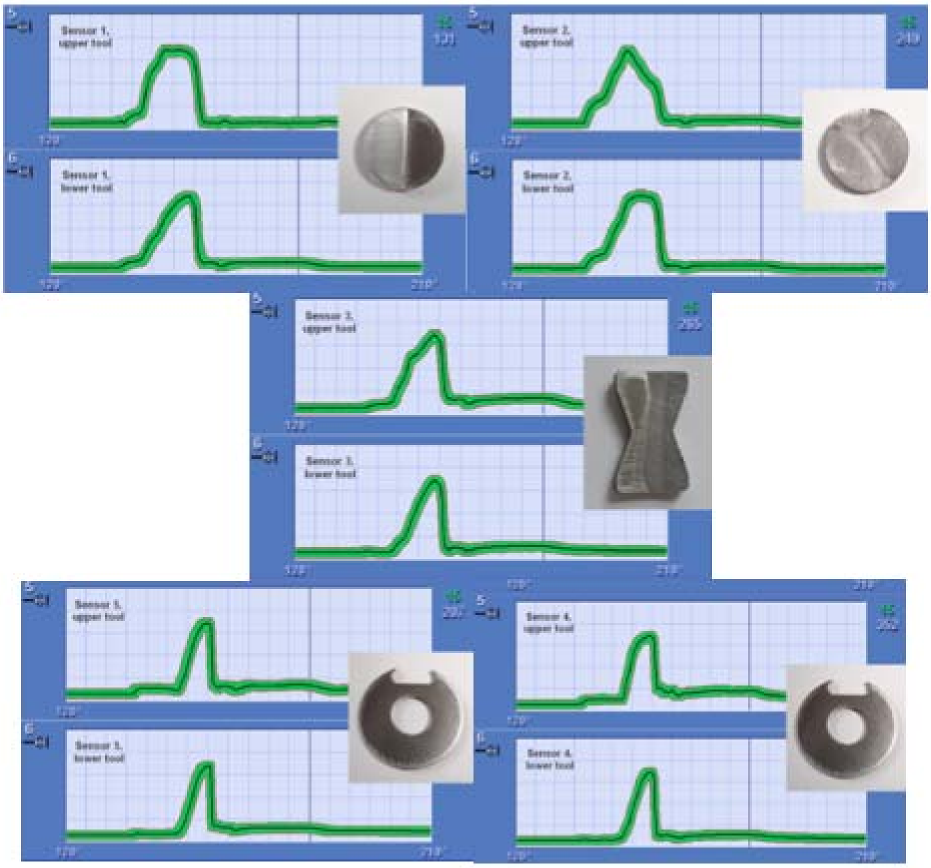


Figure 100: Comparative between upper and lower sensors in the five stations of the tool

Therefore, after doing all these trials and with the results that will be shown in the next deliverable, Brankamp decided to work with the sensors of the upper tool. More results about the detection of defects in the process will be shown in the next deliverable.

As an example of the capabilities of the installed system, some process failures that were detected when running this tool will be shown. More process failures detection can be found in “D8- Test, Critical cases”.

<u>Feed failure:</u>

All of the next detected failures are real failures that happened in the process when this was producing parts. Next problem was related with the alimentation of the coil in the press. There was a problem with the mechanism in charge of moving the strip inside the tool and how it can be seen in the next figure the distance the strip moved was smaller than the one it should have moved. In this situation the force that different sensors measured was higher at the beginning of the curve.

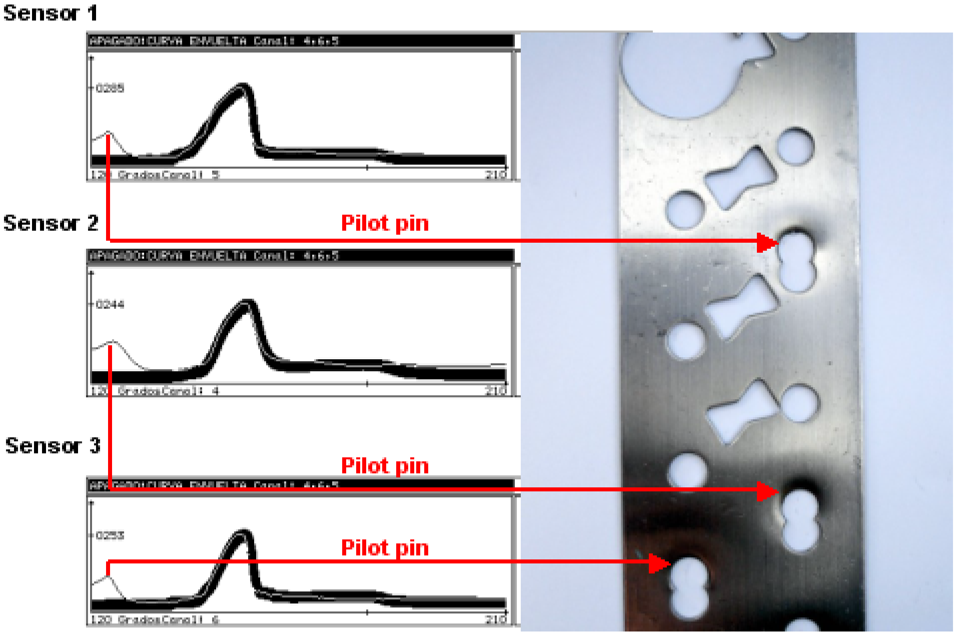


Figure 101: Process failure when feed failure.

The explanation is shown in the next figure. What happened is that the pilot pins necessary to guide the strip within the tool have crashed with this because the holes are not placed in the right position. Stopping the machine avoids future much more catastrophic problems such as tool damage.

Broken punch failure:

The last process failure detected by the Brankamp monitoring system was the breakage of a punch in the tool. As it can be seen in the figure, the signals in one of the acoustic channels increases suddenly during the punch breakage.

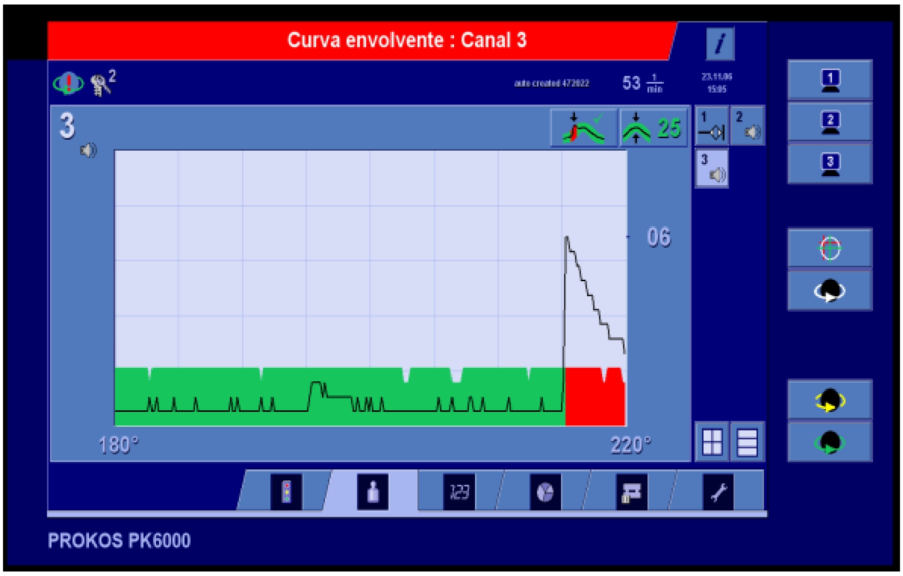


Figure 102: Acoustic emission sensor measurement during punch breakage

After showing all the previous failure detection made by the Brankamp monitoring system, it can be said that this system is getting a lot of failures stopping the machine and avoiding catastrophic failures, such as tool breakage. On the other hand, it must also be said that the Brankamp monitoring system has not been able to detect some part quality problems as the huge increment of the burr in some localised areas of the parts. In order to detect this part quality defects the artificial vision system will be used trying to link the part quality defects with the curves got from the monitoring system.

Finally and for summarising the global results achieved with the Brankamp monitoring system, a table is attached where all the process faults detected during the running of the machine with the references IA04, 0863-012 and 5828-001 are shown.

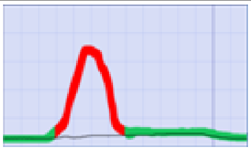
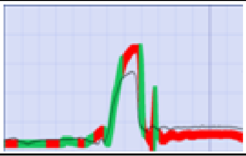
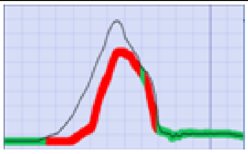
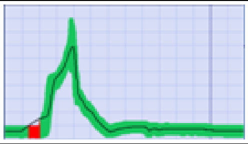
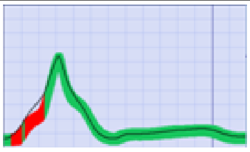
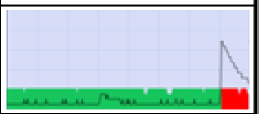
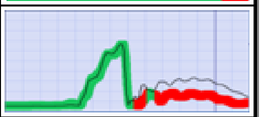
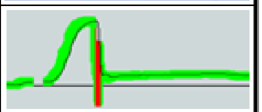
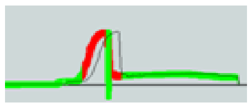
	Defect	Cause	Solution	Variables	Image
1	The steel strip did not move at all.	A badly evacuated scrap is avoiding the movement of the strip.	Extract the scrap of material and check the reason why it was not adequately evacuated.	In most of the channels the maximum real force is much smaller than the hypothetical force.	
2	The steel strip did not move the right distance.	A badly evacuated scrap is avoiding the movement of the strip.	Extract the scrap of material and check the reason why it was not adequately evacuated.	There is a force peak at the beginning of the channels which are measuring force directly in the tool.	
3	A badly evacuated scrap is blocking the first or second station.	The punches in station 1 or 2 are not evacuating the scrap properly.	Make the punches longer, move the ram down and check the dies´wear.	There is a force peak just before the maximum force in channels 4 and 5.	
4	A badly evacuated scrap is blocking the third station.	The punch in station 3 is not evacuating the scrap properly.	Make the punch longer, move the ram down and check the die's wear.	There is a force peak just before the maximum force in the third station.	
5	A badly evacuated scrap is blocking the fourth or fifth station.	The punches in station 4 or 5 are not evacuating the scrap properly.	Make the punches longer, move the ram down and check the dies´wear.	There is a force peak just before the maximum force in fourth or fifth station.	
6	One of the punches is broken.	Excessive wearing of the punches.	Extract the broken punch and replace it with a new one.	The force gradient is bigger than 20 in channel 3.	
7	There is a badly evacuated part inside the tool.	The extraction system is not working properly.	Extract the part and check the extraction system.	The force is very low at the end of the connection rod force curve.	
8	The strip is sticky to the pilot pins or punches.	Excessive wearing of punches or pilot pins.	Replace the faulty punch or pilot pin.	There is a force peak at the end of the curve in fourth or fifth station.	
9	The machine is not working at its nominal speed.	The monitoring system started checking the curves to early.	Re-start the machine.	All the force curves are out of the envelopes during the entire stroke.	

Figure 103: Summary of failures detected at Industrias Alzuaran

At the same time and during the production of the aforementioned references another study has been developed. The main purpose of the study was to identify a relation between the quality of the edge in the parts and the force curves supplied by the Brankamp monitoring system. In order to get this a correlation between the burr height and the force at the Brankamp curves was made. The study began with the punches completely sharpened and lasted during 40000 strokes. Next image shows the variables that were measured in the study.

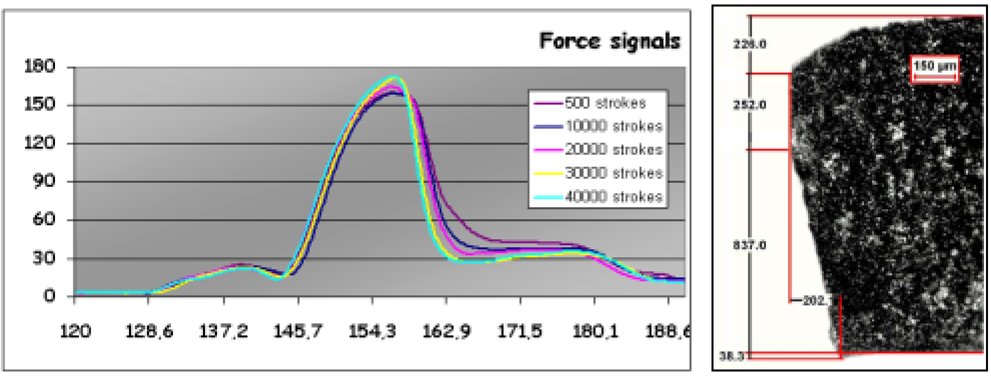


Figure 104: Force and part burr variation in fucntion of number of strokes

As it can be seen in the previous image, the maximum value of the Brankamp monitoring force curves and the main dimensions of the produced parts were correlated. Samples of the production were taken at the beginning and after each 10000 strokes, which means at 0, 10000, 20000, 30000 and 40000 strokes. The signals measured from the Brankamp system were the force at the connection rod, the force at the tool (for each cutting station) and the value of the acoustic emission signals. The final correlation of the forces and the height of the burrs are shown in next image.

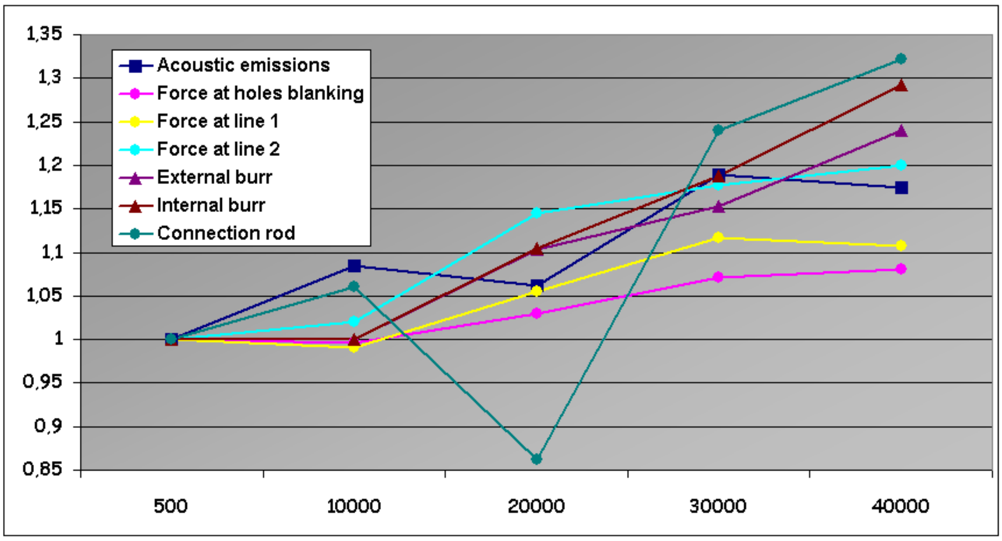


Figure 105: Evolution of force and burrs from 0 to 40 thousand strokes

The final conclusion of this study is that there is a correlation between the evolution of the forces and the evolution of the burr at the parts. It can be seen in the previous image how the forces grow up during the running of the production and how the height of the burrs also increases. This conclusions lead to the possibility of controlling the burr at the parts by monitoring the forces at the tool.

3.4.2.2.2 Artificial Vision System results

Before implementing the Artificial Vision system working together with the Brankamp monitoring system and with the Expert System in Industrias Alzuaran, a test phase was made in Mondragon University in order to find different problems that could happen in terms of part quality. Next figure shows the final artificial vision system placed in Mondragon University where the test phase was made.

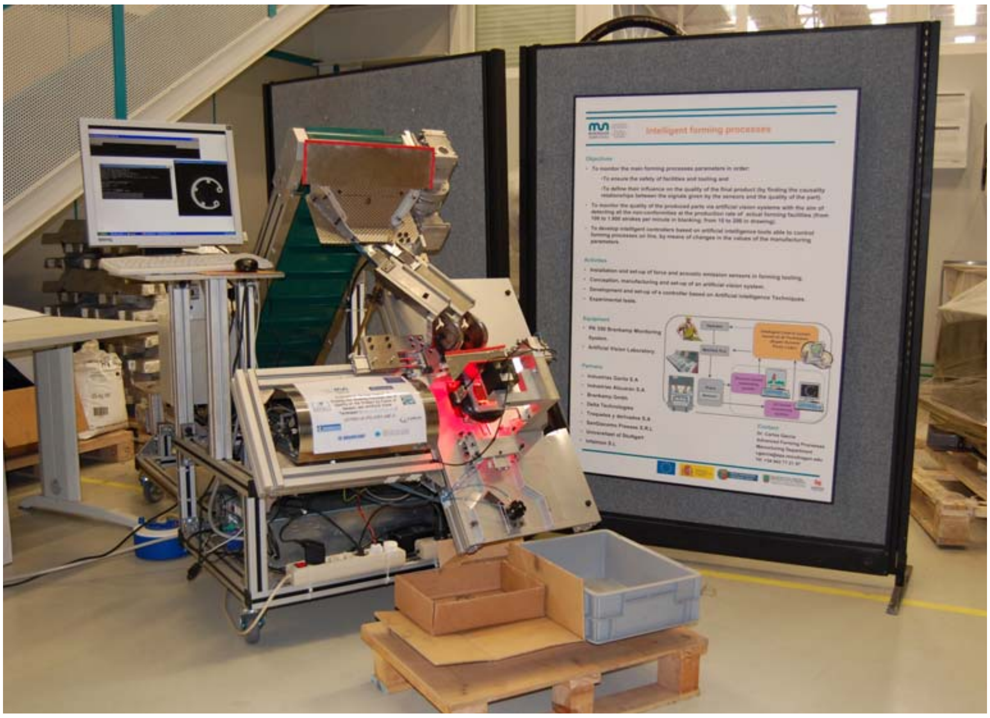


Figure 106: Artificial vision system at test phase

Although the artificial vision system is going to check the quality of three different references, the test phase was performed with only one of them, the reference 5828-001 produced at Industrias Alzuaran. This is the part that is being produced at Industrias Alzuaran most of the time, almost half million parts per month and this is the reason why the artificial vision set up was made with this reference. The specifications of the chose reference are shown in next figure.

Alzuaran

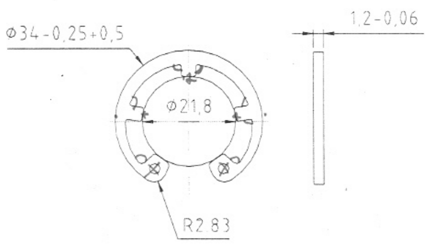
GAMA DE CONTROL PRODUCTO-PROCESO

CODIGO:	SEC.:
5828-001	**P2/P3**

CLIENTE: TORDESPI	FASES	FASES/SECCIONES	HERRAMIENTA	MATERIAL
REFER.: 70.10858	ANTERIOR	41/MP	TRANSPORTE	CK-67 de 52x1,16
EDIC./FECHA: 27-07-04	A REALIZAR	02/P3	E6-14-01	CK-75 de 52x1,16
DENOM.: ANILLO INTERIOR	SIGUIENTE	06-08-19-22-41	HOC01 + HOR01	TEMPLE + RVENIDO

FA	PO	DESCRIPCION DE LA CARACTERISTICA	COTA A CONTROLAR MAXIM	COTA A CONTROLAR MINIM	UTIL DE CONTROL Y CODIGO	PLAN DE VIGILÀNCIA NIVELES 1	2	3	LOTE	MET	ACCION CASO DE DEFECTO
01		TROQUELADO									
	00	APROBACIÓN INICIO DE O.F. (*) (**)									
	01	ESPESOR 1,20-0,06	1,20	1,14	MICROMT 201	5/IF	----	----	----	AIF	230
	02	Ø INT "d3" 21,8 ±0,2	22,00	21,60	P. DE REY 200	5/IF	----	----	----	AIF	230
	03	Ø EXT 34 +0,5 –0,25	34,50	33,75	P. DE REY 200	5/IF	------	------	--------	AIF	230
	04	Ø "d5" 2,5 Min		2,5	P. DE REY 200	5/IF	------	------	--------	AIF	230
02		TROQUELADO									
	00	APROBACIÓN INICIO DE O.F. (*) (**)									
	01	ESPESOR 1,20-0,06	1,20	1,14	MICROMT 201	5/IF	----	----	5000	SPC	1234
	02	REBABAS O GOLPES	Mínimas		VISUAL	5/1H	----	----	5000	----	1234
	03	**IDENTIFICACION DE CAJAS AL 100%**			MANUAL	F/L	----	----	----	----	123

CROQUIS:



NOTA: SE ENTIENDE POR REBABAS MINIMAS LAS QUE SE DESPRENDEN CON FACILIDAD "NO" ADMITIENDOSE COMO REBABAS LAS PRODUCIDAS POR DESGASTE O ROTURA DE HERRAMIENTA.

CRITERIOS DE ACEPTACIÓN:

(*) Aprobación (AIF) por el operario de fase/s en la correspondiente Hoja de Ruta (O.F.), en los apartados:

- FASE A REALIZAR (La indicada en la O.F.)
- APROBACIÓN "AIF" (Número de operario)
- REALIZA AUTO-CONTROL (Número de operario)
- VºBº OPERARIO/S (Firma de operario/s)
- FECHA VºBº (Fecha de aprobación de Inicio Serie y auto-control puede ser la misma)

Esta verificación es extensible a los cambios de bobinas o rollos, no debiéndose repetirse las aprobaciones en la O.F. siempre que se mantenga lo especificado en la pauta.

(**) Aprobación (AIF) o decisión de inicio o continuación de la fabricación por DAC en los casos de no conformidad con el contenido de la Gama de Control, dejando constancia de los valores obtenidos en AF012.1.

NOTAS:
RECUBRIMIENTO FOSFATADO

DISTRIBUCION:	REALIZADO: DAC	APROBADO: DAC	SELLO	RECIBI: DP
ORIGINAL:PROG_INF/ DAC DOCUMENT.: ARCHIVO (1) PRODUCCION: P2/P3 (1)	J.O.V.	M.Gorostidi	INDUSTRIAS ALZUARAN, S.L. DPTO. DE CALIDAD	J.Mª. ANDRES
	FECHA: 18-05-05	FECHA: 18-05-05		FECHA: 18-05-05

AF002.2-04

Figure 107: Specifications of the reference 5828-001 produced at Industrias Alzuaran

The analysis that was made at this test phase was focused on several priorities. First priority was to check the response of the artificial vision system developed when detecting bad quality parts in terms of presence of "pikuta" and also deformed parts. The presence of "pikuta" was detected by the lateral camera and the presence of deformed parts by the upper camera. Another priority was the evaluation of the reliability of the system in terms of wrong detection of good quality parts. It is also very important that the system do not detect bad parts when the quality of them is good. And finally another priority was the calculation of the time necessary to perform the quality checking of the parts. Depending on this time the cadence of the machine can be adjusted.

Defects detection test phase

In order to evaluate the capacity of the artificial vision system to detect the presence of "pikuta", 100 parts without "pikuta" were mixed up with only one part that had "pikuta" and all them were analysed by the artificial vision system. The result was that the part with "pikuta" was detected by the artificial vision system and was sorted out from the other parts. On the other hand, two parts that did not have "pikuta" were classify like parts with "pikuta" and this is something that at the final integration of all the system in Industrias Alzuaran will be checked (explained in workpackage 6). Although the most important point to check at this phase was the detection of the "pikuta", next an excel table with all the dimensions measured with the upper camera is given too.

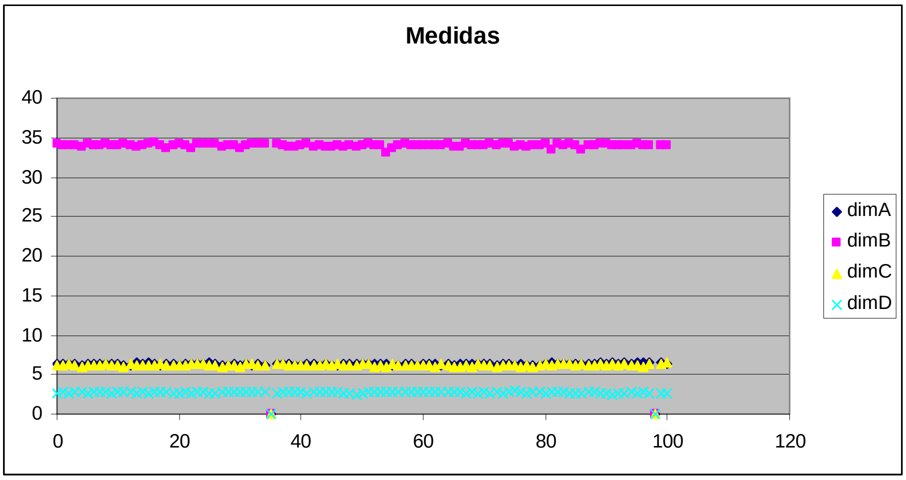


Figure 108: Dimensions of 101 parts measured with the upper camera

In the previous figure it can be seen how the repeatability of the upper camera is very high. Each colour represents one of the important dimensions of the part. The dimensional accuracy of the upper camera is 0.11 millimetres, which is more that enough than the specifications of the part.

After analysing the efficiency of the lateral camera to detect the presence of "pikutas", next the upper camera was evaluated in terms of detection of deformed parts. In order to get this, the research team took two good parts and after getting their right dimensions, they bended the parts, making the diameter of one of them smaller and the diameter of the other one bigger. The results for the part that became bigger are shown in next figure. In the figure it can be seen how at the beginning the external diameter of the part is around 34 millimetres. Next the diameter was enlarged up to 36 millimetres and finally up to 37 millimetres. The artificial vision system was able to detect this variation and shorted out the deformed parts.

dimA	dimB	dimC	dimD
6.462	34.040	6.204	2.834
6.462	33.950	6.120	2.943
6.547	34.015	6.036	2.834
6.377	33.989	6.204	2.834
6.462	33.989	6.204	2.834
6.462	**35.041**	6.288	2.943
6.377	**35.956**	6.204	2.834
6.377	**36.010**	6.288	2.943
6.377	**35.819**	6.288	2.943
6.462	**35.844**	6.372	2.943
6.462	**37.022**	6.372	2.834

Figure 109: Dimensions evolution with increased diameter

At the same time the same test was made but decreasing the diameter of the part. In next figure it can be seen how the final diameter of the part is smaller than the right one. Therefore the part was shorted out as bad quality part.

dimA	dimB	dimC	dimD
0.000	**31.448**	0.000	2.725

Figure 110: Dimensions evolution with decreased diameter

From these first results it was concluded that the artificial vision system was able to detect both deformed parts and the presence of “pikutas” and therefore the detection of bad quality parts was assure.

Wrong detection of good quality parts

Next step in the test phase was to evaluate the reliability of the artificial vision system in terms of wrong detection of good quality parts. It is very important that the artificial vision system will recognise all the defective parts, but it is also important that the artificial vision system will not reject parts that are good. In order to test this, the same part was checked by the artificial vision system one hundred times and the variation of its dimensions was computed. Next the results of this test are explained.

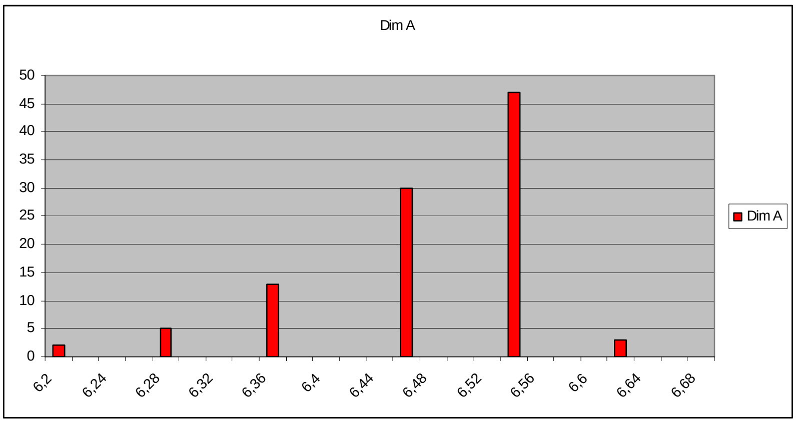


Figure 111: Width variation in area in front of the ears

First tested dimension is represented in previous figure. It corresponds to the area situated in front of the ears of the part. It can be seen how the minimum is 6.2 millimetres and the maximum is 6.64 millimetres. This variation corresponds to 4 pixels, each pixels being 0.11 millimetres. The average value of the dimension is 6.482 millimetres.

The second dimension corresponds to the external diameter of the evaluated part. In this occasion, it can be seen in next figure how the variation goes from 33.1 to 34.1 millimetres, which means around one millimetre. The average value of the dimension is 33.913 millimetres. In the figure are also marked the upper and lower tolerance for this dimension and it can be concluded that all the parts were good in terms of upper tolerance but there could be a few problems in terms of lower tolerance. This will be checked in the final implementation phase at Industrias Alzuaran (explained in workpackage 6).

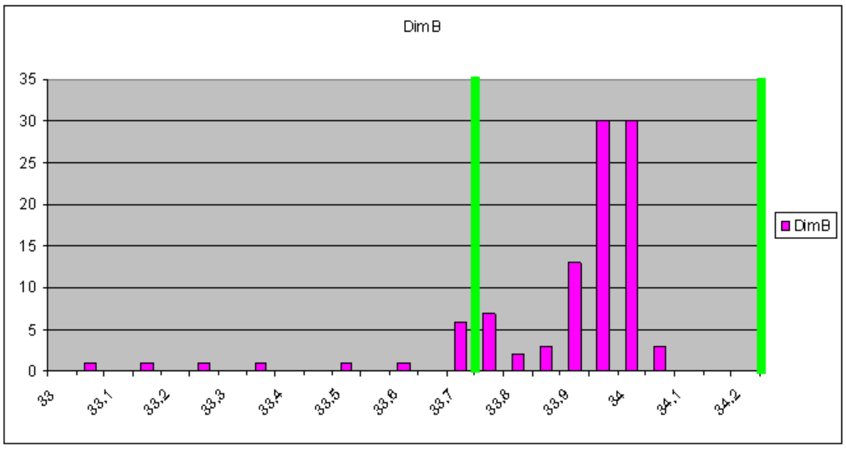


Figure 112: Variation in the external diameter of the part.

Next dimension to be analysed is the width of the ears of the part. In this occasion, it can be seen in next figure how the variation goes from 6.04 to 6.48 millimetres, which means around 4 pixels again. The average value of the dimension is 6.207 millimetres.

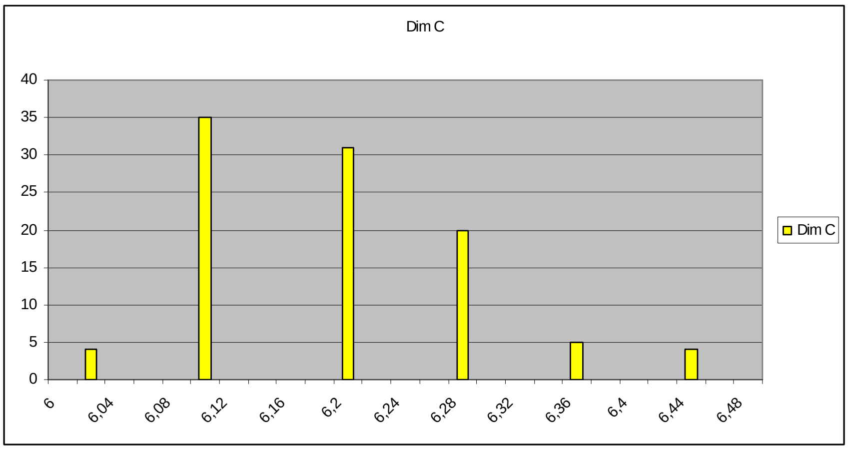


Figure 113: Width variation in the ears of the parts

And finally the last dimension that was measured is the diameter of the small holes in the ears of the parts. In this occasion, it can be seen in next figure how the variation goes from 2.83 to 2.94 millimetres, which means around 1 pixel. The average value of the dimension is 2.899 millimetres. In this case the variability is very low.

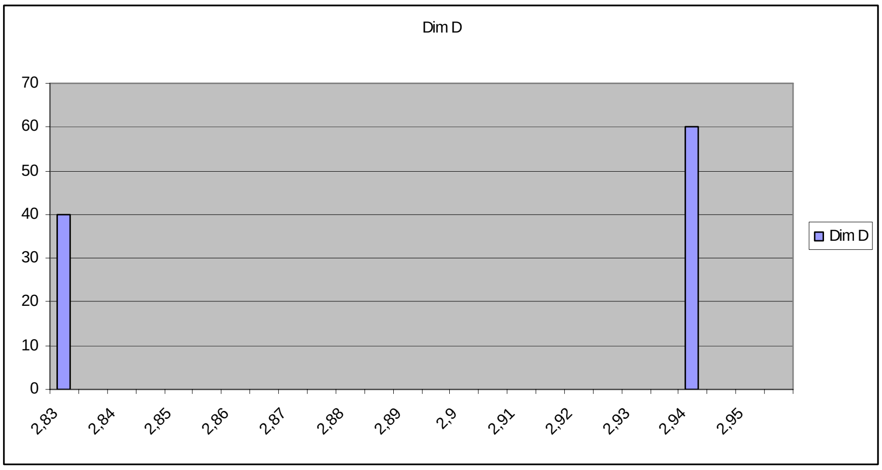


Figure 114: Diameter variation of the small holes at the ears.

From these first results it was concluded that the artificial vision system had a big repeatability although a few more tests should be made mostly concerning the big diameter of the part.

<u>Time calculation for parts evaluation</u>

And finally another very important characteristic of the artificial vision system is the time that it needs to compute the quality of the parts. For this calculation several test were made and the time was measured. In next figure a distribution of the time for the evaluation of 100 parts is represented.

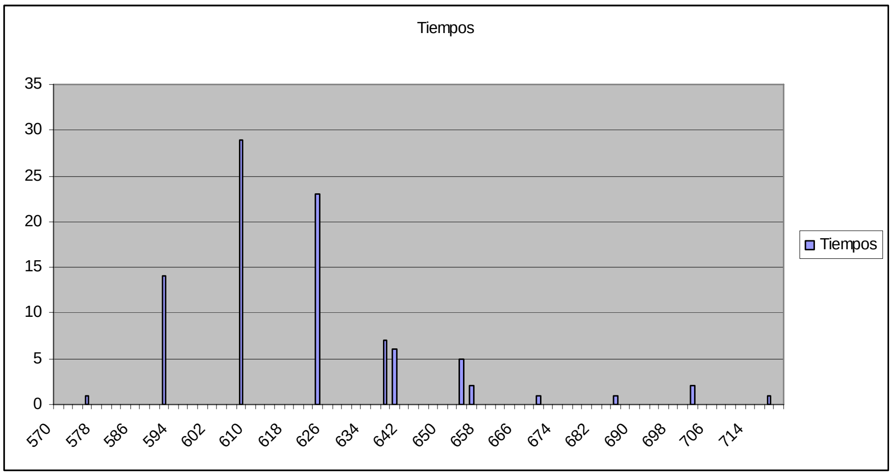


Figure 115: Necessary time for part quality measurement

It can be seen in previous image of the necessary time is not always exactly the same and the distribution of time follows the shape of a Gauss bell. Next the exact timing for the 100 experiments is given.

Tiempo (ms)	Repeticiones
576	1
592	14
608	29
624	23
638	7
640	6
654	5
656	2
670	1
686	1
702	2
718	1

Figure 116: Timing for part quality measurement

In the previous figure is given the exact amount of seconds per part and how many times that time has been achieved. In this way, from 100 parts, 29 times the algorithms needed 608 seconds, 23 times the algorithms needed 624 second and so on. The average time is around 623 milliseconds per part. This means a cadence 96 parts per minutes or 48 strokes per minute.

Although it was already mentioned in the first periodical report, next, and as an example and in order to understand better the results of this previous phase, the steps that the artificial vision system executes when finding the defects and dimensions of the parts will be shown. In this case, the studied reference is the 0863-012. For more information, in “D7- Integration in a common environment” all the developed algorithms are explained. The steps are explained next:

1. Original image of the part.
2. The algorithms look for a contour with a size corresponding to the size of the part.
3. The algorithms find the centre of the part and calculate the external diameter of the part (dimension B).
4. The algorithms find the internal and external profile of the part.
5. The algorithms find and measure the small holes in the parts (dimension D).
6. The algorithms find the corners of the part.
7. The algorithms take several measurements of the width of the corners and give back the maximal measurement (dimension C).
8. The algorithms show the user where the maximal width of the corners of the part is.
9. The algorithms measure the width of the part in the area in front of the holes (dimension A).

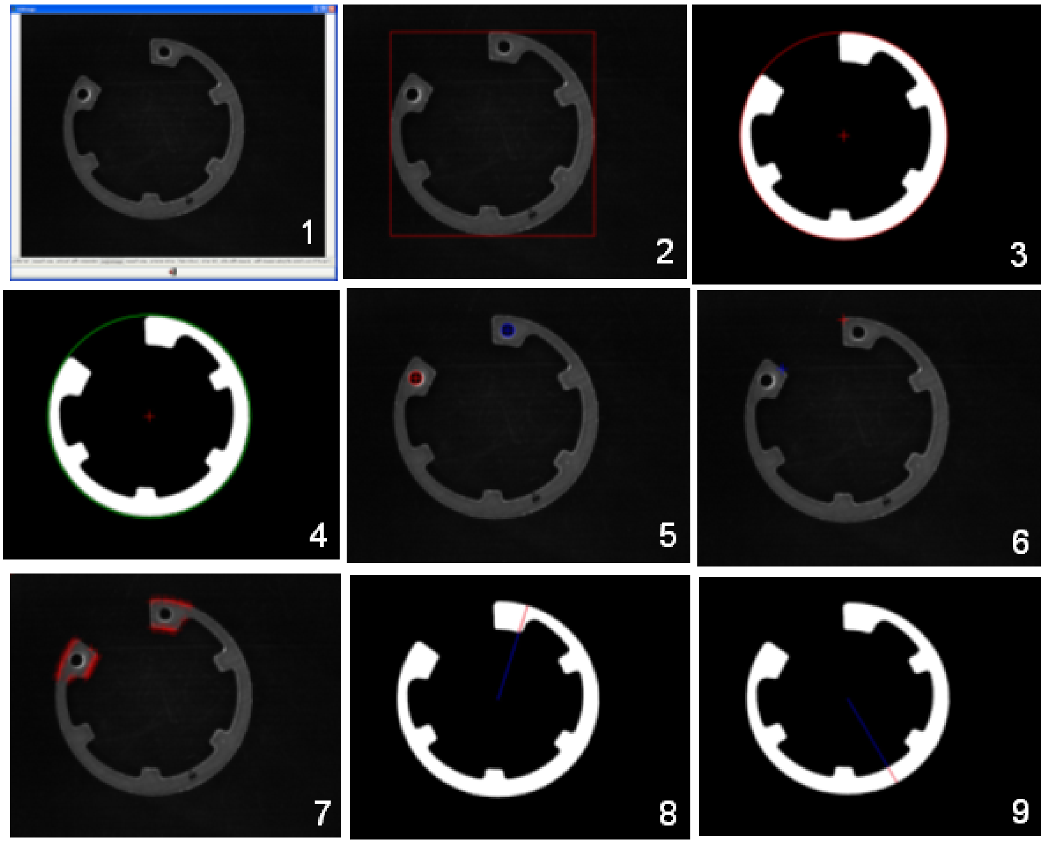


Figure 117: Steps in the part quality calculation

After doing all these steps, the algorithms show the user the final results.

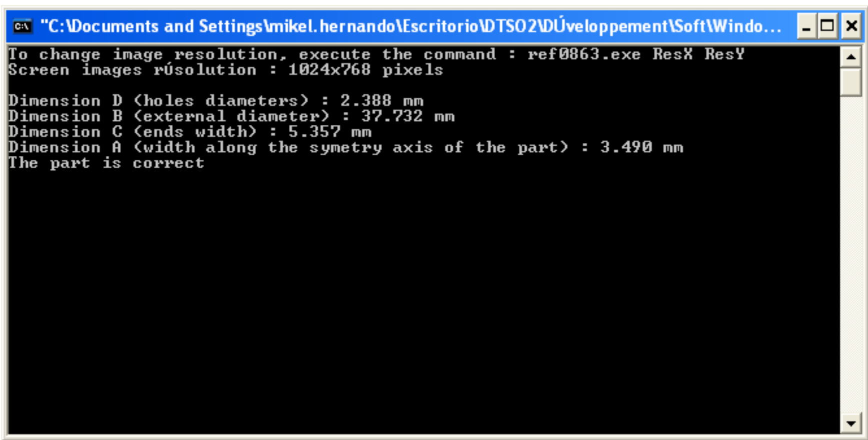


Figure 118: Artificial vision system graphical user interface

Next two examples of defective parts detected by the artificial vision system are shown. Anyway, more cases can be found in “D8- Test, Critical cases”. The first example shows how the artificial vision system is able to detect if any of the dimensions of the part is out of tolerances. In this case, two parts, one with the dimension A too large and the second with the same dimension too small are evaluated. It is shown in the next figure how the algorithms evaluate the part.

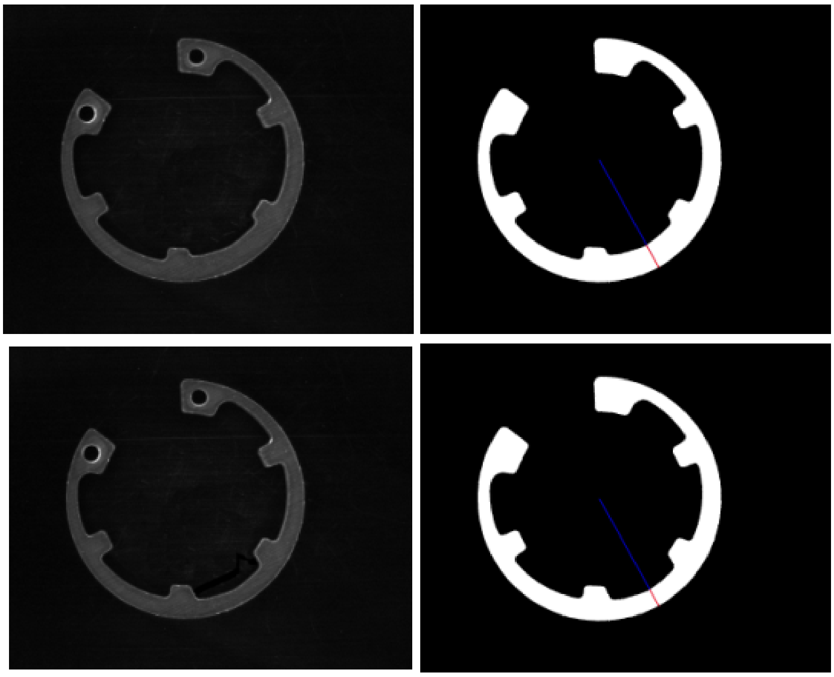


Figure 119: Measurement of the dimension A in both parts.

And in the next figure the real value of the dimension for both parts is given by the artificial vision system graphical user interface.

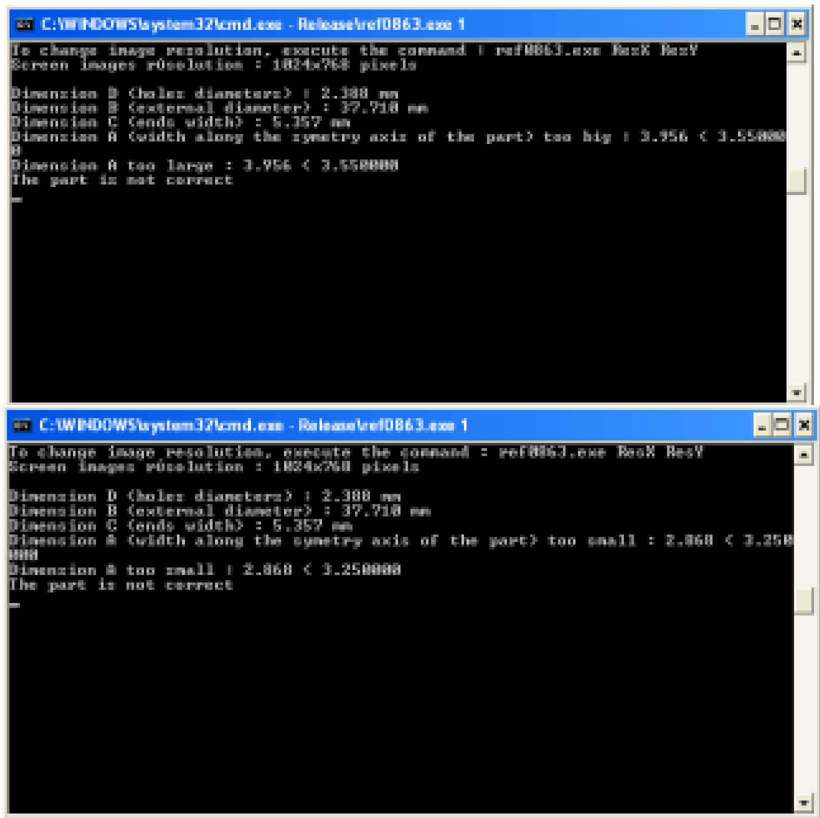


Figure 120: Artificial vision system interface in both cases.

Finally in the next example it will be shown how the artificial vision system is able to detect that one of the internal holes of the part is missed (punch breakage) and advices this to the operator to repair the broken punch.

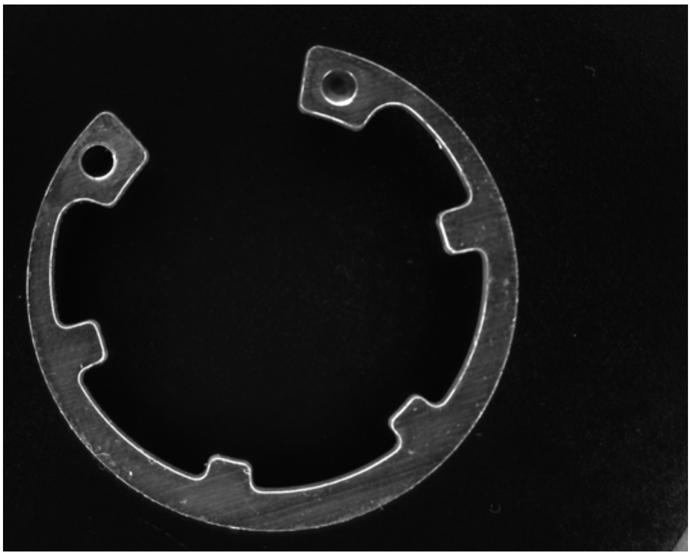


Figure 121: Original image of the defected part.

And next the artificial vision system GUI tells the operator about the founded defect.

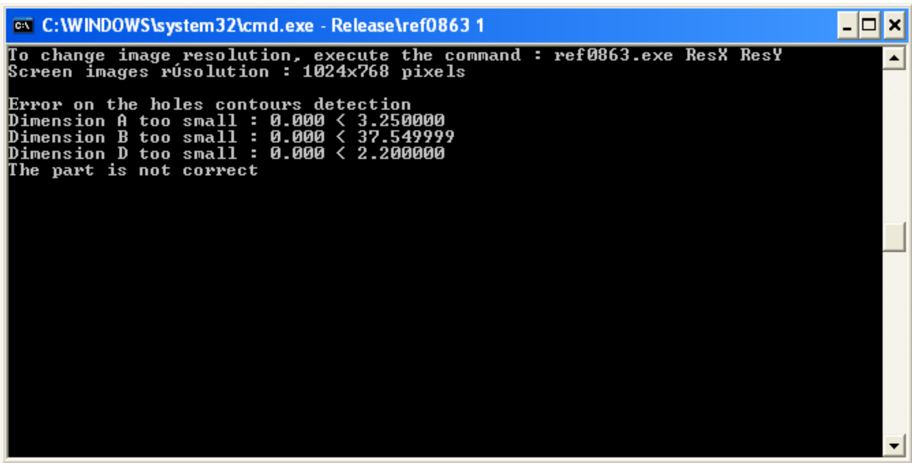


Figure 122: Artificial vision interface saying that the part is defective.

And finally the treatment of the lateral picture of a part big pikuta is shown in the next image. It can be clearly seen how the pikuta is shown by the camera and how at the end, in the contours, the pikuta is detected as a peak in the lower side of the part. The steps for this algorithm are the next:

1. Original image of the part.
2. The algorithms look for a contour with a size corresponding to the size of the part.
3. The algorithms delete the possible noises in the picture that disturb the part.
4. The algorithms look for the external contour of the part and check if there is any peak in the upper line that defines the contour. If a line is found in that upper line then there is a "pikuta" and the part is defective.

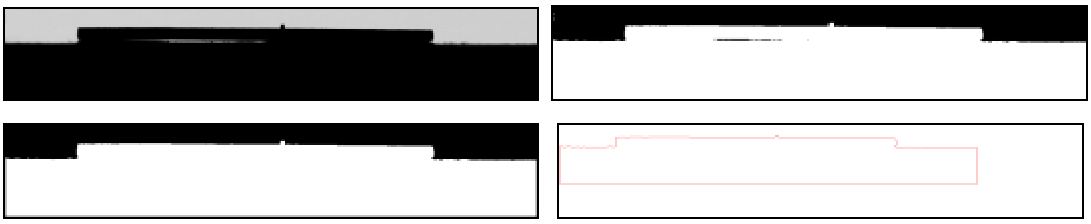


Figure 123: Treatment of the lateral image of a part with "pikuta"

Finally, and it was said in workpackage 3, an image where the graphical user interface of the artificial vision system is shown. In the figure, it is shown how the user is informed about the quality of the upper and lateral picture.

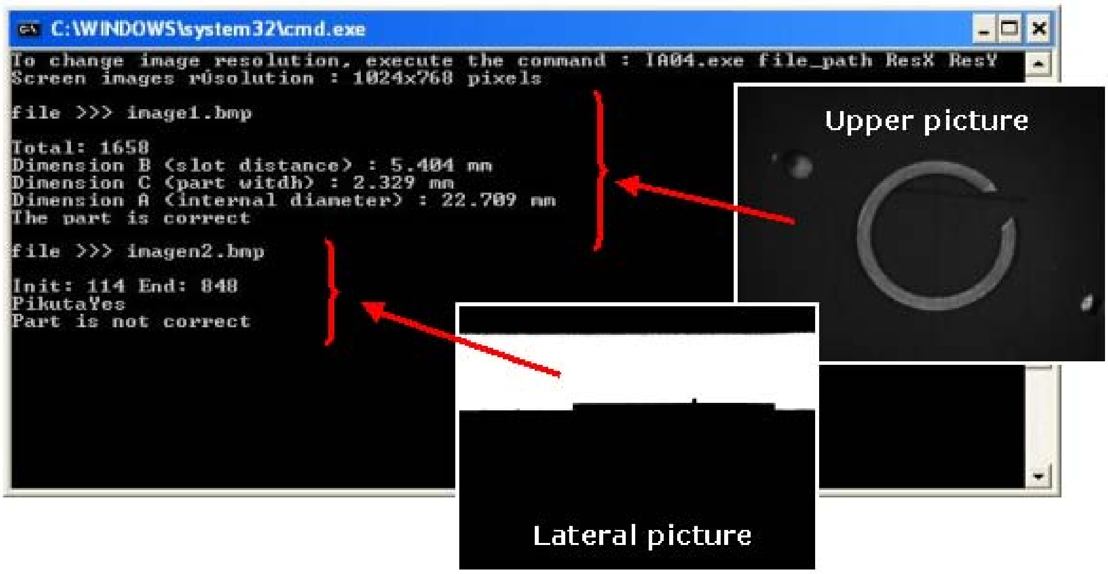


Figure 124: Graphical User Interface of the developed artificial vision system

3.4.3 Deviations from Project work programme and corrective actions

Concerning the monitoring system there is no deviation from the work programme, the Brankamp system is already working in the press in Industrias Alzuaran, connected to a PC and data are being recorded with the aim of evaluating deeply its curves.

Concerning the artificial vision system the work is a bit delayed from the work programme mainly due to two reasons. First, several problems were found when trying to develop correctly the lateral image for evaluating the part. As it was explained in the previous workpackage, there is no solution (vision system) capable of achieving all of this project’s necessities. Therefore and after evaluating it, the work team decided to work with the best possible solution and this delayed the development of the system.

After that and another reason that was not taken into account, the long period of time that the artificial vision system customer needed to supply them. The components of the artificial vision system are very special and because of this the time needed was longer.

Anyway all this has been taking into account, the upper view for evaluating the part is almost finished and the lateral view will be set-up and tested very soon in the laboratories of the University of Mondragon. After that, the artificial vision system will be installed in Industrias Alzuaran.

3.4.4 List of deliverables

Del. no.	Deliverable name	Workpackage No.	Date due	Actual/Forecast delivery date	Estimated indicative person/month*	Used indicative person/month*	Lead contractor
D7	Integration in a common environment	4	12	12	2	2	RTD2
D8	Tests: critical cases	4	12	12	3	3	RTD1

3.4.5 List of milestones

Milestone no	Milestone name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
M 4.1	Press and progressive tooling prototype provided with force and AE sensors and AV system	4	10	14	RTD2
M 4.2	Database with the results of the two monitoring systems	4	12	14	RTD2

3.5 Workpackage 5. Development of the control system

3.5.1 Workpackage objectives and starting point of work at beginning of reporting period

The objectives of the Workpackage 5 are the following ones:

- To develop the control system, able to identify the occurrence of defects in the workpart (kind of defect, placement, importance), as well as other disturbances like overloads, waste penetration, crack or excessive wear of the tooling. This control system has to be able to work in an industrial environment: presence of dust, darkness… and has to be fast. It will be based on two modules for signals and images analysis and processing and a decision module based on artificial neural networks (RTD1).
- To identify the optimal conditions of each monitoring system to detect the occurrence of all kinds of defects (RTD1, RTD2).
- To develop a user-oriented interface in order to easily adapt the monitoring and control systems to a new workpart, having into account that the dimensions and shape of the workpart, and the position and size of the defects change from one workpart to the other (RTD1 with the participation of RTD2).

The different tasks defined at the beginning of the project are the following ones:

Task 5.1: Signal and image analysis and processing

The analysis of the critical cases recorded during the task 4.2 should allow us to perform the following work:

- Define the signal processing tools adapted to the nature of each defect (RTD1)
  1. Signal screening to avoid ambient noise and interferences,
  2. Time-frequency analysis to identify the time and frequency characteristics of the signal related to the phenomenon studied,
  3. Conventional processing methods: time-based, frequency-based, energy-based, statistical, etc.,
  4. Extraction of the relevant parameters based on a statistical analysis (correlation, discrimination, classification).

These processing tools must be quick, easy, and reliable in order to implement them in an industrial environment.

- For the sensors based monitoring system (RTD1, SMEP3):
  1. Identify on-line, using the capabilities of PK550, the threshold of each signal which defines the working area where good workparts are produced.
  2. Identify, for the occurrence of each defect, the differences between the signals corresponding to good parts and the signals corresponding to defective workparts.
  3. Identify the defects that are not detected by the system.
- For the AV based monitoring system (RTD2, SMEP4)
  1. Identify, (for the system developed by Delta Technologies), the patterns that are related to the production of good workparts.
  2. Identify, for the occurrence of each defect, the algorithms and strategies better detecting the occurrence of defective workparts.
  3. Identify the defects that are not detected by the system.

- Identify the optimal conditions of each monitoring system to detect the occurrence of all kinds of defects (RTD1, RTD2):
  1. Placement of the sensors.
  2. Adjustment conditions of the sensors.
  3. Signal treatment and processing for the sensors based monitoring system
  4. Illumination for the AV system.
  5. Algorithms for each of the defect when using the AV system.
  6. Image processing strategies and parameters for the AV monitoring system

Task 5.2: Development of real-time processing modules adapted to the cases studied

- Design and develop real-time signal and image processing modules, based on artificial neural networks (which have proven during the project CAUPRES: Automatic Control of Sheet Metal Forming [MAR_F02] to be suitable methods for workpart quality control). In this first stage, the critical cases already produced will be used for the initial tuning of the system (RTD1).
- Analyse the reliability of the developed control for the detection of the different defects, applying them to new cases directly produced at SMEP7 site. During these tests, a film shall be shot.

Task 5.3: Development of the interface for the easy adaptation of the system to a new workpart (custom oriented)

- Develop the user interface and the "help menus" for the easy modification of the control parameters in order to make easy the adaptation of the control system to a new workpart (RTD1).

3.5.2 Progress towards objectives

The proposed schedule for the tasks described in the previous section is the one shown in the next picture:

Description of workpackages, tasks and specific reports	Year 1															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
WP 5: Development of the control system																
Task 5.1: Signal and image analysis and processing						X	X	X	X	X	X	X				
Task 5.2: Development of real-time processing modules adapted to the cases studied								X	X	X	X	X	X	X		
Task 5.3: Development of the interface for the easy adaptation of the system to a new workpart (custom oriented)												X	X	X	X	X

Figure 125: Schedule of the fifth workpackage

The work done and the most important results achieved in Workpackage 5 are described in the next lines of the present report.

3.5.2.1 Development of the control system

Traditionally, human operators have controlled manufacturing processes helped by local controllers that maintain the main process parameters close to the values estimated by the operators. The figure of human operators still remains in most of the manufacturing processes because the implementation of global controllers has not offered good results yet. The reason why the application of global controllers to manufacturing processes has not been achieved yet is that traditional control techniques such as optimal control, adaptive control or predictive control are only suitable in some specific cases.

The most applied traditional control strategy is the process control with feedback (PID control). Although feedback control has been applied to several fields, it only yields satisfactory results when: first, the process is linear, or at least the process behaviour in a small range close to the position where the main variables usually work is linear. Second, when the process response is quick, otherwise the control system is saturated. And third, when there are not any external disturbances that affect the behaviour of the system.

If these conditions are not fulfilled, the solution is to apply some other traditional control techniques that work based on mathematical models of the processes. These techniques are feedforward control, predictive control, adaptive control, model base control, optimal control or modal control. The biggest limitation when applying these techniques is that the development of a detailed model of virtually any real industrial process, even a relatively simple one, is likely to be very complicated. Therefore, the control engineer usually faces a solution in which a control system must be designed on the basis of a simplified description (model) of a complex process and therefore the final results are quite poor.

Among others, the fields where traditional controllers have reached good performance are: level control, pressure control, control of volume flow and volume mass, control of energy or control of temperature and enthalpy. Direct applications can be found in control of mechanical separation processes, control of heat exchangers, control of evaporators or control of drying processes. And the final industrial users are pulp and paper industry, oil extraction and refining industry or petrochemical industry.

On the other hand, there exist some other processes that show a high non-linear behaviour and that are almost impossible to be defined with mathematical models. A clear example is sheet metal forming processes. These processes are inherently quite unstable and their main variables, like the material behaviour during deformation, the lubrication and friction at the material/tool interface or the tools´ wear are highly non linear. Therefore, the application of traditional controllers to these processes does not offer good results.

Due to the presence of so many different process behaviours within the industry, there has been a tendency toward two schools of thought in the choice of a model structure for use in a control system. One school believes that the model should be based on known physical phenomena that characterise the process; that is, a first principle model (traditional control techniques). The other school tends toward a black box approach, which uses observed relations between the input and the output of the process to characterise a general, usually non linear transformation (transfer function) where all the parameters are unknown.

The high complexity of sheet metal forming processes makes the control based on traditional techniques (first school) not to offer good results and thus the control techniques based on observed relations (second school) seem to be the most suitable solution. Among the techniques belonging to this second school, Artificial Intelligence (AI) has shown the most successful results. AI can be defined as the branch of the computer science that takes care of the automation of the intelligent behaviour. This means that AI gathers a group of techniques and tools which main purpose is to simulate the human behaviour and apply it to different life fields. Among AI techniques, Expert Systems have been one of the most successful techniques applied to the control of forming processes.

An Expert System is a set of linguistic control rules that provides an algorithm which can convert the linguistic control strategy based on expert knowledge into an automatic control strategy. At the present research project, the control system (the Expert System) is the responsible for adjusting the parameters of the press in order to get the process working correctly and stable. To reach this objective, the control system gathers information from the artificial vision system and from the monitoring system, processes this information and finally sends advices, via the graphical user interface to the operator, with the correct adjustment of the process parameters.

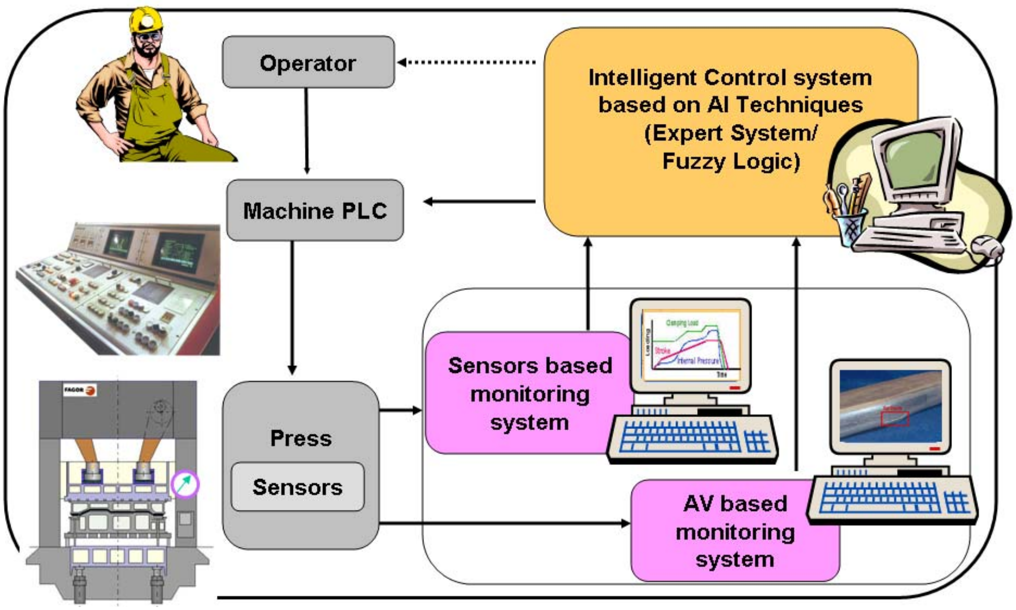


Figure 126: General scheme of the Control System

Therefore the core of the control system is an expert system that mimics the human expert operator. The expert system can be defined as a problem-solving and decision-making system based on knowledge codified from the experience of human specialists in the field. The main advantages of the Expert Systems compared with the actual control strategy based on a human operator is the achievement of more consistent answers for repetitive tasks, decisions and processes, efficiently and quickly and without any lack of performance because of pressure or tiredness. This faces an increasingly problem in the actual manufacturing processes: human operators are less and less able to react as quick and precise as the production rates and quality requirements demands. In this case, the human experts are the operators of Industrias Alzuaran and Industrias Garita, and the domain is sheet metal forming processes.

In order to develop the Expert System different computer tools can be found in the market and a deep study of these different options has been made taking into account different features like:

- Kind of knowledge that they allow to explain.
- Commercial license.
- Facility to communicate with a Graphic User Interface (GUI).
- Communication with other systems (artificial vision system and monitoring system).
- Operative system where they can be installed (Windows or Linux)

Among the different options studied, Clips has been chosen because it allows to explain both boolean and fuzzy knowledge, and other languages like C or Python have libraries to make possible the communication among them. Clips is also able to be executed from C language and in this way it is very easy to develop a GUI (Graphical User Interface) using in this case GTK libraries. At the same time the communication with other systems is very easy developed. Therefore the expert system has been developed in Clips, following the steps pointed out in next section.

<u>Acquisition of the knowledge</u>

The first step in the development of the expert system is to identify the expert and the domain. To identify the expert has not been difficult, because the operators of Industrias Alzuaran and Industrias Garita are the human experts that the expert system has to mimic, and the manufacturing processes have been identified like domains of each expert system.

The second step is to acquire the knowledge that the operator have about the process. In other words, the operator has to transfer to the Control Engineer the knowledge that he/she has acquired with the experience. This knowledge acquisition has been made via two different ways: interviews with the operators and working together with them at the forming facilities. In this way the control engineers have been able to acquire the knowledge of the operators for a future implementation into the Expert System.

Figure 127: Transferring Knowledge

Development of the knowledge base

After getting the knowledge of the experts about the manufacturing processes, the control engineers have developed the knowledge bases where all that knowledge and experience have been implemented.

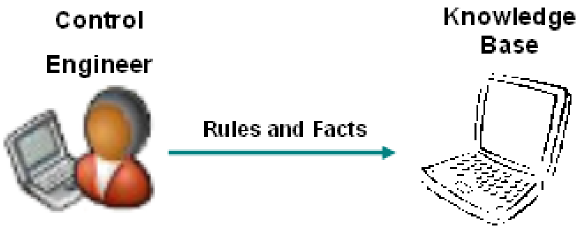


Figure 128: Representation of Knowledge into the database

For the development of the knowledge bases the control engineers have tried to follow the same reasoning that the human operator apply to solve the problems at the facilities. Control engineers realised that human experts apply these three next questions to solve the problems:

1. First they have to detect what is the reason for a machine instability/stop or for the producnction of defective parts.
2. Second they have to analyse the possible reasons for the malfunction at the forming facility.
3. And finally, they have to find the solution that should be applied to restart the production in the most satisfactory way.

Therefore and following the schema propose at the previous lines, the control engineers developed a database that is shown in the next figure. In the figure it is shown how, from the knowledge of the operators and from the experience that they got when working together with the operator, nine different process faults were detected at the forming facility. In the figure it can also be seen how for each process fault a reason and a solution to be applied are given.

For example for process fault number 3, the detection of a metal scrap that is blocking the first or second station, the reason is that the punches at station number 1 or number 2 are not evacuating the scarp in a proper way and the solution that should be applied is to make the punches longer, to move the ram down in order to let the punches reach a lower position and to check the wearing of the dies. It is well know from the operator knowledge that if these steps are followed the process fault is solved. At the same time it has to be pointed how the expert system is able to advice the operator about the position inside the tool where the problem is taking place. This is due to the fact that there are several sensors inside the tool and therefore the Brankamp system is able to detect the position of the fault at the tool.

	Defect	Cause	Solution
1	The steel strip did not move at all.	A badly evacuated scrap is avoiding the movement of the strip.	Extract the scrap of material and check the reason why it was not adequately evacuated.
2	The steel strip did not move the right distance.	A badly evacuated scrap is avoiding the movement of the strip.	Extract the scrap of material and check the reason why it was not adequately evacuated.
3	A badly evacuated scrap is blocking the first or second station.	The punches in station 1 or 2 are not evacuating the scrap properly.	Make the punches longer, move the ram down and check the dies´ wear.
4	A badly evacuated scrap is blocking the third station.	The punch in station 3 is not evacuating the scrap properly.	Make the punch longer, move the ram down and check the die's wear.
5	A badly evacuated scrap is blocking the fourth or fifth station.	The punches in station 4 or 5 are not evacuating the scrap properly.	Make the punches longer, move the ram down and check the dies´ wear.
6	One of the punches is broken.	Excessive wearing of the punches.	Extract the broken punch and replace it with a new one.
7	There is a badly evacuated part inside the tool.	The extraction system is not working properly.	Extract the part and check the extraction system.
8	The strip is sticky to the pilot pins or punches.	Excessive wearing of punches or pilot pins.	Replace the faulty punch or pilot pin.
9	The machine is not working at its nominal speed.	The monitoring system started checking the curves to early.	Re-start the machine.

Figure 129: Knowledge database for the process faults

<u>Analysis of the Brankamp monitoring system</u>

Once that the knowledge base is created and that for each fault at the machine, the expert system knows the reason and how to solve it, next step is to develop and automatic system able to know exactly which fault is happening at the forming facility. As it was stated in previous lines, the expert system only has the information coming form the Brankamp monitoring system and from the artificial vision system in order to know the process fault at the facility. Therefore a system able to select the right fault when the machine is stopped using the information from the monitoring systems must be developed.

In order to get the previous purpose, a treatment of the process curves of the Brankamp monitoring system for its later analysis was made. As it was explained in workpackage 2 and in workpackage 4, the Brankamp monitoring system creates graphics that are composed of three curves, the lower envelope curve, the actual curve and the upper envelope curve. Whenever the actual curve stays between the lower and upper curve, the Brankamp will not detect any process fault and the process is considered to remain stable. On the other hand, if the actual curve goes beyond the lower or upper curve the Brankamp monitoring system will stop the machine because a process fault is detected. Depending on the position and size where the actual curve goes beyond the envelope curves, different process faults will happen at the forming facility. The main purpose at the present stage is to develop a curve treatment able to analyse the position and size of the overloads.

For making this analysis, the control engineers evaluated the process curves at the present forming facility and considered that the most meaningful parameters to define the curves are the next ones:

1. Channel number: Identify the sensor where the first fault (process signal going beyond the envelope curves) happens.
2. Lower/upper: Identify if in the previous fault the process signal has gone beyond the upper or the lower envelope curve.
3. Number of faults: Counts how many times the process signal has gone beyond the envelope curves.
4. Initial time: Identifies the first time when the process signal has gone beyond the envelope curves.
5. Real maximum value: Represents the maximum value of the process signal.
6. Real maximum value time: Represents the time at which the process signal is maximum.
7. Hypothetical value: Calculates, at the time when the first process signal reaches its maximum value, the value that the process signal would have if no fault had happened (see next figure a).
8. Gradient: Calculate the slope of the faulty process signal. In order to get, the difference between the faulty process signal maximum value and its value in the previous measuring time is calculated (see next figure b).
9. Time percentage of the last fault: Calculates the length (in percentage) of the last fault compared to the total length of the curve (see next figure c).
10. Fault in the process signal slope up: Identifies if the process signal goes beyond the envelope curves during the rising flank of the force curves.
11. Fault in the process signal slope down: Identifies if the process signal goes beyond the envelope curves during the falling flank of the force curves (see next figure d).

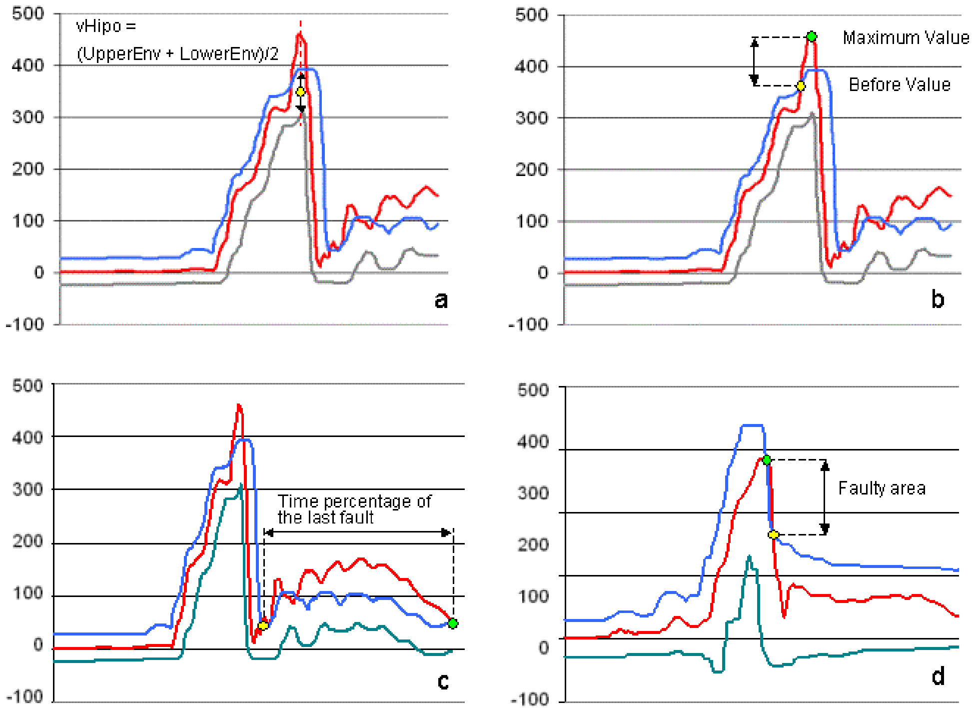


Figure 130: Parameters extraction from faulty curves

Following the previous explanation, each faulty curve is pre-processed and defined by all these parameters. As an example, a curve and the parameters extracted from it are described in next figure.

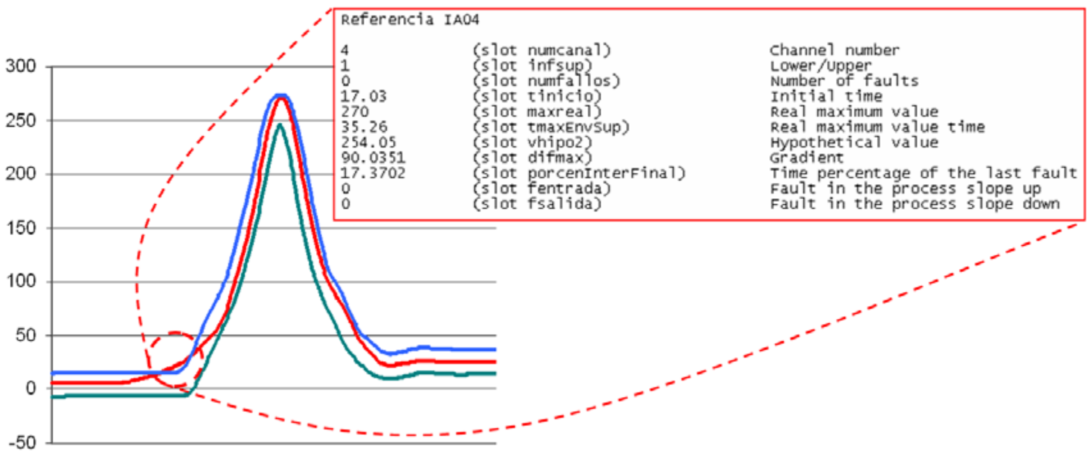


Figure 131: Faulty curve and its parameters

Once the parameters were extracted from the faulty curves, next step was to create the necessary rules in order identify the different faults. The creation of these rules is a very simple procedure: IF a set of antecedents are fulfilled THEN a set of consequences is given to the operator via the graphical user interface.

In this way the control engineers created different rules that linked the curves coming from the monitoring system with the faults at the database explained previously. This generates an automatic system able to analyse the information of the monitoring system and therefore able to automatically suggest ways to solve the problems at the forming facility to the operator. Next three rules for three different process faults are explained.

Broken punch

IF

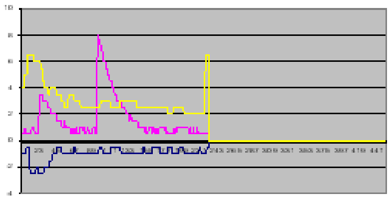
Rule: Faulty channel is number 3 AND the value of the gradient is bigger than 20

THEN

Consequence: Defect: There is a broken punch in the tool.

Cause: Excessive wearing of the punches

Solution: There are two possibilities:



If the punch broken length is short, replace the broken punch

If the punch broken length is long, extract the coil and replace the broken punch

Figure 132: Antecedents and consequences for the detection of broken punches

Improperly evacuated scrap

IF

Rule: Faulty channel is number 6 AND the initial time is lower than 20 AND the fault is an upper fault

THEN

Consequence: Defect: There is a scrap inside the tool.

Cause: Improperly evacuated scrap.

Solution: Replace the die, move the ram down or change to a longer punch.

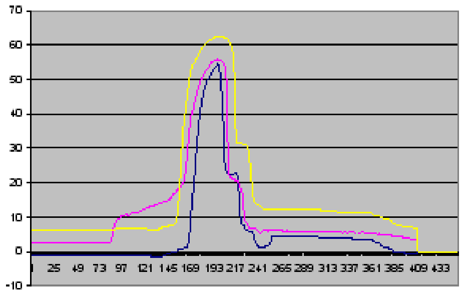


Figure 133: Antecedents and consequences for the detection of bad evacuated scraps of material

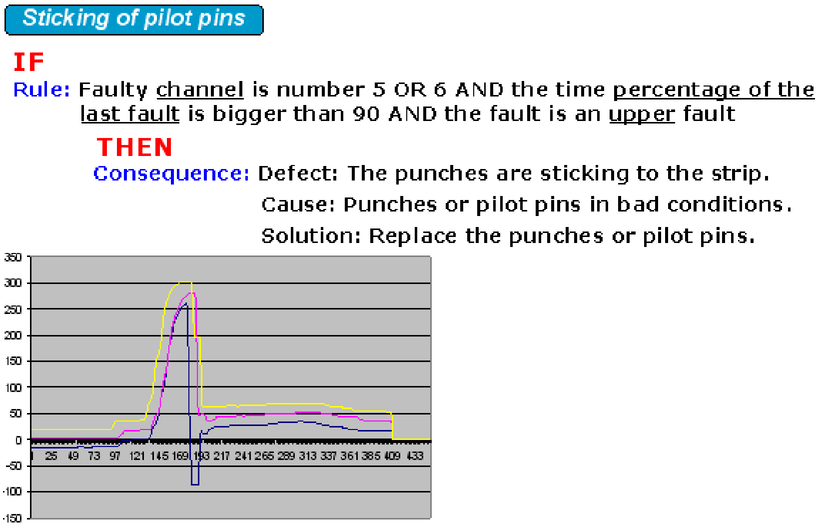


Figure 134: Antecedents and consequences for the detection of pilot sticking

So after linking the knowledge database with the information coming from the Brankamp monitoring system, the new knowledge database is the next one:

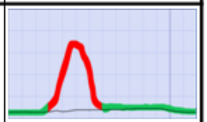
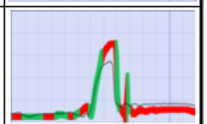
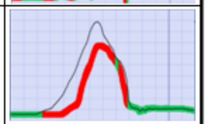
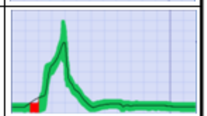
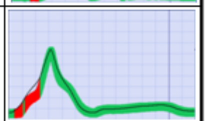
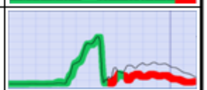
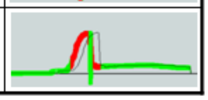
	Defect	Cause	Solution	Variables	Image
1	The steel strip did not move at all.	A badly evacuated scrap is avoiding the movement of the strip.	Extract the scrap of material and check the reason why it was not adequately evacuated.	In most of the channels the maximum real force is much smaller than the hypothetical force.	
2	The steel strip did not move the right distance.	A badly evacuated scrap is avoiding the movement of the strip.	Extract the scrap of material and check the reason why it was not adequately evacuated.	There is a force peak at the beginning of the channels which are measuring force directly in the tool.	
3	A badly evacuated scrap is blocking the first or second station.	The punches in station 1 or 2 are not evacuating the scrap properly.	Make the punches longer, move the ram down and check the dies´wear.	There is a force peak just before the maximum force in channels 4 and 5.	
4	A badly evacuated scrap is blocking the third station.	The punch in station 3 is not evacuating the scrap properly.	Make the punch longer, move the ram down and check the die's wear.	There is a force peak just before the maximum force in the third station.	
5	A badly evacuated scrap is blocking the fourth or fifth station.	The punches in station 4 or 5 are not evacuating the scrap properly.	Make the punches longer, move the ram down and check the dies´wear.	There is a force peak just before the maximum force in fourth or fifth station.	
6	One of the punches is broken.	Excessive wearing of the punches.	Extract the broken punch and replace it with a new one.	The force gradient is bigger than 20 in channel 3.	
7	There is a badly evacuated part inside the tool.	The extraction system is not working properly.	Extract the part and check the extraction system.	The force is very low at the end of the connection rod force curve.	
8	The strip is sticky to the pilot pins or punches.	Excessive wearing of punches or pilot pins.	Replace the faulty punch or pilot pin.	There is a force peak at the end of the curve in fourth or fifth station.	
9	The machine is not working at its nominal speed.	The monitoring system started checking the curves to early.	Re-start the machine.	All the force curves are out of the envelopes during the entire stroke.	

Figure 135: knowledge database with the information of the monitoring system

In this way, whenever the monitoring system stops the machine, the expert system will get the information, will process it and will inform the operator about the fault at the process, the reason and the solution that should be applied.

The Expert System has been running in the blanking facility during the last six months connected to the sensor based monitoring system. Up to now, four different references are controlled and nine different process faults have been found and implemented into the Expert System (see figure 5). Among the incidences, the most important are: strip feed failures due to bad extracted parts, strip feed failures due to slugs of material inside the tool, misalignment of the strip inside the tool, clogging of the strip to the tool during withdrawal of the ram, detection of broken punches and detection of double parts inside the tool due to bad extracted parts. Besides this, the intelligent controller is able to detect the position within the tool where the incidence has happened. In this way the operator only has to consult in the graphical user interface of the expert system in order to know the incidence, its position in the tool, its cause and the solution.

During the learning phase, which lasted during the production of more or less 200000 parts, the 95% of the process faults at the blanking facility were detected. After this learning phase and during the next six months, new knowledge was implemented in the Expert System and nowadays the success rate is close to the 100%. This means that the Expert System is able to define very accurately most of the process faults, not giving false errors at any time nor defining in a wrong way the process faults. At the same time the production rate of the machine has not been modified, meaning that the Expert System is able to work at the production rate not being a bottle neck in the process. The percentage of defective parts produced at the blanking facility has been slightly decreased from a 0.1% down to a 0.08% which means a 20%. This decrement in the production of defective parts has been mainly due to the application of the monitoring system although the implementation of the Expert System results also in a better resolution of the process faults what leads to a reduction in trials and production of defective parts when solving the process faults. Finally, one of the most important achievements of the implementation of the Expert System is the reduction in time, and therefore in cost, when solving machine stops. With the introduction of this Expert System the operator do not need to look for the fault in the facility but he directly finds in the interface of the Expert System a message with the instructions to solve the problem. Although no measurements have been made due to the complexity of measure this short of variables, it is estimated a reduction of about 50% in the time that the operator uses to solve the machine stops in the blanking facility after the implementation of the Expert System.

3.5.2.2 Development of the Graphical User Interface (GUI)

Although the results achieved with the expert system have been very satisfactory, another very important point is to allow the operator to have access to all the results. Therefore a GUI (Graphical User Interface) has been developed to communicate the control system with the user and inform this about the evolution of the project. Next a brief explanation of how the developed graphical user interface works is given.

The control system has been developed for several references. This is why the Graphical User Interface has an initial configuration window.

Figure 136: Initial configuration window

In this window (previous figure) the operator has the possibility to choose the reference to work with. Once the operator has chosen the reference, and when the process is working stable and the quality of the produced parts is good enough the operator will see in the screen the next message.

Figure 137: Message for good quality production

On the other hand when something strange happens in the process or when the quality of the produced parts is out of tolerances the operator will be advised in the next way. In the next figure the global view of the screen with a faulty production is shown.

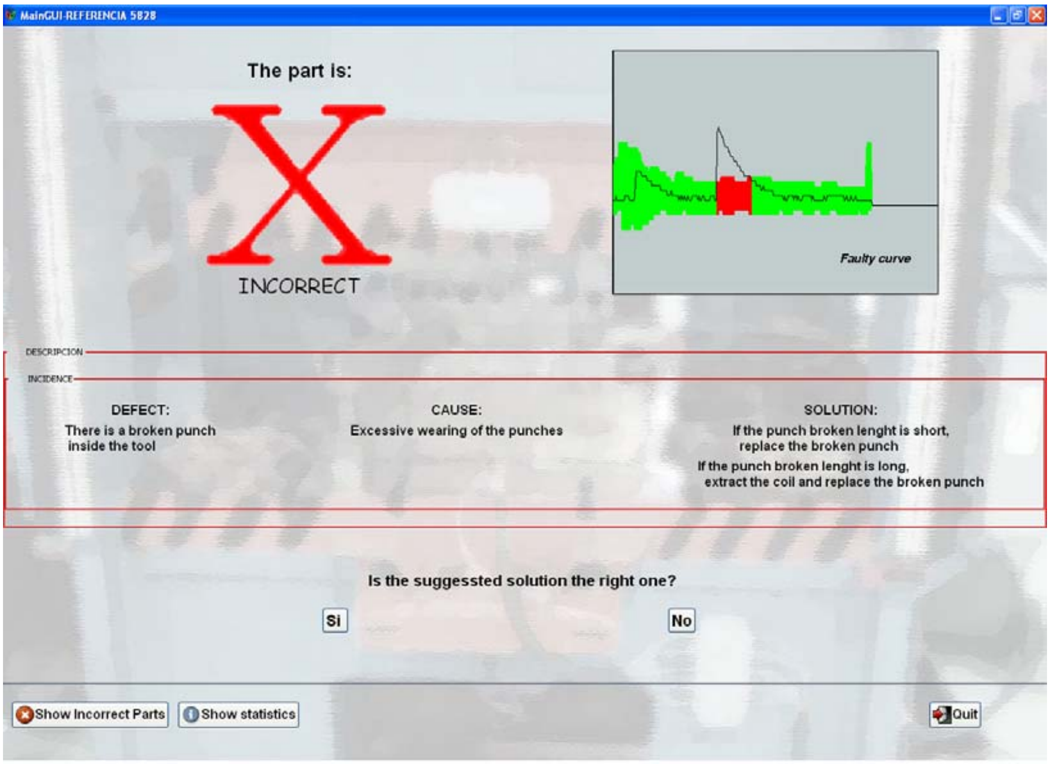


Figure 138: Graphical user interface with a faulty production.

It can be observed that from a normal production the screen suffers several changes. First of all, the previous shown figure 123 will change and the next one will appear in the screen.

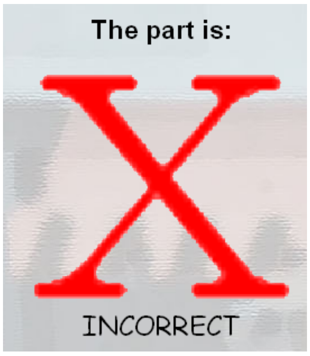


Figure 139: Message advising the operator about the faulty situation.

At the same time, the screen will show the operator where the problem is coming from. For example in the next example a faulty curve from the monitoring system made the control system to detect an instable process.

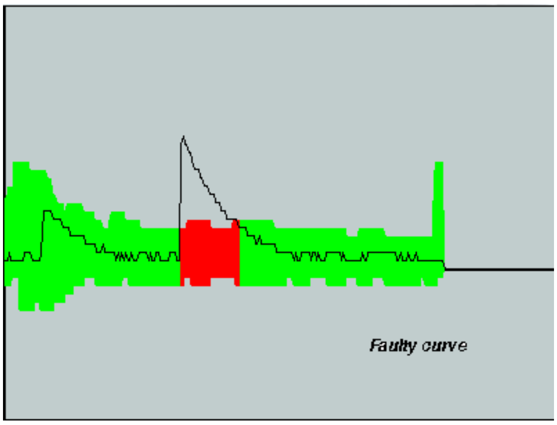


Figure 140: Faulty curve measured by the monitoring system.

And finally in the middle of the screen the main information coming from the control system is given. There the operator can find which the fault in the process is, and which its causes and the solutions to be solved are. This is the main advantage of this control system.

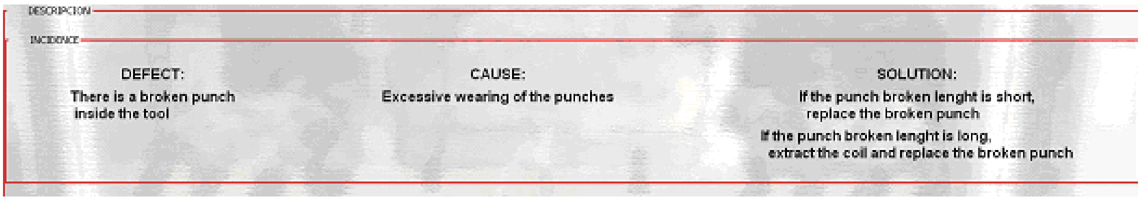


Figure 141: Description of the incidence

Once the operator read the screen he/she can give his/her feedback to the system and introduce if the given information is correct or not. This is shown in the next figure.

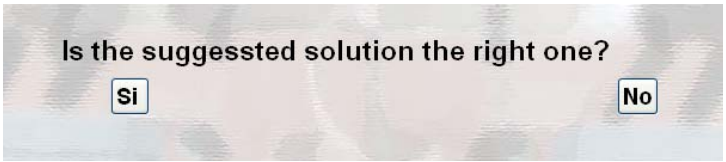


Figure 142: Validation of the suggested solution.

Then if the information is incorrect, the operator can introduce which the real fault in the process has been.

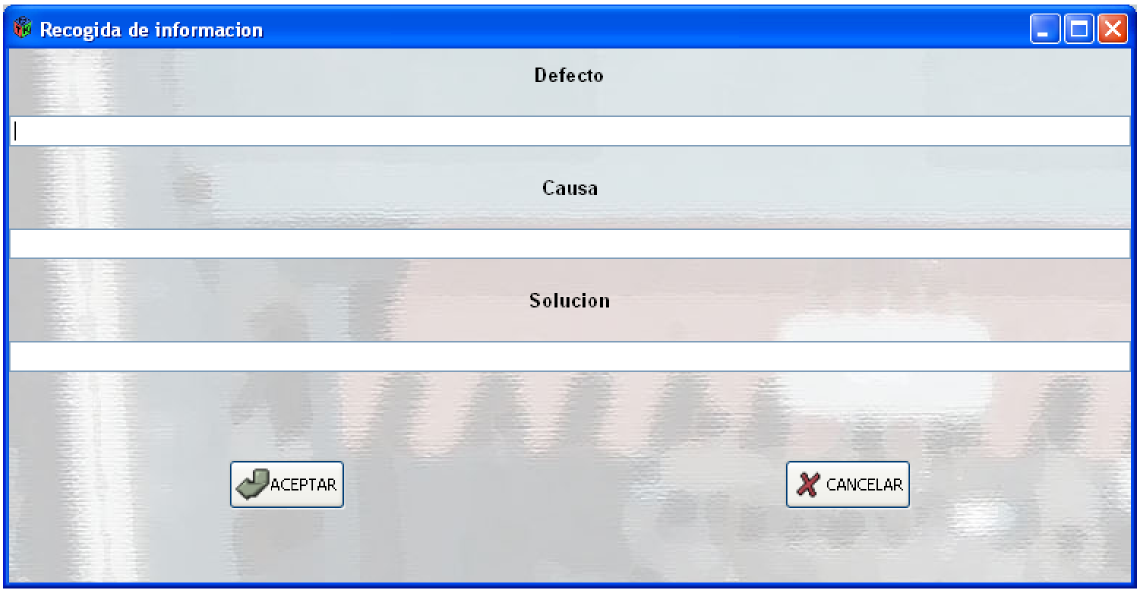


Figure 143: Interface for the introduction of new information

Apart from the main functions of the control system shown in the previous section, the graphical user interface allows the user to check for some extra information that can be important for the set up of the process.

Figure 144: Extra options of the control system.

For example the operator can get access to the last faults occurred in the process as well as to the last defective manufactured parts. This is shown in the next two figures.

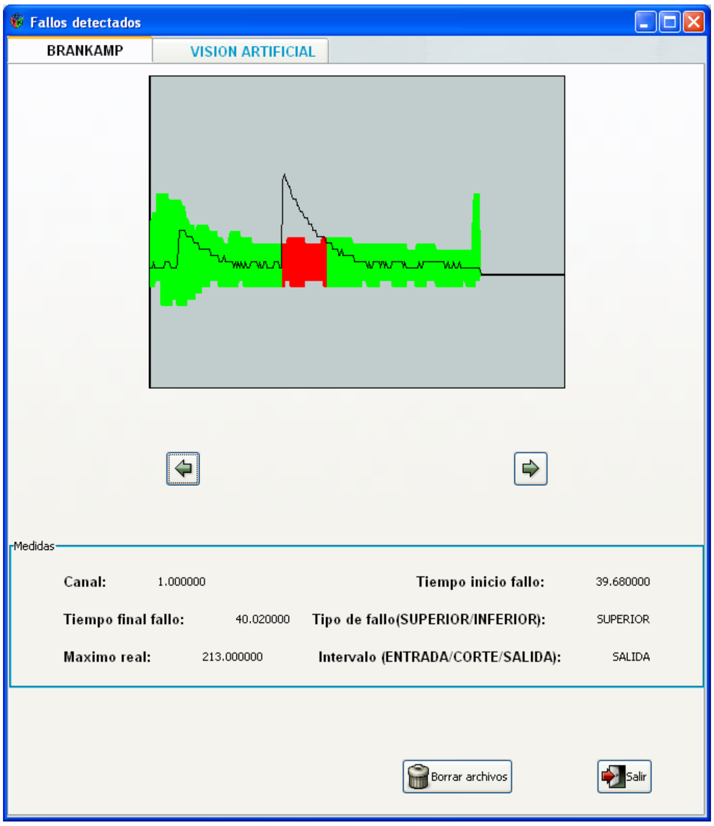


Figure 145: Data of the last fault in the process.

Figure 146: Data of the last defective produced part.

And finally the operator can get access to the statistics of the control system where he/she can check the quality of the solutions given by the control system. This is shown in the next figure.

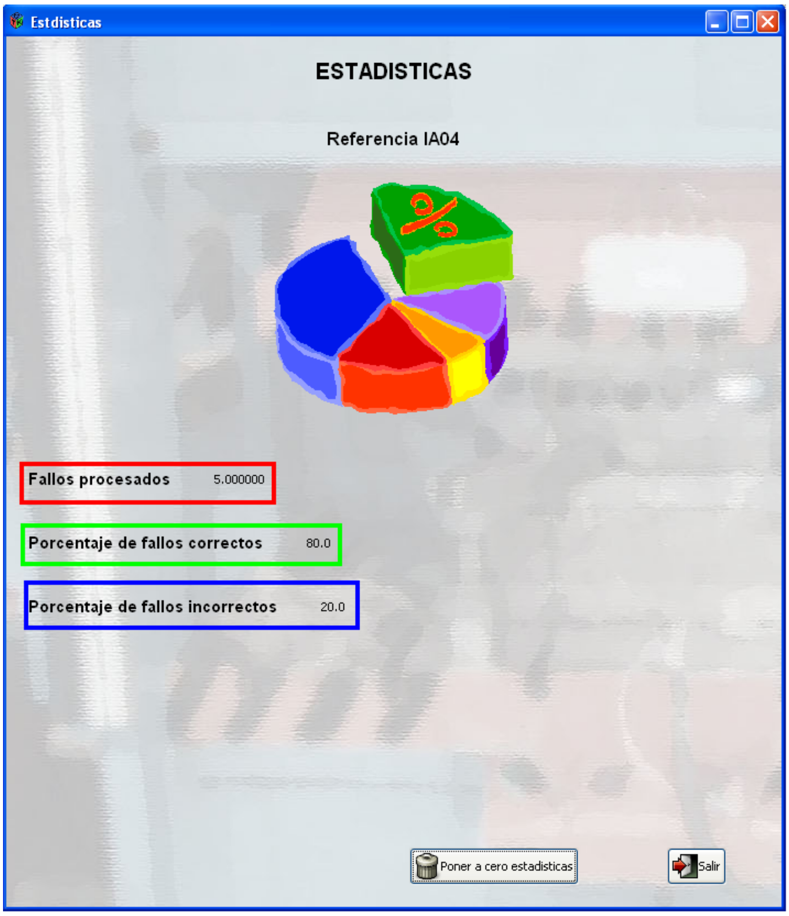


Figure 147: Statistics about the performance of the control system

All the labels and advices are in Spanish because the user of this GUI will be the operators of Industrias Alzuaran and Industrias Garita and they understand Spanish better than English.

3.5.3 Deviations from Project work programme and corrective actions

No major deviations from the work plan appeared.

3.5.4 List of deliverables

Del. no.	Deliverable name	Workpackage No.	Date due	Actual/Forecast delivery date	Estimated indicative person/month*	Used indicative person/month*	Lead contractor
D9	The control system: software and hardware, signal analysis and processing techniques and algorithms	5	18	18	4		RTD1
D10	Custom oriented interface for the adaptation of the complete system to a new workpart	5	18	18	2		RTD1

3.5.5 List of milestones

Milestone no	Milestone name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
M 5.1	Strategy for the signal and image analysis in order to identify the occurrence of each type of defect	5	14	14	RTD1
M 5.2	Programme that automatically detects the occurrence of a defect, identifies which type of defect is, and shows this in the monitor of the PC	5	16	16	RTD1

3.6 Workpackage 6. Real size validation in a production line

3.6.1 Workpackage objectives and starting point of work at beginning of reporting period

The objectives of the Workpackage 6 are the following ones:

- To check and validate the integration of the two control systems in a common computer environment and in an industrial application for blanking operations (RTD1, SMEP7, SMEP3, SMEP4, SMEP7, SMEP8).
- To validate the control system in a complex tooling with blanking and deep drawing operations (RTD1, SMEP8).
- To detect the fields of improvement of the diagnosis and control systems (RTD1, RTD2, SMEP3, SMEP4).

The different tasks defined at the beginning of the project are the following ones:

Task 6.1: Definition of the validation conditions and choose of the validation industrial case

- Define two industrial cases for the validation (SMEP3, SMEP4, RTD1, RTD2), which will take place at SMEP7 (blanking operations) and SMEP8 (deep drawing) sites, in two stages, under the direct supervision of RTD1. The industrial cases have to meet the following conditions:
  - Have a high production volume, in order to guarantee that some defects will be encountered.
  - Be complicated parts, where defects appear currently.
  - Fit the conditions required for the adaptation of the developed control system into it.
- Define the conditions of the validation tests: process parameters (machine speed, cadence, tooling adjustment, lubrication…).

Task 6.2: Adaptation of the control system to the validation conditions

- Analyse of the industrial case specificities: placement, dimensions and characteristics of the machine and tooling used, production rate, type, dimensions and geometry of the produced part… (SMEP3, SMEP4, RTD1, RTD2)
- Analyse of the modifications needed to install the sensors in the machine and the tooling (SMEP3).
- Sensors placement and preliminary verification (SMEP3, RTD1, SMEP7, SMEP8).
- Analyse of the possibilities for the AV system: placement of the cameras, lightening… (SMEP4, RTD2)
- AV placement and preliminary tests (SMEP4, RTD2, SMEP7, SMEP8).
- Modifications needed in the control system for adaptation to the industrial cases (SMEP3, SMEP4, RTD1, RTD2).

Task 6.3: Industrial validations

- Perform the industrial tests recording continuously the information given by the sensors based system, by the AV system, and by the control system concerning the quality of the parts that are being produced (SMEP7, SMEP8, RTD1).

- Compare the above mentioned information with the quality of the produced parts in order to detect whether the systems work properly (RTD1, RTD2, SMEP7, SMEP8).
- Verify the performance and detect the errors of the three systems: sensors based and AV based monitoring systems and control system (RTD1, RTD2, SMEP3, SMEP4).

During the test on the production lines, a film shall be shot. It shall eventually serve as a demo tool.

Task 6.4: Control system improvements

- Improve the system, including the two monitoring systems and the control system (SMEP3, SMEP4, RTD1, RTD2).

3.6.2 Progress towards objectives

The proposed schedule for the tasks described in the previous section is the one shown in the next picture:

Description of workpackages, tasks and specific reports	Year 1												Year 2											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
WP 6: Real-size validation on a production line																								
Task 6.1: Definition of the validation conditions and choose of the final industrial case													X	X	X									
Task 6.2: Adaptation of the control system to the validation conditions															X	X	X	X	X	X				
Task 6.3: Industrial validation																	X	X	X	X	X	X		
Task 6.4: Control system improvements																					X	X	X	X

Figure 148:Schedule of the sixth workpackage

The work done and the most important results achieved in Workpackage 6 are described in the next lines of the present report.

3.6.2.1 Selection of the industrial case and definition of validation conditions

Although at the beginning it was proposed that the developed system should be able to be applied in different manufacturing facilities, during the progress of the project it was stated that when working with artificial vision systems the application of these system to different industrial processes is very complicated and this is the main reason why the final validation of the developed system has only been made at Industrias Alzuaran. Anyway, and as it was described in previous workpackages, Mondragon University and Industrias Garita are working in parallel to this project with the purpose of developing an artificial vision system for the quality control of the reference chosen at Industrias Garita. The development of this system will finish in 2009 and the purpose is to evaluate its performance as it has been evaluated the performance of the system developed during the present project at Industrias Alzuaran.

Therefore the reference chosen for the evaluation of the control system developed at the present project has been the reference 5828-001. Next a short description like the one given in workpackage 3 about this reference is explained next.

Reference 5828-001 belongs to the automotive industry and is used, as in the case of reference 0863-012, to fix the steering wheel systems. For this reference the main dimensions to be controlled are shown in next figure.

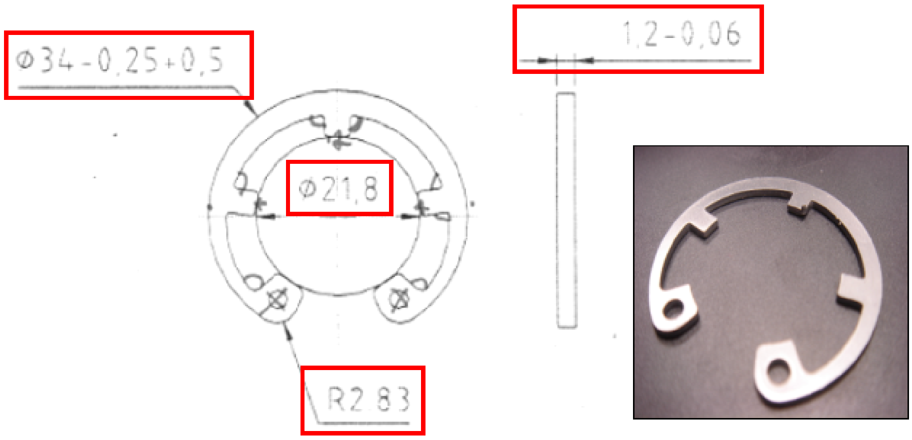


Figure 149: Reference 5828-001 manufactured in Industrias Alzuaran

The main defects to control at the present reference are very similar to the ones of the previous references (geometry of the part, flatness of the part, dents in the part, burrs at the part), but especially one defect, the most critical one has to be considered. This defect, named as pikuta, is shown in the next figure.

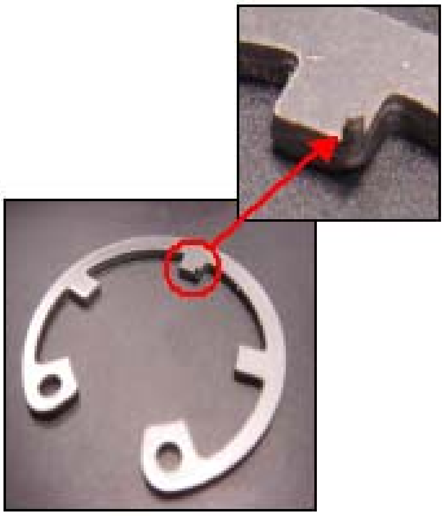


Figure 150: "Pikuta", most critical defect in the parts produced at Alzuaran

As it can be seen in the previous figure, the "pikuta" is a localised big burr that appears in the parts when a punch micro crack happens. This defect can happen in all the references produced in Industrias Alzuaran since all them are produced by blanking processes.

The material used to produce this reference is spring steel with a high tensile limit and a very short elongation. The hardness of the material is also very high, 93 HRB and this is the main reason why the forming tools suffer very high wear and problems like the previous described “pikuta” happens. Next a table with the main charactsristics of the material is given.

COMPOSICION QUIMICA					
[Sin título]ono ...(C)	0,710	Silicio ..(Si)	0,200	Manganeso (Mn)	[illegible]
Fósforo ...(P)	0,013	Azufre ....(S)	0,002	Aluminio .(Al)	[illegible]
Cromo ....(Cr)	0,240	Níquel ...(Ni)	0,000	Cobre ....(Cu)	[illegible]
Niobio ...(Nb)	0,000	Titanio ..(Ti)	0,000	Molibdeno.(Mo)	[illegible]
Vanadio ...(V)	0,000	Boro ......(B)	0,000	Nitrógeno (N)	[illegible]
Plomo ....(Pb)	0,000				

ENSAYOS MECANICOS	
Resistencia (Nw/mm²) ....:	626,00
Lím. Elástico (Nw/mm²) ..:	583,00
Alargamiento (%) ....:	13,50
Dureza (HRb) ....:	93

Figure 151: Main characteristics of the material used to produce the reference 5828-001

The manufacturing process of the present reference is made in a progressive tool composed of 4 different stations. The entire forming process is composed of four stations:

1. Cutting of the guiding holes
2. Cutting of the central small holes at the ears of the parts
3. Checking of the correct cutting of the small holes
4. Final cutting of the parts and separation from the strip material.

Next an image of the tool used to produce the reference 0863-012, which is similar reference to the one evaluated at the end of the project is given. In the figure it can be seen how all these parts are produced following the same manufacturing process, the one described in the above lines.

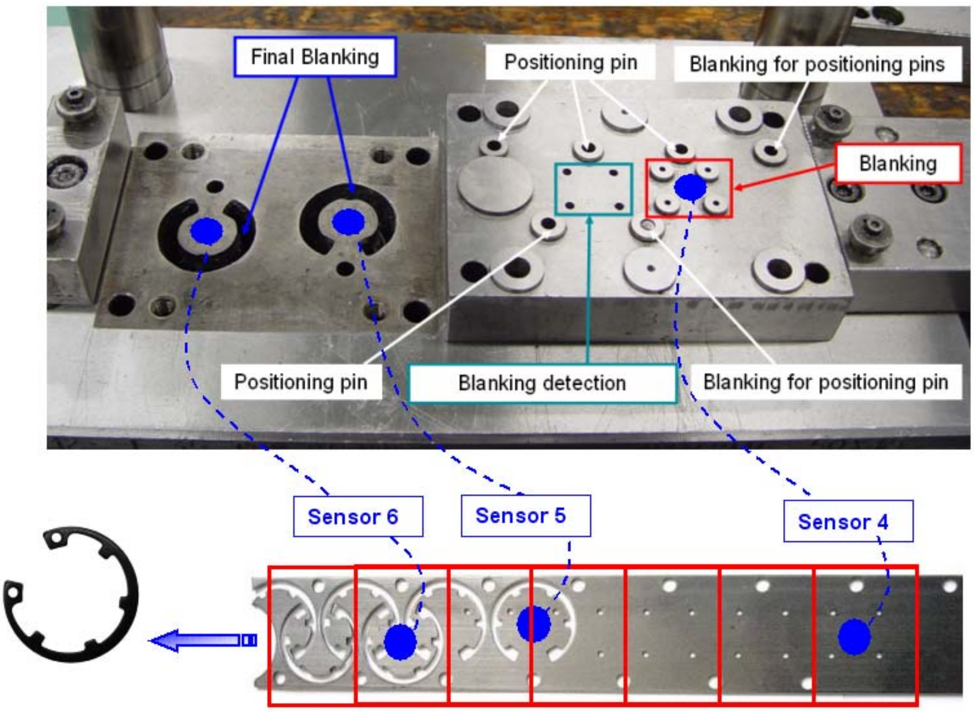


Figure 152: Position of the sensors in the tool for the production of the reference 0863-012

As it can be seen in the previous figure and as it was stated in workpackage 2, for the monitoring of the reference 5828-001 six different sensors were used. Three of them were allocated inside the tool, one measuring the force for the cutting of the small holes at the ears of the parts and two more for measuring the force at each line in the tool for the final cutting of the parts. Two more acoustic sensors were used for the detection of punch breakage, one working during the cutting phase and another one working during the withdrawal of the ram. And finally another sensor was installed in the connection rod of the machine with the idea of globally control the entire process.

The actual reference was chosen because nowadays the production of this part at Industrias Alzuaran is very high, producing more then half million parts per month. This allowed the research team to work during long periods of time in the manufacturing facility. The working conditions at the machine were imposed by the responsible at Industrias Alzuaran. Then, the cadence of the machine was set up at 50 strokes per minute, producing 2 parts per stroke, what means that 100 parts were produced per minute during the tests.

The facility chosen for the production of this reference and therefore, where the control system was installed was a Fagor mechanical press of 125 tons. The forming facility is equipped with a decoiler, a straigthener and a feeding system that feed the material into the machine. An image of this facility is given in next figure.

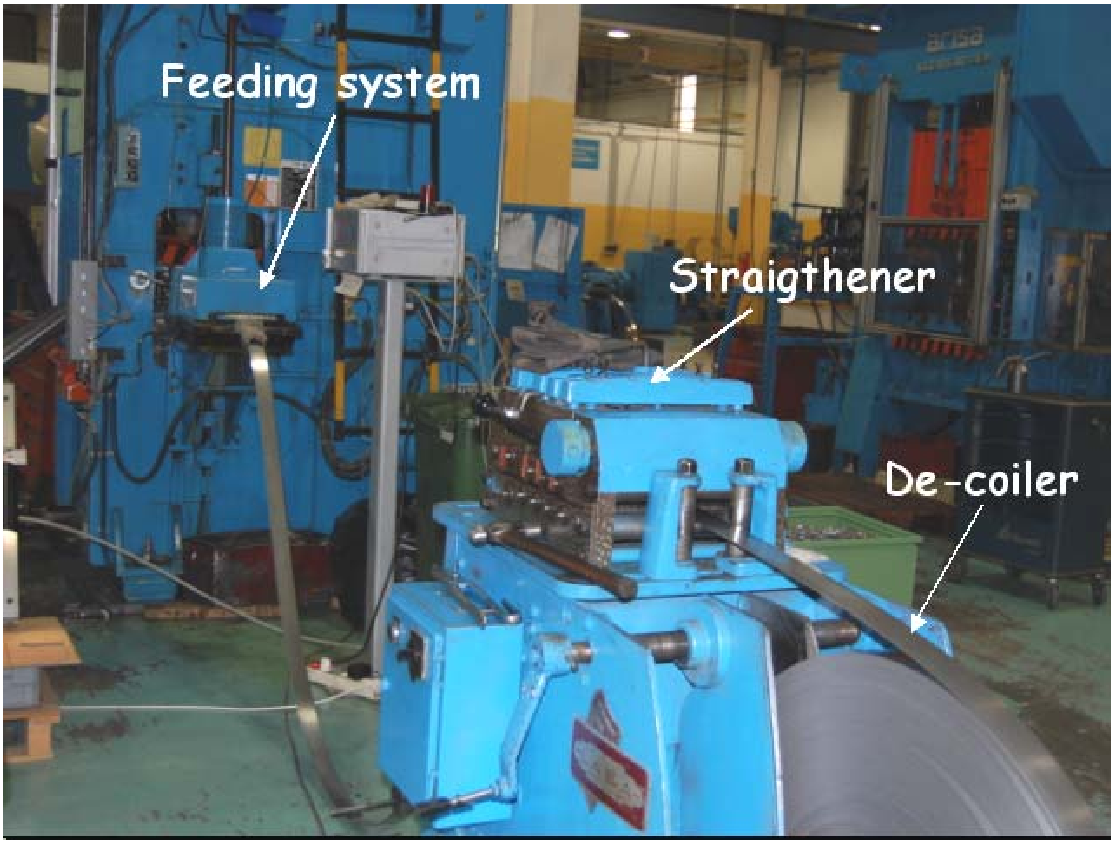


Figure 153: Material feeding system into blanking facility at Industrias Alzuaran

After going into the press, the material arrives to the tool and the parts are separated from the strip of material. There, the parts are evacuated by pressurized air towards the front side of the machine and the strip of material keeps on its way and it is cut before falling down into a container. This can be seen in the next figure where the PVC tubes that evacuated the parts are shown and the blade that cuts the strip of material into scraps is also shown.

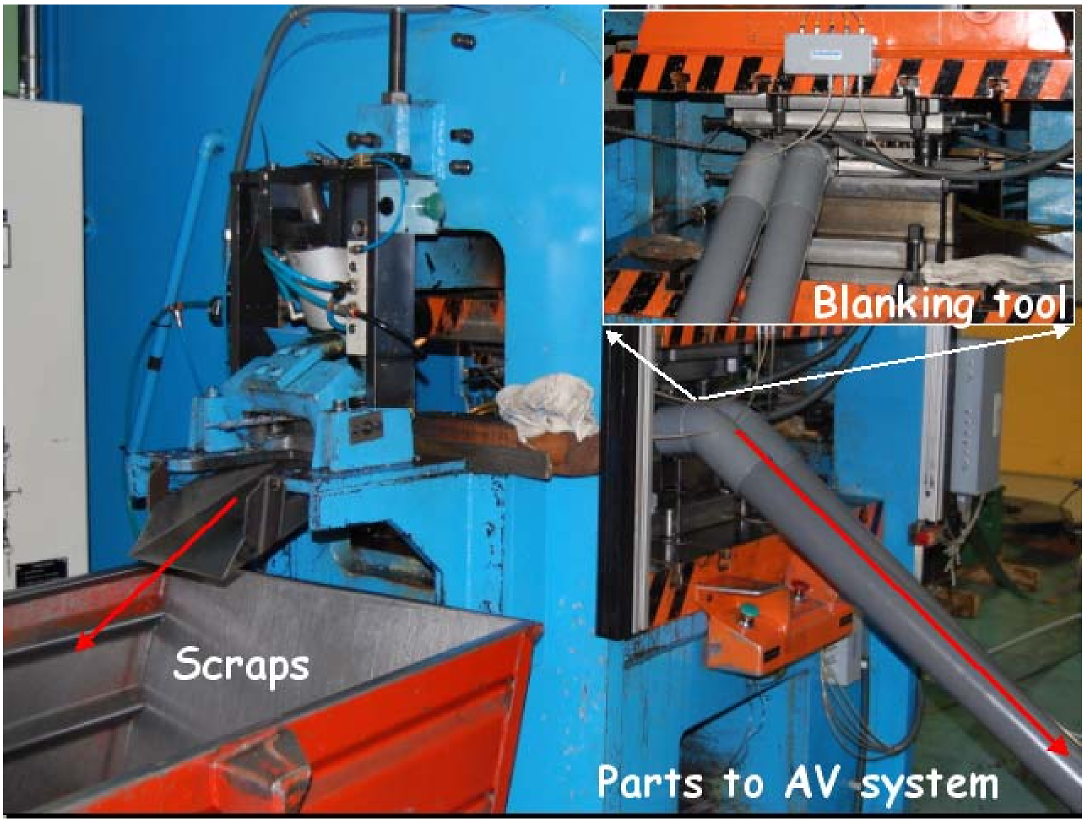


Figure 154: Produced parts and scrap evacuation from blanking facility.

3.6.2.2 Adaptation of the industrial facility to the developed control system

The previous section describes the forming facility where the final tests were made at Industrias Alzuaran. At the previous section the main modifications and new implementations that the research team made at the facility in order to introduce the control system are explained.

A general view of the complete system working at Industrias Alzuaran in given in next figure. As it can be seen in the figure the global system is composed of three different sub_systems, the monitoring system, the artificial vision system and the control system that gathers the information of the two previous system. The first one detects any problem during the manufacturing process, the second one detects if any part is produced in a defective way, sorting it out from the produced parts and the last system, the control system makes an evaluation of the information and tells the operator which are the actions that will solve the problem at the forming facility or at the quality of the produced parts in the fastest and most efficient way.

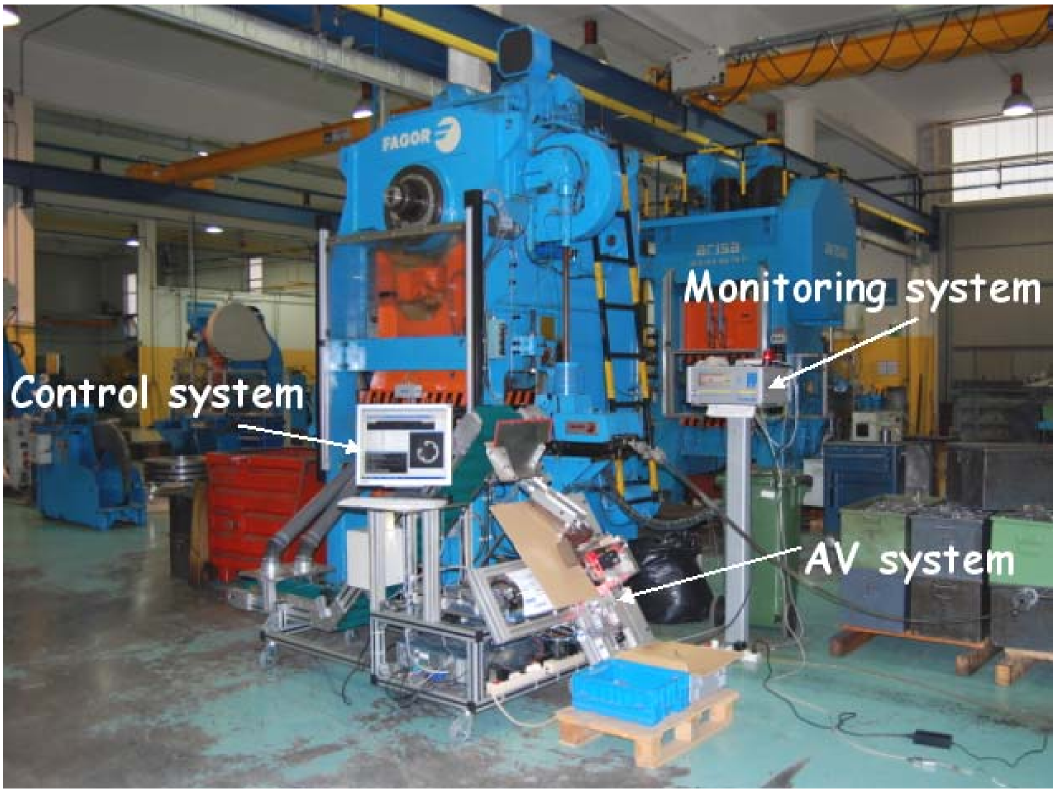


Figure 155: Global system installed at the forming facility in Industrias Alzuaran

First of all and as it was explained in workpackaged 2, the Brankamp monitoring system was installed in the forming facility. A resume of this installation is given in next figure, for more details check the description of workpackage 2.

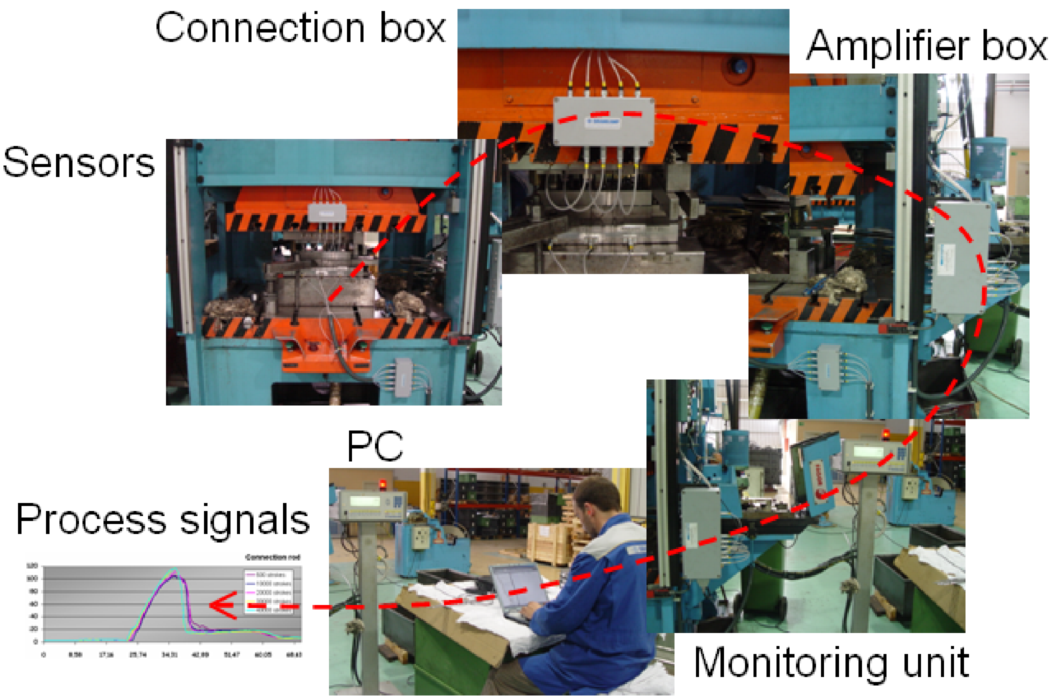


Figure 156: Architecture of the monitoring system installed at Industrias Alzuaran

In the previous figure it is explained how the Bankamp monitoring system is composed of the sensors installed at both the tool and machine, the connection box that was installed in the ram of the machine and where all the signals are gathered to be conducted to the PK unit, the amplification box that treats the signals and converts the intensity signals into voltage signals, the monitoring unit, in this case a PK538 unit, and finally a PC where the control system is installed and that treats the signals coming from the monitoring unit.

The second sub_system that compose the entire system is the artificial vision system. The artificial vision system was already explained in workpackage 3 although here it will be explained how this system has been introduced into the forming facility in Industrias Alzuaran. This explanation is supported with two images taken at Industrias Alzuaran.

In the first figure, it is shown how the parts are conducted from the tool to the artificial vision system. The tool used to produce this reference is a double effect tool. When the part is blanked from the strip, the part stays with the upper tool and when the ram is in the upper position, an ejector hits the parts and falls down with the force of gravity. When the part is falling down from the upper towards the lower tool, a flow or air blown out the parts from the tool (position 1 in next figure). Then the parts leave the tool and go into two metallic parts especially designed to match with the tool. The metallic parts and the tubes where these metallic parts ends are shown in position 2 of next figure. In position 3 of next figure the PVC tubes where the parts fall down to the conveyor belt are shown.

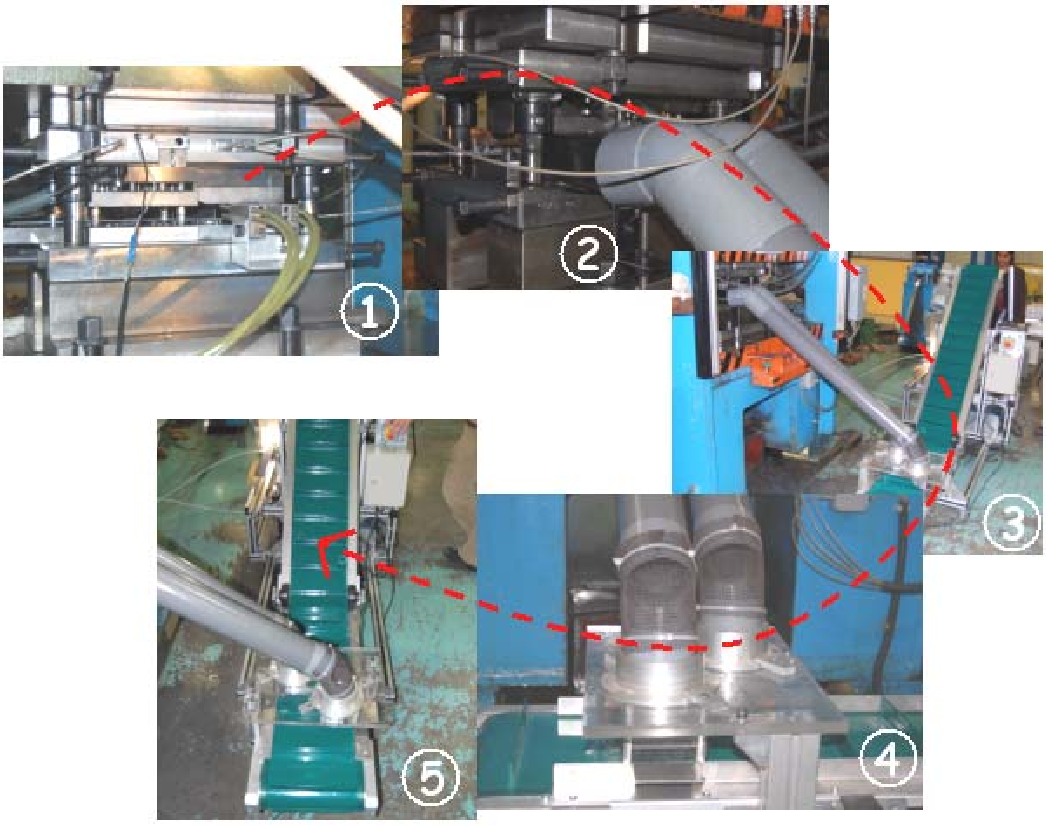


Figure 157: Parts extraction from the machine to the AV system

After this, the parts fall down into the conveyor belt by the connection that the research team prepared to link the PVC tubes with the conveyor belt. This can be seen in position 4 of next figure. With this connection each part belonging to each line of the tool gets a position in the conveyor belt and in this way the union of the different parts is avoided. This was a critical factor from the beginning of the project because it was stated that if two parts are together for a moment, they connect one each other and is almost impossible to split them away. In order to get a good performance, the research team made holes in the PVC tubes and covered them with metallic net. In this way the parts fall down to the conveyor belt but the air that push them to the conveyor belt is released through those holes and do not move the parts after arriving these to the conveyor belt. Finally as it can be seen in position 5 of next figure the parts go up in the conveyor belt and finish in the funnel that is the beginning of the artificial vision system.

Once the parts arrive to the artificial vision system they follow the next way. First of all the parts fall down into two different funnels, one funnel per line in the tool (position 1 in next figure). These funnels make the parts to arrive to the “magic boxes“ developed by the research team as it can be seen in position 2 of next figure. The idea of these magic boxes is to position the parts creating two vertical buffers that will feed the artificial vision system and will compensate the variations in cadence of the forming facility. The concept of these “magic boxes“ was already explained in workpackage 3. So from the vertical buffers two lateral tongues feed alternatively parts from the two different lines at the tool to the area where the pictures are taken. This area is shown in position 3 of next figure. As it was explained in workpackage 3 two different pictures are taken per part.

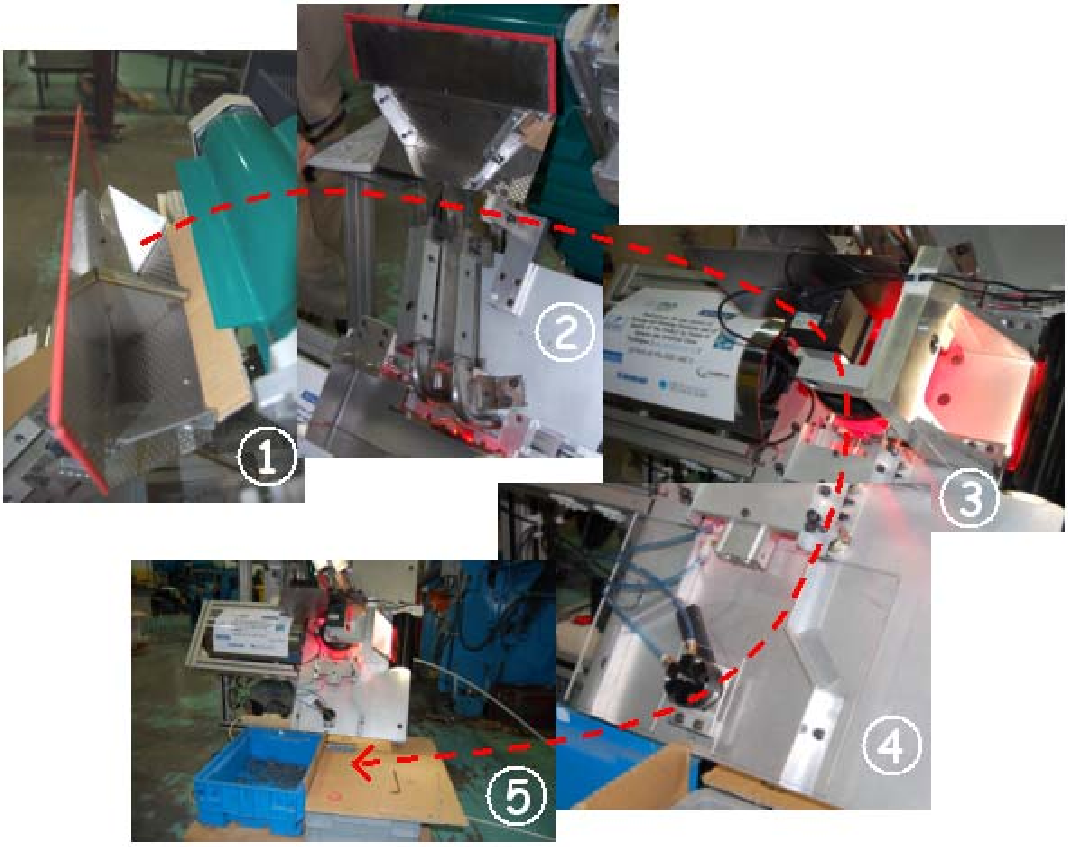


Figure 158: Artificial vision system architecture.

After taking the pictures of the parts, a flow of air push the part to leave the area of the pictures and a rotational cylinder sort out the parts depending on their quality (this can be seen in position 4 of previous figure). Finally at the end of the artificial vision system there are two boxes, one for the good quality parts and another one for the parts that are defective (this can be seen in position 5 of previous figure).

And finally the third sub_system is the control system that was developed in the same computer that the artificial vision system. In order to get a compact and easy to use system, it was decided that the artificial vision and the control system would be implemented into the same structure and since the monitoring system is commercial, this last would be implemented alone. At the same time, the Brankamp system is used for all the references produced at the present forming facility and on the hand, the artificial vision system and the control system are only prepared to work with the references studied during the project. In next figure a better picture of the three system is working at Industrias Alzuaran is given.

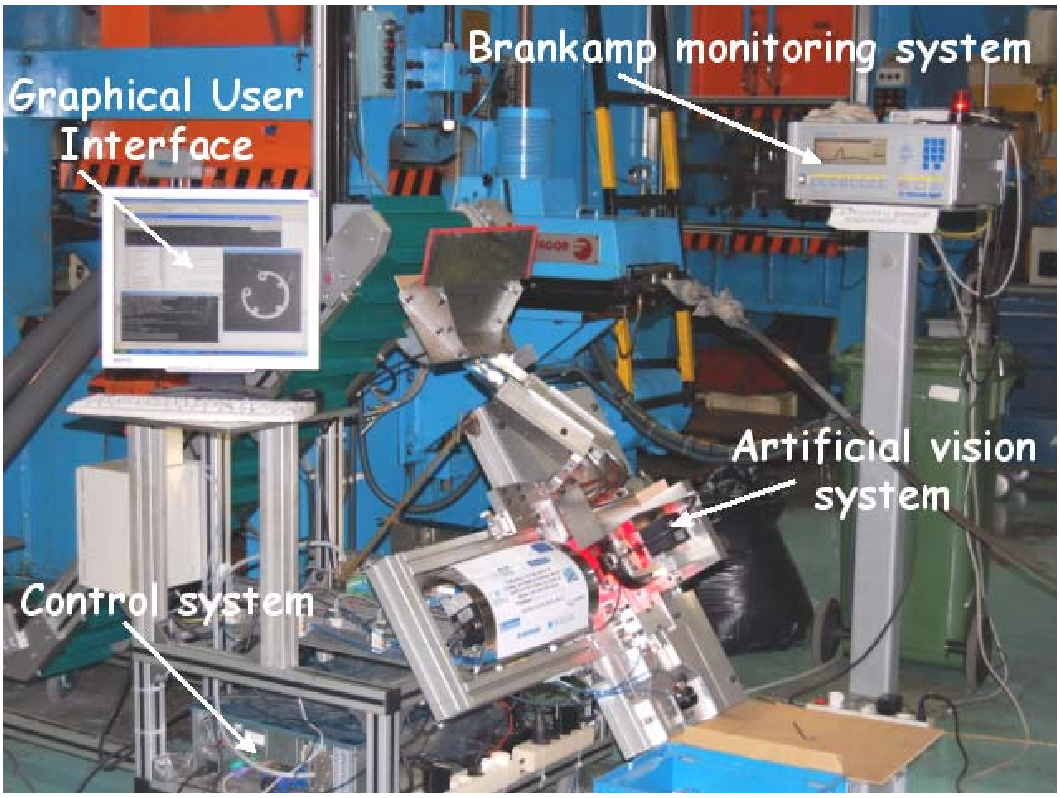


Figure 159: Global system architecture

In previous figure it is shown how the Brankamp system is separated from the entire global system and is connected to it via a serial line that download the faulty signal coming from the forming facility when this is stopped due to process instabilities. At the same time the artificial vision system and the control system have been installed in an aluminum profiles structure very easy to be removed from the forming facility. In this way when the references that have been studied at the present research project are manufactured all the system is linked to the forming facility very esaily and after this it can be removed and kept safe close to the machine.

3.6.2.3 Achieved results at Industrias Alzuaran

The results that the research team has got during the entire project in Industrias Alzuaran have been very interesting. As it was said in previous workpackages, the development of the artificial vision system has been the main bottleneck of the project, mainly due to the chosen references to work with. The retaining rings produced at Industrias Alzuaran have shown a very high difficulty for its handling, mostly due to the fact that if they join one each other is very difficult to separate them and this makes that stockings in the artificial vision system happen. Due to all the previous mentioned reasons, the research team had to ask for an extension of the project and in this way the final tests at Industrias Alzuaran were made.

At this point the results of each sub_system will be explained for a later global explanation of the performance of the global control system. The monitoring system, the Brankamp PK 538 unit has been working at Industrias Alzuaran for 18 months during the project. The unit was installed to control three different references and very good results were achieved from the beginning. The research team made a big effort in order to develop a database where all the process instabilities found by the monitoring system were written down. In next figure all these instabilities, common to the three references due to their similarity are given.

	Defect	Cause	Solution
1	The steel strip did not move at all.	A badly evacuated scrap is avoiding the movement of the strip.	Extract the scrap of material and check the reason why it was not adequately evacuated.
2	The steel strip did not move the right distance.	A badly evacuated scrap is avoiding the movement of the strip.	Extract the scrap of material and check the reason why it was not adequately evacuated.
3	A badly evacuated scrap is blocking the first or second station.	The punches in station 1 or 2 are not evacuating the scrap properly.	Make the punches longer, move the ram down and check the dies´wear.
4	A badly evacuated scrap is blocking the third station.	The punch in station 3 is not evacuating the scrap properly.	Make the punch longer, move the ram down and check the die's wear.
5	A badly evacuated scrap is blocking the fourth or fifth station.	The punches in station 4 or 5 are not evacuating the scrap properly.	Make the punches longer, move the ram down and check the dies´wear.
6	One of the punches is broken.	Excessive wearing of the punches.	Extract the broken punch and replace it with a new one.
7	There is a badly evacuated part inside the tool.	The extraction system is not working properly.	Extract the part and check the extraction system.
8	The strip is sticky to the pilot pins or punches.	Excessive wearing of punches or pilot pins.	Replace the faulty punch or pilot pin.
9	The machine is not working at its nominal speed.	The monitoring system started checking the curves to early.	Re-start the machine.

Figure 160: Knowledge database for process faults at Industrias Alzuaran.

The monitoring system exhibited a very good performance and most of the problems at the forming facility were detected by this system. As it can be seen in previous figure the research team found nine different process stabilities in the forming facility at Industrias Alzuaran. On the other hand, the research team also found that although the monitoring system was able to detect most of the process stabilities, some of them were not found and leaded to defective parts that were not detected. Therefore the research team started to work in the artificial vision system able to detect the defective parts that the monitoring system was not able to detect, with the idea of implementing both systems working together and reducing the chances to produce defective parts at the studied forming facility. An example of these defective parts not detected by the monitoring system is given in next figure.

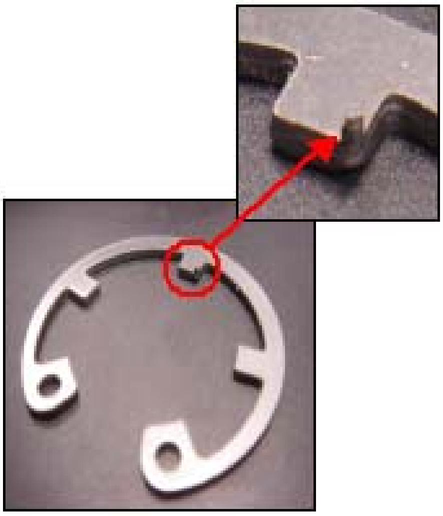


Figure 161: "Pikuta", most critical defect at the parts produced in Industrias Alzuaran.

Since the first data and results of the monitoring system were got from a very early stage of the project, the research team also started to develop to control system that would be able to know the reasons of the instabilities at the forming facility and the solutions that should be applied to solve them. After evaluating different techniques of the artificial intelligence, the research team agreed that the best one to be used at the present project was an Expert System. More information of the developed expert system can be found in the description of workpackage 5 at the present report but in order to summarise, what the research team got with the use of this expert system was to link the information coming from the monitoring system with the knowledge and experience of the operator of the forming facility. This linkage allowed to a computing program to know the reasons and solutions that should be applied when any of the process stabilities described in the previous page at the present document appear at the forming facility, and doing all this in an automatic way, without the need of the human being. Explained with other words, whenever the forming facility was stopped by the Brankamp monitoring system because a process stability was found, the expert system was able to explain to the operator the reasons why the machine stop happened and the solution that should be applied to solve it. The main advantage of this expert system is that the time that the operator needs to solve the process fault is considerably reduced and at the same time, for forming processes controlled by more than one operator, a common strategy when solving machine stops is achieved. Next image shows how the research team linked all the process faults detected by the Bankamp system with the knowledge of the operator.

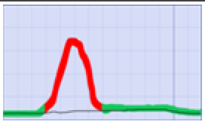
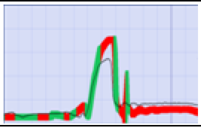
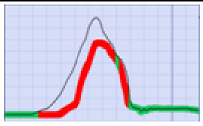
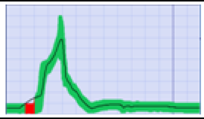
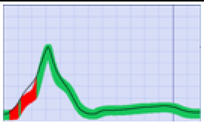
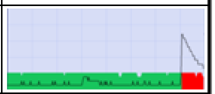
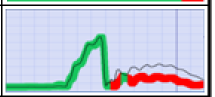
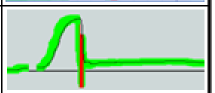
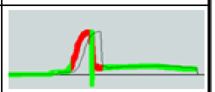
	Defect	Cause	Solution	Variables	Image
1	The steel strip did not move at all.	A badly evacuated scrap is avoiding the movement of the strip.	Extract the scrap of material and check the reason why it was not adequately evacuated.	In most of the channels the maximum real force is much smaller than the hypothetical force.	
2	The steel strip did not move the right distance.	A badly evacuated scrap is avoiding the movement of the strip.	Extract the scrap of material and check the reason why it was not adequately evacuated.	There is a force peak at the beginning of the channels which are measuring force directly in the tool.	
3	A badly evacuated scrap is blocking the first or second station.	The punches in station 1 or 2 are not evacuating the scrap properly.	Make the punches longer, move the ram down and check the dies´wear.	There is a force peak just before the maximum force in channels 4 and 5.	
4	A badly evacuated scrap is blocking the third station.	The punch in station 3 is not evacuating the scrap properly.	Make the punch longer, move the ram down and check the die's wear.	There is a force peak just before the maximum force in the third station.	
5	A badly evacuated scrap is blocking the fourth or fifth station.	The punches in station 4 or 5 are not evacuating the scrap properly.	Make the punches longer, move the ram down and check the dies´wear.	There is a force peak just before the maximum force in fourth or fifth station.	
6	One of the punches is broken.	Excessive wearing of the punches.	Extract the broken punch and replace it with a new one.	The force gradient is bigger than 20 in channel 3.	
7	There is a badly evacuated part inside the tool.	The extraction system is not working properly.	Extract the part and check the extraction system.	The force is very low at the end of the connection rod force curve.	
8	The strip is sticky to the pilot pins or punches.	Excessive wearing of punches or pilot pins.	Replace the faulty punch or pilot pin.	There is a force peak at the end of the curve in fourth or fifth station.	
9	The machine is not working at its nominal speed.	The monitoring system started checking the curves to early.	Re-start the machine.	All the force curves are out of the envelopes during the entire stroke.	

Figure 162: Process faults detected linked to the knowledge of the operator.

The main difference when working with the expert system can be seen in next image where the graphical user interface of the Brankamp monitoring system and the graphical user interface of the developed expert system are compared. It can be seen in the figure that when using the graphical user interface of the monitoring system, the operator does not find the reasons and solutions that should be applied, he only finds that the monitoring system has stopped the forming facility due to a problem in one of the sensors. He can check the sensor or channel number and he can also check for the shape of the fault. But no more information is given to the operator. On the other hand, when the expert system analyses the information of the monitoring system and its graphical user interface is used, the operator finds more information than only the shape of the fault and the number of the channel. The operator also finds a complete description of the fault at the forming facility, the reasons why this fault has happened at the forming facility and the solution that should be applied to solve it. This comparison can be seen in next figure.

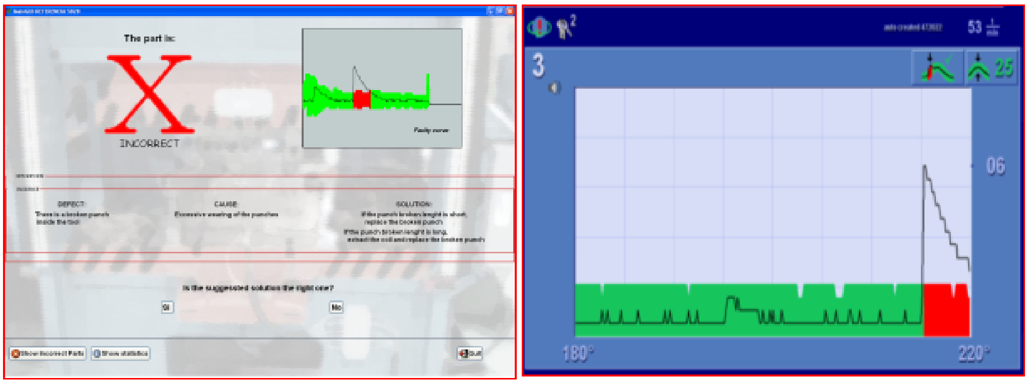


Figure 163: Comparison between Graphical User Interfaces.

Next for a better understanding a view of the Graphical User Interface developed for the present project is given. In this Graphical User Interface different areas can be found. The operator will check if the process or part is correct or not, if it is not correct the operator will find the faulty curve coming from the monitoring system or the faulty part coming from the artificial vision system and finally in the lower area of the GUI, the operator will find an explanation about the fault, its cause and solution.

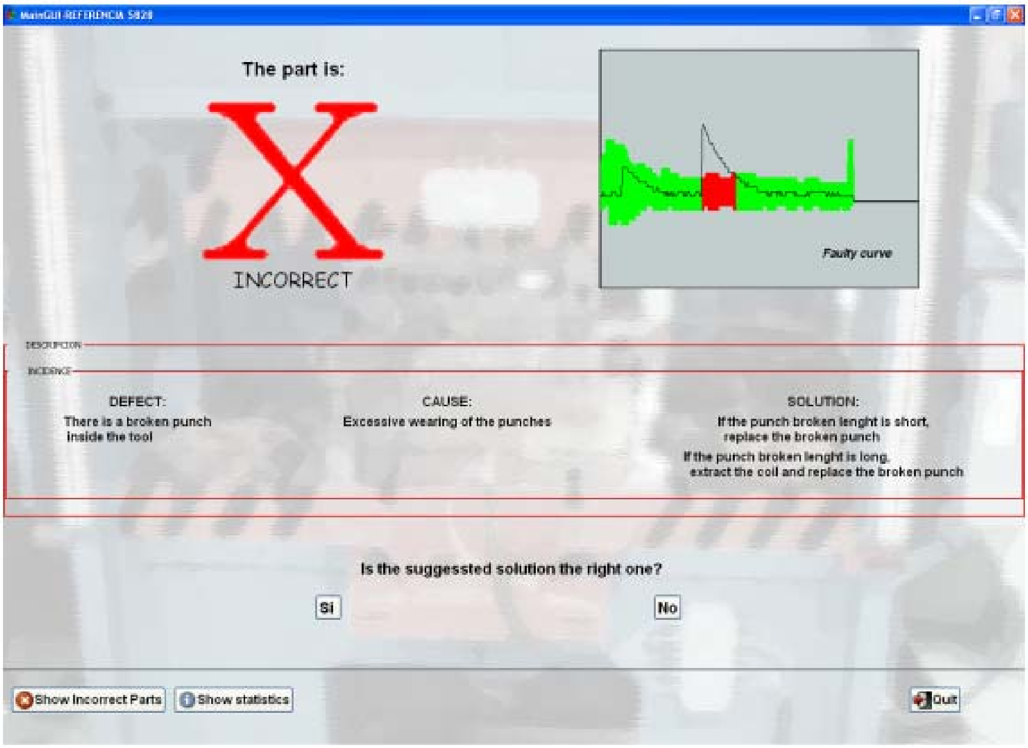


Figure 164: Graphical User Interface developed for the Expert System.

And finally the research team has also been working in the development of an artificial vision system for the quality assurance of the 100% of the produced parts. More information about this system can be found in the explanation of the workpackage 3 at the present report, but a summary of the results achieved will be made here.

At the beginning of the project the research team though to develop a common artificial vision system for the references produced at Industrias Alzuaran and for the reference produced at Industrias Garita. Although the objective was very good it was found from the beginning that the development of artificial vision system depends very much on the shape and production ratio of the parts to be controlled and this is why very soon it was decided to develop two different systems, one for each company. The artificial vision system developed for Industrias Alzuaran has already been finished and has been tested working in situ in this company. The production rate was 100 parts per minute and although good results have been achieved, the research team found that a few modifications should be made in order to increase the efficiency of the system. The major problem found at the system was the possibility of stocking of parts in the system what would stop completely the production facility.

Figure 165: Upper and lateral picture for part quality evaluation

The results achieve with the present system is a working cadence of 100 parts per minute, taking two pictures per part (previous figure) and analysing up to five different dimensions and the presence of “pikuta” per part. The evaluation time per part is around 620 milliseconds and the repeatability of the system can be checked in the next figure where the main dimensions of the parts over the time are represented.

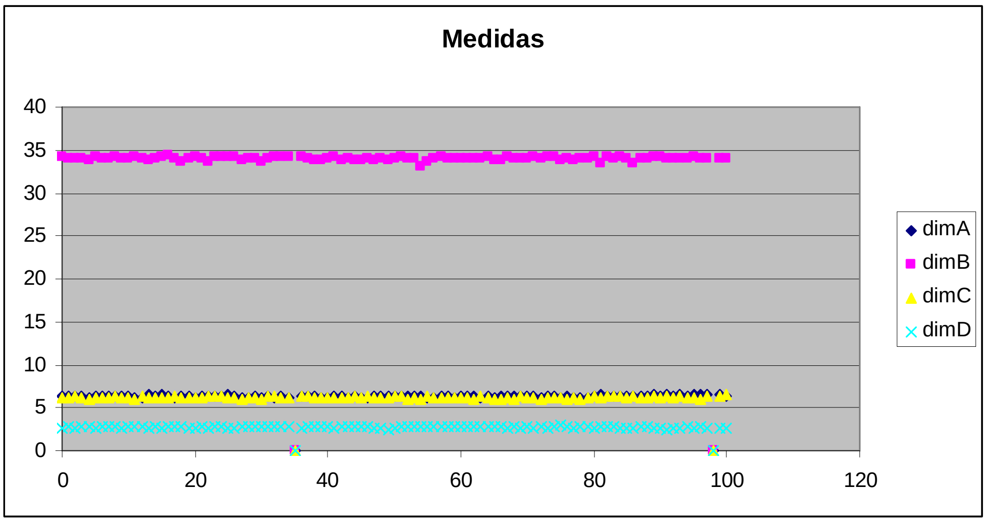


Figure 166: Evolution over time of the main dimensions of the part (upper camera)

Then, although the artificial vision system is working well, its reliability is not good enough yet because the research team has found in the final tests that some parts can stocked in the system stopping it completely and therefore stopping the production of parts at the forming facility. In order to solve this situation, Industrias Alzuaran and Mondragon University will keep on working during a few more months in order to reduce these problems and to make the system as reliable as possible. All the problems encountered at the system are explained in the next section of the present document.

3.6.2.4 Future research lines for the control strategy improvement

Next the future lines that the research team think that should be done in order to improve the performance of the global control system and to make possible to convert the global expert system into a commercial system are explained. This section has been divided into four different sections, in the first three ones the future lines for the improvement of the different sub_systems that compose the global system will be explained. At the end, a global description of all the things that should be made in order to improve the overall performance of the system will also be given.

3.6.2.4.1 Future research lines regarding process monitoring

The results that the research team has got with the use of the Brankamp monitoring system during the project have been really successful. As it was explained in previous sections of the actual report, the research team found up to nine different process instabilities with the use of the Brankamp monitoring system. Some instability had as consequence tool breakage and some other had as consequence the production of defective parts.

On the other hand, although the results of the Brankamp monitoring system were quite good the research team also found that this system was not able to detect some process instabilities that had as consequence bad quality parts. The defect that the Brankamp monitoring system was not able to detect was the growth of micro cracks in the blanking punches that had as consequence the production of parts with big localised burrs in some areas of the parts, the so called “pikuta”.

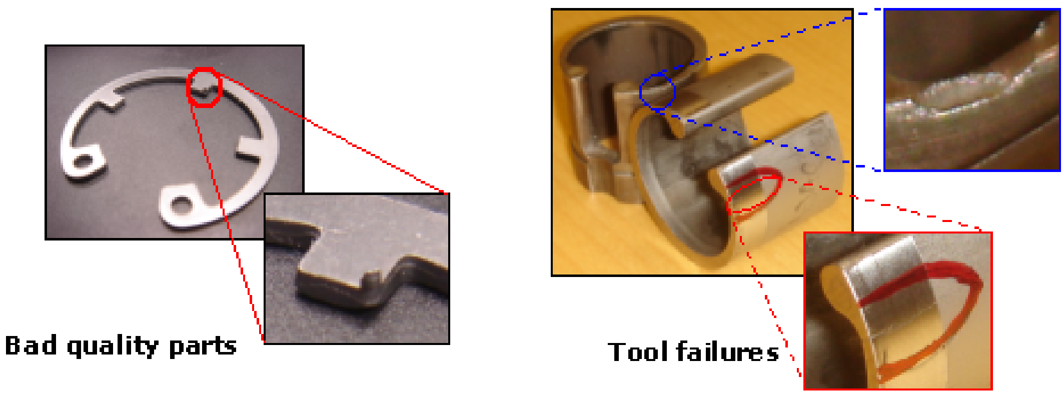


Figure 167: Part with “pikuta” and micro cracks in blanking punches

Brankamp Gmbh has already started to work on a strategy to be able to detect all these failures. The main challenge when detecting this short of defects is that the variation in the process curve is very small because the cracks in the punches are very small too. Therefore, the Brankamp monitoring system compares the actual curve with the previous recorded curves and since they are very similar the system does not detect any failure at the process. Nowadays Brankamp is already developing a new strategy that will differentiate the small changes due to a normal random evolution of the process, like material features and lubrication from deviations due to continuous signal variations like chipping of the punches. In this way a better approach to detect this short of failures will be achieved.

3.6.2.4.2 Future research lines regarding artificial vision for quality assurance

Regarding the development of artificial vision systems for quality assurance two different areas must be highlighted, the handling of the parts and the acquisition and treatment of the images. Concerning the first of these areas, the experience of the research team during the project is that artificial vision depends very much on the shape and size of the parts to be controlled, and also depends very much on the production rate of the forming facility. At the beginning of the project the research team proposed to develop a common artificial vision system for the parts produced at Industrias Alzuaran and for the parts produced at Industrias Garita. After evaluating each of the parts, the final conclusion is that they belong to very different families and therefore all the necessary elements for the construction of artificial vision system are very different. One of the main conclusions is that it is very difficult to create an artificial vision system able to evaluate different short of parts. This has as a consequence that industrial companies need one different artificial vision system for each of the references to be evaluated. Even if the references belong to the same family, if high rates want to be achieved, the systems will need to be modular because the handling of the parts must be specified for each reference.

For example at the present research project, two different artificial vision systems were constructed, one for Industrias Alzuaran and the other one for Industrias Garita. The one constructed for Industrias Garita is only prepared to evaluate one reference, the reference called Synemblock. On the other hand, the artificial vision system developed for Industrias Alzuaran was though to work for three different references. Although the vision elements are common to all these three references, the mechanism of the system for handling the parts must be different, depending of the dimensions of the parts. Therefore the best solution at this level would be to create a modular system compatible with several references and easy to be adaptable to all them.

In the future, Mondragon University and Industrias Azluaran will work on the artificial vision prototype developed because nowadays (from a mechanical point of view) it is prepared to work with one of the references and Industrias Alzuaran would like to be able to work with at least three references. So with the actual vision components, Mondragon University together with Industrias Alzuaran will develop a modular system able to handle the three references at production rates over 100 parts per minute.

So a future research line for artificial vision system development is the research on modular systems able to handle different short of parts and able to handle them in a flexible, fast and reliable way. A good solution would be to create a very flexible system able to be used with several part's families and in this way when a new system will be created, engineers will not have to develop it depending on the part to be controlled, but they will take this flexible system and with a few modifications they will be able to prepare it for evaluating the new part.

On the other hand, concerning the image treatment strategy developed by Delta Technologies and Mondragon University, very good results were achieved. As it was explained in workpackage 3, the research team proposed to develop a parallel strategy: to use intelligent cameras that use FPGAs to perform the most consuming steps and to make only part of the treatment at the computer. In order to get this, two intelligent cameras based on FPGAs were developed by Delta Technologies and part of the algorithms were implemented there. This means that the cameras are able to take the pictures, to binaries, to delete the noises and extract the contours, and later they send the contours to the computer that measures the dimensions of the parts. This approach is graphically described in next figure.

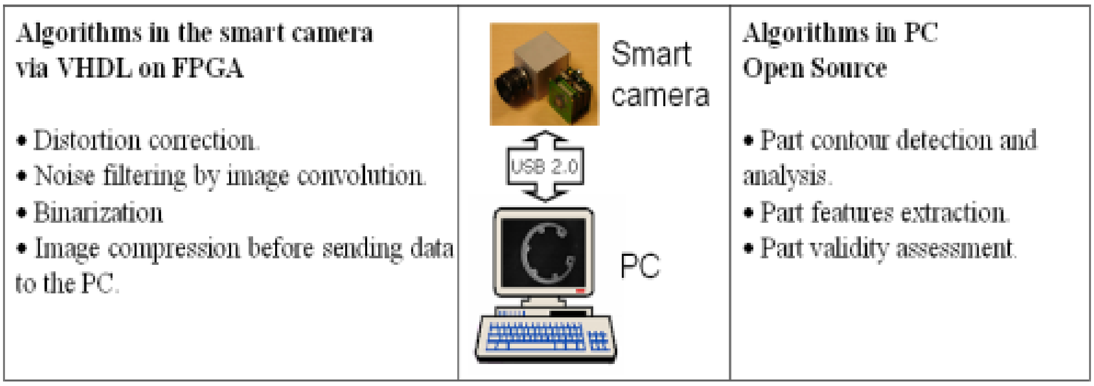


Figure 168: Software and hardware codesign approach

With this new approach the total time can be considerable reduced (up to 100 times) and nowadays at the application developed for Industrias Alzuaran the processing time is more or less 100 milliseconds per part. At the same time the total time for the quality control of each part was reduced down to 500 milliseconds, which means that around 120 parts per minute can be tested at the developed system.

The final conclusion is that when developing this kind of systems a good balance must be achieved between speed and flexibility. It is true that when most of the algorithms are integrated into the FPGA of the cameras the necessary time for the treatment of the images decrease. Using FPGAs can develop a system 100 times faster than a normal computer. On the other hand, if several references must be evaluated or if the customer wants a very flexible system it is better not to integrate a lot of algorithms into the FPGAs because reprogramming this short of systems is quite complicated.

Therefore a future research line concerning the development of faster vision systems goes through the development of easy reconfigurable FPGAs for flexible intelligent cameras construction.

3.6.2.4.3 Future research lines regarding intelligent control of forming processes

Regarding the development of intelligent systems able to control forming processes, the research team found that although the results achieved with the expert system developed at the present research project were very succesful, it had two main limitations. The first limitation is that the developed expert system was able to work only at the studied forming facilities. The reason for this is that the expert system was developed depending on the process faults that were got at the forming facilities. This means that if the same expert system is move to another company out of the companies at the research project it will not offer good results. This fact was explained in workpackage 5 at the present report. The solution to this drawback is already been solved by Brankamp Gmbh and Mondragon University. A new strategy for defining the process faults that the Brankmap monitoring system finds is being developed and it is expected that a prototype of this new expert system will be available in 2009. At the same time, and depending on the final results, Brankamp Gmbh is thinking to introduce this expert system into its new monitoring units. The main expected benefits of this introduction will be a reduction in the neccesary time to restart the forming facilities after the detection of process faults and the development of standarised databases for all the operators.

At the same time Mondragon University will research in a short future about the possibility to use artificial intelligent techniques for the on line control of forming processes. One of the main limitations of the processes chosen at the present research project was their high dynamic. In Industrias Alzuaran up to 120 parts per minute were produced and in Industrias Garita 30 parts per minute were produced. This high dynamic of the processes makes that the expert system will work as an intelligent surveillance system because only after forming the parts the system is able to detect if any defect has happened in the process. Next step would be to develop a system able to control on line the process, what means a system able to follow the change of the part inside the tool and able to propose changes of parameters on line in order get always the highest possible quality at the part.

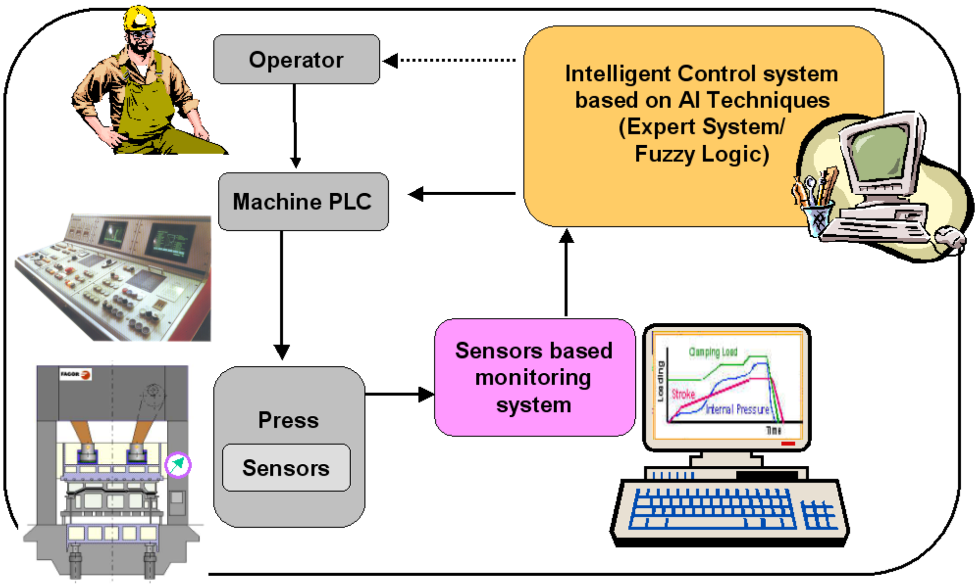


Figure 169: On line control of hydroforming processes

If this purpose wants to be achieved, the dynamic of the process must be very slow and therefore the control system will have time to react and change the setting of the process. Mondragon University has been working during the last few years in hydroforming processes. The dynamic of these processes is very low and are very suitable for testing this new control strategy. Therefore it is expected that Mondragon University will research in the on line control of hydroforming processes in the short future. In fact some contacts with companies and universities of different countries of Europe have already been made and the creation of the consortium for the project has already started.

3.6.2.4.4 Future research lines regarding systems development for forming processes global control

In the final meeting that took place at Mondragon in April 2008, the reseach team of the present project discussed about the possibility to develop global systems composed of monitoring strategies, vision strategies and intelligent control strategies. After evaluating the advantages and limitations of the different sub_systems it was agreed that the main difficulty for developing a global system like the one developed at the present research project would be the handling of the parts. If a complete global system able to evaluate the quality of all the produced parts wants to be developed, a handling system able to position all the parts in front of the cameras should be achieved. During the present research project this has been the most difficult task and as it was explained before a very deep study of this topic should be made.

3.6.3 Deviations from Project work programme and corrective actions

The end of the project has to be delayed 6 months due to the difficulty for developing an artificial vision for the parts produced in Industrias Alzuaran. Anyway, at the end the system was developed and tested in the forming facility and although a few improvements were found the overall result was pretty good.

3.6.4 List of deliverables

Del. no.	Deliverable name	Workpackage No.	Date due	Actual/Forecast delivery date	Estimated indicative person/month*	Used indicative person/month*	Lead contractor
D11	Industrial validation: specifications, tests, and results	6	24	30	3	4	SMEP8

3.6.5 List of milestones

Milestone no	Milestone name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
M 6.1	Choice of the industrial case, including the conditions for the validation	6	15	15	SMEP8
M 6.2	Quality control system working on the industrial case for blanking	6	16	20	SMEP8
M 6.3	Quality control system detecting defects in drawing workparts	6	18	20	SMEP8
M 6.4	Industrial validation tests successfully completed	6	22	24	SMEP8
M 6.5	Detection of the field of improvement of the control system	6	23	24	SMEP8

3.7 Workpackage 7. Review and assessment

3.7.1 Workpackage objectives and starting point of work at beginning of reporting period

The objectives of the Workpackage 7 are the following ones:

- To ensure the achievement of the goals and objectives of the project (all the partners)
- To introduce modifications in the work planning, corrective actions or new activities, if necessary (all).

The different tasks defined at the beginning of the project are the following ones:

- Once the objectives of the project quantified, in order to be able to react on time and to face any disturbance, a constant review of the on-going of the project and a periodical assessment of the results (in terms of “objectives”, as defined), will be carried out.
- RTD1 is responsible for this, as coordinator of the project, but the decisions will be taken in the Management Committee.
- In case problems arise making difficult to attain the technological objectives, the Commission will be reported via the Officer, and corrective actions will be proposed and taken if necessary.
- Besides technical problems, management related disturbances and troubles can arise as well. These are also to be considered, as they can put into risk not only the technical objectives of the project, but also the strategic ones. In this case, the same procedure will be undertaken: the Management Committee will analyse the trouble and take the corrective decisions, and, if necessary, to report the Commission.

3.7.2 Progress towards objectives

The proposed schedule for the tasks described in the previous section is the one shown in the next picture:

Description of workpackages, tasks and specific reports	Year 1												Year 2											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
WP 7: Review and assessment	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Figure 170: Schedule of the seventh workpackage

The work done and the most important results achieved in Workpackage 7 are described in the next lines of the present report.

3.7.2.1 Request for Amendment

At the beginning of the project some changes were proposed to the commission. Next a copy of the request form amendment where all the proposed changes are exposed is written:

1- The following entity is removed from the list in Article 1.2 due to its no accession to the contract:

OTTO Vision Technology GmbH (SME) established in IM STEINFELD, 3, JENA, D-07751, Germany represented by Gunter Otto, Director, and/or Reinhardt Otto, Director, or her/his/their authorised representative (“contractor”)

The reason why the coordinator of the project **MONDRAGON GOI ESKOLA POLITEKNIKOA J.M.A S.COOP** established in Loramendi, 4, Arrasate (Guipuzkoa), 20500, Spain, represented by Javier RETEGUI ALBISUA, GENERAL DIRECTOR, and/or Mila BELATEGUI TROJAOLA, FINANCIAL OFFICER, or his/her/their authorised representative ask The **European Community** (“the Community”) represented by the **Commission of the European Communities** (“the Commission”), itself represented for the signature of this contract by Achilleas MITSOS, Director General for Research Directorate-General or his Duly authorised representative, to remove the above mentioned contractor from the list in the article 1.2 is that the coordinator of the project has many doubts about the real interest the above mentioned contractor has in getting the technical objectives proposed in the project.

2- At the same time Delta Technologies Sud Ouest (SME), represented for the purpose hereof by Guy Canova, Chief Executive Officer or his/her/their authorised representative established in 2 IMPASSE MICHEL LABROUSSE, Toulouse, France acting as its legal authorised representative, hereby requests to become a contractor to contract nº 017900 relating to project On-line Control of Drawing and Blanking Processes and of the Quality of the Product by Fusion of Sensors and Artificial Vision Techniques (PRO2CONTROL) signed between the Commission of the European Community and **MONDRAGON GOI ESKOLA POLITEKNIKOA J.M.A S.COOP** and accepts, in accordance with the provisions of the aforementioned contract, all the rights and obligations of a contractor starting the 1st November 2005 should the Commission not oppose to this request within six weeks upon its receipt.

The reasons why the coordinator of the project (**MONDRAGON GOI ESKOLA POLITEKNIKOA J.M.A S.COOP**) proposes this new contractor Delta Technologies Sud Ouest (DTSO) to become a contractor of the above mentioned project are:

1. The proposed contractor Delta Technologies Sud Ouest (DTSO) has already worked with **MONDRAGON GOI ESKOLA POLITEKNIKOA J.M.A S.COOP** in other projects.
2. The coordinator of the project (**MONDRAGON GOI ESKOLA POLITEKNIKOA J.M.A S.COOP**) finds that the technical knowledge of the new contractor Delta Technologies Sud Ouest (DTSO) is high enough according with the technical requirements of the project.

3- Therefore, Delta Technologies Sud Ouest will take over the rights and obligations of **OTTO Vision Technology GmbH** ask of 1st November 2005 and any reference in the contract, including Annex I and the table of the estimated breakdown of costs, to **OTTO Vision Technology GmbH** shall be deemed to be a reference to Delta Technologies Sud Ouest.

4- Delta Technologies Sud Ouest will take the rights and obligations of **OTTO Vision Technology GmbH** and taking into account that the effort of this new contractor to performance the same tasks will be different, some changes have been made in the previous budget proposed for Otto. Anyway, the total amount of Delta Technologies Sud Ouest´s budget remains equal to the previous budget proposed for Otto and there is only a redistribution of the money as it can be seen in the new Annex I “Description of Work”. The total amount of the rest of the contractors and the total amount of the project do not suffer any change.

5- Finally, and concerning the Protection of Knowledge located money for Brankamp, some changes have been made in the budget of Brankamp. The money located for Protection of Knowledge has been moved to Personnel costs. Anyway, the total amount of Brankamp´s budget remains equal to the previous budget proposed and there is only a redistribution of the money as it can be seen in the new Annex I “Description of Work”. The total amount of the rest of the contractors and the total amount of the project do not suffer any change.

3.7.2.2 Modifications in the work planning, corrective actions or new activities

The overall objective of the present research project can be mainly divided into four different areas: development of the monitoring system, development of the artificial vision system, development of the control system and integration and set-up of the three systems working together.

Concerning the first part of the project, the development of the monitoring system, Brankamp the leader in this workpackage has already designed, installed and tested the monitoring systems in Industrias Alzuaran and in Industrias Garita. In Industrias Alzuaran, Brankamp installed the monitoring system and is nowadays prepared for working with 8 channels. The monitoring system is controlling three different references and the results are very satisfactory as it was explained in workpackage 6. In Industrias Garita, Brankamp also installed a monitoring system with five channels and nowadays the reference Synemblock is being controlled. The results at Industrias Garita have also been successful as it was explained in wrokpackage 6. No major deviations have happened during the development of this part of the project, only the related ones with the fact that this is an industrial project, and therefore matters like production schedules should be taken into consideration.

The main delay from the work plan is related with this second part of the project; the development of an artificial vision system able to control the quality of the produced parts. The reason for this it that at the beginning of the project it was planned that OTTO Vision Technology GmbH was going to develop the system. OTTO Vision Technology GmbH is a German company with a lot of experience in the development of this kind of systems and therefore the work plan for this task was quite short. But at the beginning of the project OTTO Vision Technology GmbH left the project and this development has been done by the University of Mondragon, by the University of Stuttgart and by Delta Technologies that have not a lot of experience in the development of this type of systems, being the time to develop the system a bit larger. Anyway although some problems were found when designing and testing the vision system, and therefore the development time was much longer than the initial proposed in the project, at the end of the project the artificial vision prototype was finished and has been installed in Industrias Alzuaran as it was described in workpacakged 6.

Concerning the development of the control system, an expert system for blanking and drawing processes has been created and prepared to work with a monitoring system (in this case with a Brankamp monitoring system) and with an artificial vision system (in this case with the one developed for the project). The expert system has been linked to the Brankamp monitoring system and after a few months of setting up the achieved results have been very successful. All these results were explained in workpackage 5 and 6. At the same time the expert system was linked to the artificial vision system and the results were also very good. These results were also shown in workpackage 5 and 6.

And finally, about the communication between all the systems, as it was shown in workpackage 6 all the systems have been working together in Industrias Alzuaran getting very good results as far as process stabilities and part quality is concerned.

3.7.3 Deviations from Project work programme and corrective actions

No major deviations have happened in the project. The biggest one is the one concerning the development of the artificial vision system for testing the quality of the formed parts. It has already been said that the main reason for the delay in this task is that one of the partners left the project and although another one came into it, this last did not have so much experience about developing artificial vision systems focus on forming operations.

3.7.4 List of deliverables

Del. no.	Deliverable name	Workpackage No.	Date due	Actual/Forecast delivery date	Estimated indicative person/month*	Used indicative person/month*	Lead contractor
D12	Technical and management review (intermediate report)	7	12	12	2	2	RTD1
D13	Technical and management review (final report)	7	24	24	2		RTD1

3.7.5 List of milestones

Milestone no	Milestone name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
M 7.1	Intermediate report on technical review	7	12	12	RTD1
M 7.2	Final report on technical review	7	24	24	RTD1

3.8 Workpackage 8. Explotation and dissemination

3.8.1 Workpackage objectives and starting point of work at beginning of reporting period

The objectives of the Workpackage 8 are the following ones:

- To ensure the exploitation of the results of the project by the development of an industrial system (SMEP3, SMEP4).
- To ensure the dissemination of the results of the project (RTD1, RTD2).

The different tasks defined at the beginning of the project are the following ones:

- The main purpose of this workpackage is to disseminate the results of the project in the scientific and technical fields and spread them in the industrial companies related to sheet metal forming process of small dimensions parts. For this work, RTD2 is responsible although both RTD1 and RTD2 will publish scientific and technical papers and organize industrial courses and symposiums.
- Every year, a workshop will be organized under the topic of control systems in sheet metal forming. Research Centres and Universities, as well as industrial companies will be invited in order to discuss the latest advances and results and the trends concerning this subject. RTD1 is responsible for this.
- A web page will be open from the beginning explaining the objectives of the project, the tasks accomplished or in work and the results expected and got. This page will be actualised every two months. RTD1 will be responsible for this.
- The advances of the project will appear every year in the annual report of both RTD1 and RTD2.
- Finally, from the end of the project, a training course will be prepared and annually given using the infrastructure given by IRAUNKOR, the Training Centre linked to RTD1 (more than 11.000 hours given in training courses to the industry during the academic year 2002/2003).Progress towards objectives

3.8.2 Progress towards objectives

The proposed schedule for the tasks described in the previous section is the one shown in the next picture:

Description of workpackages, tasks and specific reports	Year 1												Year 2											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
WP 8: Exploitation and dissemination	X	X								X	X	X						X	X			X	X	X

Figure 171: Schedule of the eighth workpackage

The work done and the most important results achieved in Workpackage 8 are described in the next lines of the present report.

3.8.2.1 Web site of the project

From the beginning of the project a web site was developed by the coordinator of the project (University of Mondragon) with two purposes. The first purpose was to facilitate the communication between all the partners and the second purpose was to disseminate the knowledge generated in the project.

The link to the web site is the next one: http://www.pro2control.net/

3.8.2.2 Scientific reportage at the television in the Basque Country

In February 2008 ETB (the television channel at the Basque Country) recorded a TV program where the running of the system developed during the project was shown. This TV program was broadcast at the Bask Country channel the 1st of March of 2008. The program also supposed a very good way to disseminate over the society the results of the project.

Figure 172: Scene of the TV program recorded in Industrias Alzuaran

3.8.2.3 Artificial Intelligence applied to sheet metal forming processes control workshop

With the aim of spreading the state of the art of monitoring and artificial vision systems and the knowledge generated in the project, a workshop took take place in Mondragon on 28th of February 2007. In this workshop researches from the University of Mondragon (Dr Carlos Garcia and Dr Alberto Izagirre), researchers from Brankamp (Mr. Juan Figueras) and researchers from Delta Technologies (Philippe Fillatreau) explained the attendants how monitoring systems (Brankamp), artificial vision systems (Delta Technologies) and artificial intelligence (Alberto Izagirre) can improve the performance of forming processes. And finally Dr. Carlos Garcia explained how the combination of all this systems to develop an intelligent controller can give greater results than the use of the systems separately.

At the meeting more than 40 attendants from all over the Basque Country and Spain listened about these control strategies and about the middle term results achieved at the present project.

A brief description of the Workshop is next shown:

Title of the workshop:

Workshop on process monitoring and quality control in metal forming processes.
Date:
28-02-2007
Objectives:

- To learn about the possibilities of sensors based monitoring systems in metal forming processes.
- To learn about the possibilities of artificial vision based monitoring systems in metal forming processes.
- To learn about the possibilities of intelligent control strategies in metal forming processes.

Agenda:
9:30 Welcome.
Xabier Sagarna, Continuous Training Manager, MGEP
Carlos Garcia, Metal Forming Processes, MGEP
09:45 Introduction: Why process monitoring?
Carlos Garcia MGEP
10:15 Metal forming processes: process monitoring and quality control by means of sensors and artificial vision systems: state of the art
Carlos Garcia, Metal Forming Processes, MGEP
10:45 Coffee break.
11:00 A commercial solution. Brankamp: experiences in monitoring of metal forming processes
Juan Figureas Brankamp
11:30 A commercial solution. DTSO: artificial vision in quality control.
Philippe Fillatreau, DTSO
12:00 Intelligent control of metal forming processes.
Alberto Izaguirre, Information and Communication Technologies, MGEP
12:30 Closing remarks
Carlos Garcia, MGEP

At the final meeting of the project that took place in April 2008 at Mondragon, it was stated that another workshop will be made in autumn 2008 in Industrias Alzuaran. The main purpose of this second workshop will be to show people from industry the capabilities of the complete control system developed during the project. In this way, people from industry will be able to see the complete system, composed of the monitoring system, the artificial vision system and the controller based on artificial intelligence tools is working in a blanking facility at Industrias Alzuaran. The main idea is to explain engineers from industry the improvements that Industrias Alzuaran has got since the installation of the system.

3.8.2.4 Papers in congress and publications in scientific journals

The research team has also made a big effort in order to spread the generated knowledge in both the scientific and the industrial world. At an scientific level, the research team has presented papers in several conferences all over the world and has published articles in scientific journals.

The papers presented in international conferences are the next:

1. Sáenz de Argandoña, E., García C., Arana N., Izaguirre A., Aztiria A. “Control de proceso en tiempo real y aseguramiento de la calidad en operaciones de embutición y corte mediante adquisición de datos y técnicas de visión artificial”. XVI Congreso de máquinas-herramienta y tecnologías de fabricación, Donostia, España, October 2006.
2. Fillatreau P., Bernard Fx., Ardanza A., Arana N., Sáenz de Argandoña E., Izaguirre A., Garcia C., Mugarza J.C. "Calibrating Camera Position Parallel to a Surface for Dimension Calculation of Flat Parts", 8th International workshop on Electronics, Control, Modelling, Measurement and Signals 2007& Doctoral School (EDSYS, GEET), Liberec, Czech Republic, May 28-30, 2007.
3. Aztiria A., Saénz de Argandoña E., García C., Arana N., Izaguirre A. “Application of Artificial Intelligent Technique for Sheet Metal Forming processes global control”. 40th CIRP International Seminar on Manufacturing Systems, 2007, Liverpool, England, May 2007.
4. Saénz de Argandoña E., Aztiria A., García C., Arana N., Izaguirre A., Fillatreau P., Terzyk T. “Control of forming processes by means of artificial intelligent techniques”. The 17th International Conference on Flexible Automation and Intelligent Manufacturing, FAIM 2007, Philadelphia, USA, June 2007.
5. Saénz de Argandoña E., Aztiria A., García C., Arana N., Izaguirre A., Fillatreau P., Bernard F.X., Terzyk T. “Cooperation Strategies between Artificial Vision System and Force-Acoustic Sensors for Sheet Metal Forming Global Control”. The 17th International Conference on Flexible Automation and Intelligent Manufacturing, FAIM 2007, Philadelphia, USA, June 2007.
6. Aztiria A., Saénz de Argandoña E., García C., Arana N., Izaguirre A. “Aplicación de técnicas de Inteligencia Artificial para el control global de procesos de conformado”. The 2nd Manufacturing Engineering Society International Conference, MESIC 2007, Madrid, España, July 2007.
7. García C., Sáenz de Argandoña E., Aztiria A., Arana N., Izaguirre A., Pop R., Galle M., Terzyk T., Fillatreau P. “Automatic detection of burrs in sheet metal cutting processes by a combination of a Sensor based Monitoring System, an Artificial Vision System and an Intelligent Control system”. 57th CIRP General Assembly, Dresden, Germany, August 2007.
8. Pop R., Saenz de Argandona E., Liewald M., Wagner S., Garcia C. ”Mit Prozesskontrolle zum Erfolg/ Künstliche Intelligenz zur Regelung von Stanzprozessen“ In: wt Werkstatttechnik online, 97th age-group (2007), 10th edition, SPRINGER-VDI-VERLAG.
9. Fillatreau P., Arana N., Sáenz de Argandoña E., Izaguirre A., Zuriarrain I., García C. “FPGA based Smart Camera For Industrial Production Control Applications”. Submitted to The 18th International Conference on Field Programmable Logic and Applications, Heidelberg, Germany, September 2008. (Waiting for acceptance.)

And the articles published in scientific journals are:

1. Saénz de Argandoña E., Aztiria A., García C., Arana N., Izaguirre A., Fillatreau P., Terzyk T. “Forming Processes Control by means of Artificial Intelligence Techniques” (accepted in Robotics and Computer-Integrated Manufacturing, accepted and to be published in summer 2008).
2. Saénz de Argandoña E., Aztiria A., García C., Arana N., Izaguirre A., Fillatreau P., Bernard F.X., Terzyk T. “Cooperation strategies between Artificial Vision System

and Force-Acoustic sensors" (accepted in Robotics and Computer-Integrated Manufacturing, accepted and to be published in summer 2008).
3. Saenz de Argandoña E., Aztiria A., García C., Arana N., Izaguirre A. An Intelligent Controller using Expert Systems for Sheet Metal Forming Processes. Manufacturing Department, Computer Science Department, Mondragón University (submitted to Expert Systems with Applications).

And finally two technical reports have been published in Spanish Journals.

1. Control de procesos de conformado en tiempo real published in the Journal Adimendun (related with Intelligent Materials and Processes), nº12, July 2006, pages 1-4.
2. Control de procesos industriales de conformado en tiempo real published in the Journal Información de máquinas-herramientas, equipos y accesorios IMHE, nº 329, October 2006, pages 10-15.

3.8.2.5 Development of an industrial system

At the final meeting that took place in Mondragon in April 2008, the partners were speaking about possible future industrialisation of the achieved results in the project and four major topics were covered:

1. First of all, Delta Technologies said that during the research project have gathered a lot of information and experience about the development of intelligent cameras based on FPGAs and applied to the quality assurance of metal forming processes. During the project Delta Technologies was able to develop such cameras and to communicate them with a computer. This has two main positive consequences: first the high speed treatment of the parts to be checked and second the flexibility of the system, because the algorithms that measure the dimensions of the part are codified in the computer and therefore are very easy to be modified. Therefore, at the present moment, Delta Technologies is prepared to supply those kind of cameras for industrial applications where high speed treatment is needed.
2. Second, Brankamp together with Mondragon University is developing nowadays an Expert System able to give advices to the operators of forming facilities. The main idea of this Expert System is that when a process fault is detected by the Brankamp system, the operator instead of finding in the Graphical User Interface a faulty curve, he/she will find a complete diagnosis/explanation about the fault at the facility, the reason why that fault happened and the solution that should be applied to solve it. The main advantage of this system will be a reduction in time for the re-starting of the production and therefore an increment in the production. At the same time, for companies that work in shifts, this improvement will make that different operators will share their knowledge and the control of the forming facility will be standardised. It is expected that the Expert System will be prepared for being installed at the Brankamp monitoring systems for the end of the year 2008.
3. Third idea is to patent the vertical buffer that was created for the artificial vision system in Industrias Alzuaran. This vertical buffer is a new idea to handle with retaining rings. What makes special this vertical buffer is the fact that with a funnel on its top, the parts can be flown out from the machine and after going through this vertical buffer, they will be packaged to be sent to the final customer. Nowadays most of the companies throw all parts to boxes and later MANUALLY, they have to be packaged. Therefore if this step could be avoided, a very tedious task would be eliminated.

4. And finally all the partners were speaking about the possibility to create a global system able to control the stability of the process (monitoring system), the quality of the parts (artificial vision system) and all this in an intelligent way (intelligent controller). At this point all the partners agreed that the main drawback to create one of these systems is the impossibility to make it universal enough. With this, partners mean that depending on the machine to be used, and the geometry of the parts to be controlled, and even the type of process, the short of elements to be used will be very different, like for example, type of cameras, lenses or illuminations in the artificial vision system or type of sensors in the monitoring system. Besides, the most difficult thing is the handling of the parts. Depending on the parts to be controlled a completely different system should be developed and therefore we would be talking about new systems for each new application. Anyway partners agreed that this could be a possible future development and they were even talking about the possibility of an spin off company that deals with such a system.

3.8.3 Deviations from Project work programme and corrective actions

No major deviations from the work plan appeared.

3.8.4 List of deliverables

Del. no.	Deliverable name	Workpackage No.	Date due	Actual/Forecast delivery date	Estimated indicative person/month*	Used indicative person/month*	Lead contractor
D14.1	Plan for using and disseminating knowledge (first version)	8	12	12	4	4	RTD1
D14.2	Plan for using and disseminating knowledge (final version)	8	24	24	4		RTD1
D15	Summary of the project.	8	12	12	4	4	RTD1
D16	Exploitation and dissemination report: patents, training courses, web page	8	24	24	4		SMEP3

3.8.5 List of milestones

Milestone no	Milestone name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
M 8.1	Web page	8	1	1	RTD1
M 8.2	First workshop on control systems in sheet metal forming processes	8	12	14	RTD1
M8.3	Second workshop on control systems in sheet metal forming processes	8	24		RTD1

3.9 <u>Workpackage 9. Coordination, management and organisation of the project</u>

3.9.1 Workpackage objectives and starting point of work at beginning of reporting period

The objectives of the Workpackage 9 are the following ones:

- To ensure efficient organisation of the work in the project: assignment of responsibilities, follow-up of the technical works in quality, in cost and in time, organisation of technical and management meetings, elaboration of deliverables...
- To face any problem (technical or not) the project may encounter.
- To achieve the objectives of the project
- To ensure the dissemination and training activities in the end of the project
- To have a unique interlocutor for the Commission and for any other company.

The different tasks defined at the beginning of the project are the following ones:

- Contacts with the Commission and EU-offficers in order to solve the problems related to the contract elaboration…
- Organisation of meetings with other partners in order to discuss about technical and management issues, although workpackage meetings will be organized by the WP-leaders.
- Reporting:
  1. A progress review report every month, prepared by the Technical Manager.
  2. Periodical reports every six months, prepared by the project Co-ordinator.
  3. Deliverables (see deliverables list), prepared by the project Co-ordinator in collaboration with the workpackage's leader.
- Management of each of the technical and dissemination and exploitation workpackages

3.9.2 Progress towards objectives

The proposed schedule for the tasks described in the previous section is the one shown in the next picture:

Description of workpackages, tasks and specific reports	Year 1												Year 2											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
WP 9: Coordination, management, organisation of the project	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Figure 173: Schedule of the ninth workpackage

The work done and the most important results achieved in Workpackage 9 are described in the next lines of the present report.

3.9.2.1 Meetings during the project

The main meetings that took place during the first period of the project are the next ones.

1. Kick off meeting celebrated at the University of Mondragon the 9th and 10th of November 2005.
2. Second meeting celebrated at IFU, University of Stuttgart the 19th of January 2006
3. Third meeting celebrated at the University of Mondragon the 6th of April 2006
4. Fourth meeting celebrated at the University of Mondragon 3rd of November 2006

And the main meetings during the second period of the project are the next ones:

5. Fifth meeting celebrated at the University of Mondragon 27th of April 2007
6. Final meeting celebrated at the University of Mondragon 19th of April 2008

The presentations, minutes and notes from all these meeting can be found in the web site of the project http://www.pro2control.net/.

At the same time, several informal meetings have been celebrated during the project, mainly between the University of Mondragon and the final users of the system, Industrias Alzuaran and Industrias Garita.

3.9.2.2 Stages of the researchers during the project

The main stages that have been made by the researches working in the project during the first period are the next.

1. Stage of Eneko Sáenz de Argandoña (University of Mondragon) in Brankamp (Düsseldorf) for learning about the Brankamp monitoring system from 12 to 17th of February 2007.
2. Stage of Tom Wittbrodt (Brankamp) in Industrias Alzauran for installing and setting up of the Brankamp monitoring system from 7th to 14th of June 2006.
3. Stage of Michael Galle and Thomas Terzyk (Brankamp) for the final tunning of the Brankamp monitoring system in Industrias Alzuaran from 11th to 14th September 2006.
4. Stage of Alberto Izagirre, Nestor Arana, Eneko Saenz de Argandoña, Lorena San Vicente and Iker Zuriarrain (all from the University of Mondragon) in Delta Technologies (Tolousse) in order to take technical decisions about the artificial vision system from 5 to 6th of Decembr 2005.
5. Stage of Alberto Izagirre and Nestor Arana (from the University of Mondragon) in Delta Technologies (Tolousse) in order to take technical decisions about the artificial vision system from 7 to 8th of September 2006.
6. Stages of Robert Pop from IFU in the University of Mondragon in order to work on the artificial vision system prototype. From 27th of February until the 11th of March, from the 3rd to 7th of April, from the 22nd of May until the 3rd of June, from the 10th to the 22nd of July, from the 2nd to the 7th of October and from the 24th of October until the 4th of November.

The main stages that have been made by the researches working in the project during the second period are the next.

1. Stage of Eneko Sáenz de Argandoña in IFU (Stuttgart university) to work on the development of intelligent controllers for sheet metal forming applications from May until August 2007.
2. Stage of Tom Wittbrodt (Brankamp) in Industrias Garita for installing and setting up of the Brankamp monitoring system from 18th to 26th of January 2007.
3. Stage of Tom Wittbrodt (Brankamp) in Industrias Garita for installing and setting up of the Brankamp monitoring system from 16th to 20th of April 2007.
4. Stage of Michael Galle and Thomas Terzyk (Brankamp) for the supervision of the Brankamp monitoring systems in Industrias Alzuaran and Industrias Garita from 4th to 6th September 2008.
5. Stage of Iker Zuriarrain in LASS (Laboratory for the Research of the System's Architecture) in Toulouse with the purpose of working together with Delta Technologies in the development of the intelligent cameras from January 2007 until March 2008.
6. Stage of Asier Aztiria in the Ulster University (Jordanstown campus) for acquisition of knowledge about self learning system with the purpose of the future development of self learning system for metal forming application from September 2007 until August 2008.
7. Stages of Robert Pop from IFU in the University of Mondragon in order to work on the artificial vision system prototype. From 31st of January 2007 until the 10th of February 2007, from the 22nd of February 2007 to 3rd of March 2007, from the 22nd of April 2007 until the 28th of April 2007, from the 10th of September 2007 to the 22nd of September 2007, from the 3rd of December 2007 to the 15th of December 2007, from the 11th of February 2008 until the 23rd of February 2008, from the 17th of March 2008 until the 22nd of March 2008 and from the 7th of April 2008 until the 19th of April 2008.

3.9.2.3 Submitted deliverables during the project

All the deliverables written during the first period of the project are the next ones:
1. D1_Software and hardware environment definition
2. D2- Mechanical prototypes descriptions (specifications and design)
3. D3- Descriptions of the sensors (force and AE) based system architecture
4. D4-Description of the AV based system architecture
5. D5- Mechanical prototype, including the sensors based system and the AV based system
6. D6- Preliminary tests on the monitoring systems, design of experiments, results and conclusions
7. D7- Integration in a common environment
8. D8- Test, Critical cases
9. 6 month periodic activity report
10. First periodic activity report
11. Intermediate economical report
12. Plan for using and disseminating knowledge (middle term)

And all the deliverables written during the second period of the project are the next ones:
1. D9- The control system: software and hardware, signal analysis and processing techniques and algorithms

2. D10- Custom oriented interface for the adaptation of the complete system to a new workpart
3. D11- Industrial validation: specifications, tests, and results
4. 18 month periodic activity report
5. Final periodic activity report
6. Final economical report
7. Plan for using and disseminating knowledge (final report)

All these deliverables can be found in the web site of the project http://www.pro2control.net/.

3.9.3 Deviations from Project work programme and corrective actions

No major deviations from the work plan appeared.

3.9.4 List of deliverables

Del. no.	Deliverable name	Workpackage No.	Date due	Actual/Forecast delivery date	Estimated indicative person/month*	Used indicative person/month*	Lead contractor
D17.1	Periodical and WP reports	9	6-18	6	5	5	RTD1
D17.2	Reports	9	12-24	12	5	5	RTD1

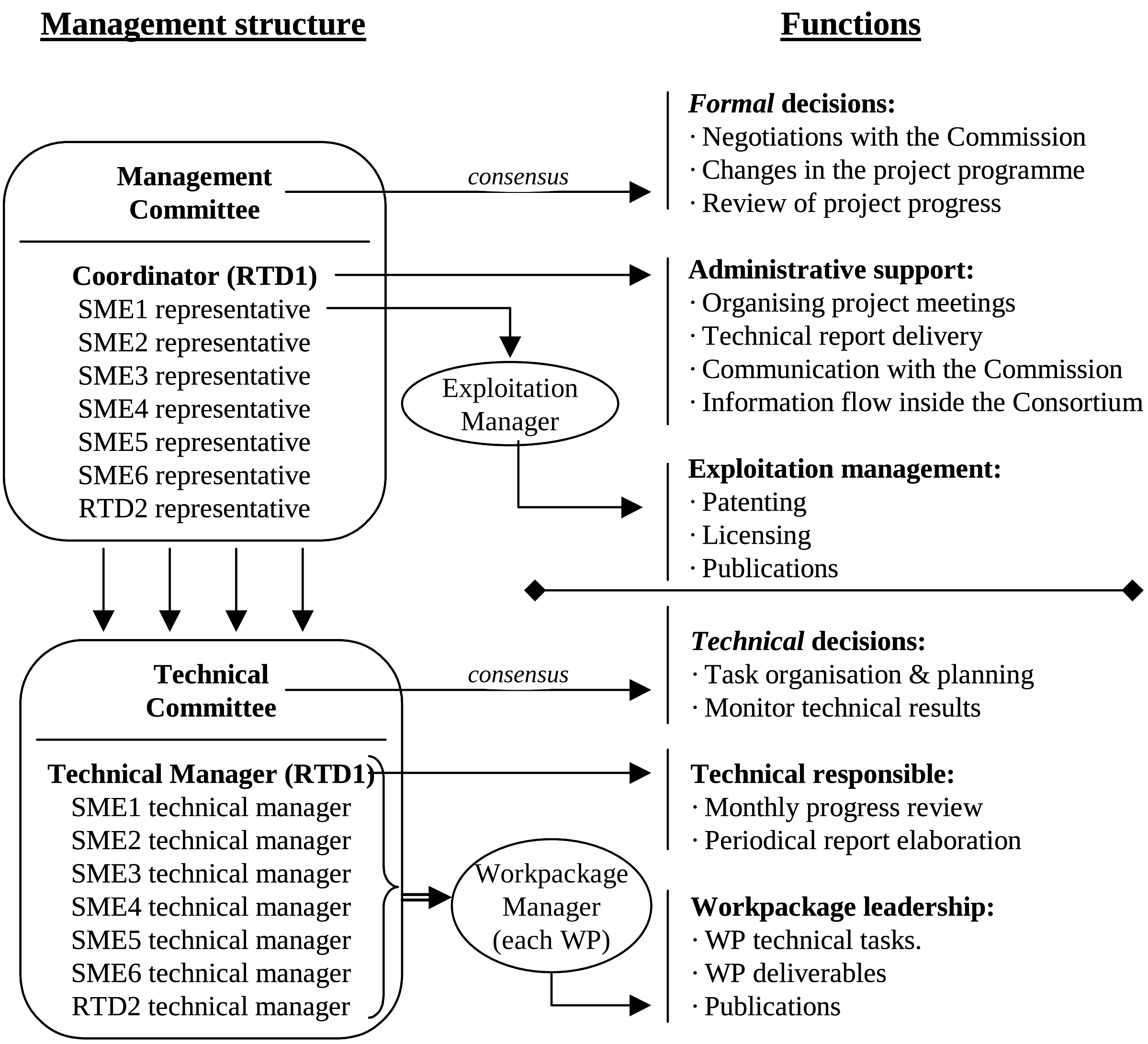
3.9.5 List of milestones

Milestone no	Milestone name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
M 9.1	6 months report	9	6	6	RTD1
M 9.2	Middle term report	9	12	12	RTD1
M 9.3	18 months report	9	18	18	RTD1
M 9.4	Final report	9	24	24	RTD1

4 Consortium management

4.1 Consortium management tasks and their achievement

The management structure of the project proposed at the beginning is shown in the following figure:



In fact, due to the small dimension of some of the SME companies, in some cases, the same person is in charge of the management and the technical tasks of the project. On the other side, we have to mention that a “hard technical committee” has spontaneously been created, including technical staff of both RTD agents (MU and USTUTT) and SMEP3 (Brankamp) and SMEP4 (Delta Technologies), with the participation of the final users SMEP7 (Industrias Alzuaran) and SMEP8 (Industrias Garita).

In this sense, staff from RTD1, RTD2, SMEP3, SMEP4 has made several exchanges and stages (RTD1 in SMEP3 and SMEP4, SMEP3 at RTD1, RTD2 at RTD1 twice, etc) that were not foreseen at the beginning of the project, in order to accomplish the technical objectives of the project.

The following table details the persons in charge of management and technical committees and, in bold, the companies of the "hard technical committee", that maintain frequently contacts and technical meetings.

Company	Management representative	Technical representative
RTD1 (MU)	D. Carlos García	D. Alberto Izagirre / D. Nestor Arana M. Eneko Sáenz de Argandoña
RTD2 (USTUTT)	D. Stefan Wagner	M. Robert Pop
SMEP3 (Brankamp)	D. Peter Schneider	D. Thomas Terzyk / M. Michael Galle
SMEP4 (Delta Techn.)	M. Guy Canova	D. Phillippe Fillatreau
SMEP5 (SanGiacomo)	M. Francesco Candelù	M. Francesco Candelù
SMEP6 (Troydesa)	M. Ramón Telleria	M. Ramón Telleria
SMEP7 (Alzuaran)	M. Mikel Gorostidi	Mrs. Belen Alzuaran
SMEP8 (Garita)	M. Antonio Arana	M. Antonio Arana

On the other hand, in order to discuss general issues of the project, six global meetings have been celebrated (as foreseen in the DoW of the project). The exact dates of these meetings can be found in the resume of the Workpackage 9 written previously in this document.

4.2 Contractors: Comments regarding contributions, changes in responsibilities and changes to consortium itself

Concerning the changes that have taken place in the project, three events must be detailed. These "problems" were solved even before the project had begun, in November 1st, and were detailed in a "Request for Amendment" sent to Mrs Polidori:

1. A new partner, Delta Technologies (SMEP4), substituted Otto, with the same tasks and role in the project. This change has resulted to be very beneficial for the ongoing of the project.
2. Delta (SMEP4) did not want to take the compromise of patenting anything at the end of the project, even if they have a detailed exploitation plan. The amount of money in Protection of knowledge was moved to Personnel Costs increasing the number of man-months.
3. In the same way, Brankamp (SMEP3), removed the money from Protection of knowledge and allocated it to Personnel Costs. For that, they proposed to increase the man-month cost per month (from 5.000 €/m to 6.960 for the Technical Tasks). They adduced that they have so elevated costs because their personnel in this branch is very well qualified.

A copy of the request for amendment can be found in the resume of the deliverable 7 made previously in this document.

In order to have a communication between all the partners of the project, a web page was designed. This web page is already working and it can be visited in this direction: **www.pro2control.net** . The web page has different sections. A section of general information and description of the project's objectives, another one that can only be used by the partners of the project, a downloading section and another section with links.

4.3 Project timetable and status

Next the initial schedule proposed for the project is shown. During the development of the project it was found that the initial timing of the project was too optimist and therefore an extension in time of six months was necessary, finishing the project in April 2008 instead of in October 2007.

Description of workpackages, tasks and specific reports	Year 1												Year 2											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
WP 1: Design, manufacturing and set-up of the mechanical prototype																								
Task 1.1: Selection of 5 specific cases and the presses for the tests	X	X																						
Task 1.2: Design and manufacturing of the 2 mechanical prototypes (for blanking and drawing)			X	X	X																			
Task 1.3: Set-up of the prototypes at SME5 site						X																		
WP 2: Development of a force and AE monitoring system																								
Task 2.1: Definition of a common hardware and software environment for the project		X	X	X																				
Task 2.2: Acquisition & set-up of the elements for the sensors based monitoring system			X	X	X	X																		
Task 2.3: Definition of the tests and initial validation of the sensors monitoring system					X	X																		
WP 3: Development of an AV monitoring system																								
Task 3.1: Acquisition and set-up of the elements for the AV based system		X	X	X	X	X	X																	
Task 3.2: Definition of the tests and initial validation of the AV monitoring system					X	X	X	X																
WP 4: Integration and recording of critical cases																								
Task 4.1: Integration of the two monitoring systems in the same environment						X	X	X	X	X														
Task 4.2: Recording on press of critical cases (at SMEP7)								X	X	X	X	X												
WP 5: Development of the control system																								
Task 5.1: Signal and image analysis and processing						X	X	X	X	X	X	X												
Task 5.2: Development of real-time processing modules adapted to the cases studied								X	X	X	X	X	X	X										
Task 5.3: Development of the interface for the easy adaptation of the system to a new workpart (custom oriented)												X	X	X	X	X								
WP 6: Real-size validation on a production line																								
Task 6.1: Definition of the validation conditions and choose of the final industrial case													X	X	X									
Task 6.2: Adaptation of the control system to the validation conditions															X	X	X	X	X	X				
Task 6.3: Industrial validation																	X	X	X	X	X	X		
Task 6.4: Control system improvements																					X	X	X	X
WP 7: Review and assessment	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
WP 8: Exploitation and dissemination	X	X								X	X	X						X	X			X	X	X
WP 9: Coordination, management, organisation of the project	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Periodic reports																								
6 months report	- -	- -	- -	- -	- -	- -➤																		
12 months report	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -➤												
Mid-term report	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -➤												
18 months report	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -➤						
24 months report	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -➤

The reason for the extension in time of the project were mainly due to the fact that the Workpackage 3 has taken much more of the initial estimated time. Therefore the main delay in the project has been found when developing the artificial vision system because the lack of experience of the partners (Delta Technologies, the University of Mondragon and the University of Stuttgart) in the development of artificial vision systems focused on quality assurance in forming processes.

Anyway after a period of training mainly with Infaimon (artificial vision system supplier) and after visiting several companies that are already working with these systems, the research team has already finished with the development of the artificial vision system and it has been linked with the Brankamp monitoring system and with the Expert System being nowadays working in Industrias Alzuaran.

So summarising although workpackaged 3 has delayed the initial schedule of the project, at the end the results of this workpackage have been considerably good and although the whole project has been delayed a bit, the results of the final facility have reached a very good performance.

4.4 Communication between partners, project meetings, possible co-operation with other projects/programmes

All the communication between partners, the project meeting and the stages of the partners in other companies has been resumed in the workpackage 9.

Only mention that two more projects have been asked to the Spanish and to the Bask Government in order to continue working and collaborating with the main purposes of the present project. Both projects, the one submitted to the Spanish Government and the one submitted to the Bask Government have been accepted and will finish in December 2008. The main idea is to validate more deeply the results of the present project when applying them to drawing operations. The partners of this project are Industrias Garita and the University of Mondragon.

5 Other issues

In this part of the document a description of the overall contributions of the group of SMEs, of RTD performers, and of other enterprises and end-users is included.

RTD	1	Mondragon Goi Eskola Politeknikoa J.M.A. S. Coop.
RTD	2	Universitaet Stuttgart
SMEP	3	BRANKAMP System Prozessautomation GmbH
SMEP	4	Delta Technologies Sud Ouest
SMEP	5	OFFICINE SANGIACOMO s.r.l.
SMEP	6	Troqueles y Derivados S.A.
SMEP	7	Industrias Alzuarán S.L.
SMEP	8	Industrias Garita S. L.

Figure 174: The different partners of the project

RTD1 is the partner that coordinates the project with the agreement of all the other partners. In addition, RTD1, in collaboration with SMEP4, is developing the algorithms that are going to be used in the artificial vision. RTD1 is manufacturing together with RTD2 the mechanical device that will allow to install the cameras of artificial vision in the presses of the different companies. At the same time another field where RTD1 is working on is the development of the expert system.

RTD2 has designed and is helping RTD1 to manufacture the mechanical device that will allow to install the artificial system.

SMEP3 has given technical support in choosing the sensors and acquisition systems for the monitoring of the processes, in the design of the modifications to the tooling, as well as in the communication protocols for the coordination of the three systems of the project (sensors based monitoring system, AV based monitoring system and AI control system). They have carried out the installation of the sensors system in SMEP7 and SMEP8.

SMEP4 is working on the algorithms for the AV system and is managing this workpackage. Their experience in this field is being very useful also for RTD1 that is carrying out physically the initial tests and the set-up.

SMEP5 is the company that in collaboration with Brankamp (SMEP3), studied the best positions and places to install the different sensors.

SMEP6 is the company that has manufactured the new tooling that nowadays is being used to manufacture the parts at SMEP8. Modifications proposed by SMEP3 in order to install the sensors were also made by SMEP6.

SMEP7 is the company where the retaining rings (references IA04, 0863-012 and 5828-001) are produced. The tooling chosen has been modified and equipped in order to be able to measure forces and acoustic emission signals at different locations. Obviously, they impose the criteria for defining a good and a bad part, describing the defects that the sensors based and the AV based monitoring systems must detect.

SMEP8 is the company where the part with deep drawing and blanking operations (reference Synemblock) is produced. The part chosen is manufactured in a tooling manufactured by SMEP6, where sensors and an AV based system will be mounted. In the same way, they impose the quality criteria in order to develop and adjust the monitoring systems and the control system.

6 Plan for using and disseminating the knowledge

6.1 Section 1 - Exploitable knowledge and its Use

As it was stated in workpackage 8, at the final meeting that took place in Mondragon in April 2008, the partners were speaking about possible future industrialisation of the achieved results in the project and four major topics were covered:

1. First of all, Delta Technologies said that during the research project have gathered a lot of information and experience about the development of intelligent cameras based on FPGAs and applied to the quality assurance of metal forming processes. During the project Delta Technologies was able to develop such cameras and to communicate them with a computer. This has two main positive consequences: first the high speed treatment of the parts to be checked and second the flexibility of the system, because the algorithms that measure the dimensions of the part are codified in the computer and therefore are very easy to be modified. Therefore, at the present moment, Delta Technologies is prepared to supply those kind of cameras for industrial applications where high speed treatment is needed.
2. Second, Brankamp together with Mondragon University is developing nowadays an Expert System able to give advices to the operators of forming facilities. The main idea of this Expert System is that when a process fault is detected by the Brankamp system, the operator instead of finding in the Graphical User Interface a faulty curve, he/she will find a complete diagnosis/explanation about the fault at the facility, the reason why that fault happened and the solution that should be applied to solve it. The main advantage of this system will be a reduction in time for the re-starting of the production and therefore an increment in the production. At the same time, for companies that work in shifts, this improvement will make that different operators will share their knowledge and the control of the forming facility will be standardised. It is expected that the Expert System will be prepared for being installed at the Brankamp monitoring systems for the end of the year 2008.
3. Third idea is to patent the vertical buffer that was created for the artificial vision system in Industrias Alzuaran. This vertical buffer is a new idea to handle with retaining rings. What makes special this vertical buffer is the fact that with a funnel on its top, the parts can be flown out from the machine and after going through this vertical buffer, they will be packaged to be sent to the final customer. Nowadays most of the companies throw all parts to boxes and later MANUALLY, they have to be packaged. Therefore if this step could be avoided, a very tedious task would be eliminated.
4. And finally all the partners were speaking about the possibility to create a global system able to control the stability of the process (monitoring system), the quality of the parts (artificial vision system) and all this in an intelligent way (intelligent controller). At this point all the partners agreed that the main drawback to create one of these systems is the impossibility to make it universal enough. With this, partners mean that depending on the machine to be used, and the geometry of the parts to be controlled, and even the type of process, the short of elements to be used will be very different, like for example, type of cameras, lenses or illuminations in the artificial vision system or type of sensors in the monitoring system. Besides, the most difficult thing is the handling of the parts. Depending on the parts to be controlled a completely different system should be developed and therefore we would be talking about new systems for each new application. Anyway partners

agreed that this could be a possible future development and they were even talking about the possibility of an spin off company that deals with such a system.

Overview table:

Exploitable Knowledge (description)	**Exploitable product(s) or measure(s)**	**Sector(s)** of application	Timetable for commercial use	Patents or other IPR protection	**Owner** & Other Partner(s) involved
1. FPGA based artificial vision camera	*Intelligent camera based on a hardware / software co-design architecture approach*	*1. Discrete manufacturing processes (sheet metal forming, forging, plastic injection…).* *2. Continuous manufacturing processes* *3. Food quality control*	*2008*		***SMP4***
2. Combination of Artificial Intelligence tools with Monitoring Systems	*Intelligent Monitoring Systems for Sheet Metal Forming Processes*	*Discrete manufacturing processes (sheet metal forming, forging, plastic injection…).*	*2009*		***SMP3***
3.Handling system for retaining rings production	*Integrated Artificial Vision and Sensor system*	*Discrete manufacturing processes sheet metal forming of retaining rings.*	*2009*	*It is expected to prepare a patent with the help of RTD1 and RTD2*	***SMEP7***
4. Integration of an Artificial Vision and a Sensors based monitoring system	*Integrated Artificial Vision and Sensor system*	*Discrete manufacturing processes (sheet metal forming, forging, injection…).*	*2010*		***SMEP3, SMEP4, RTD1***

6.2 Section 2 – Dissemination of knowledge

The knowledge acquired during the development of the project is being disseminated by different ways.

Even before the beginning of the project, a paper was published in the "Interantional Journal of Materials Processing Technologies" entitled "Artificial Intelligence Applied to Automatic Supervision, Diagnosis and Control in Sheet Metal Stamping Processes", and presented also in the AMPT (Advanced Materials and Processes Technologies)

Conference in Gliwice, Poland, in May 2005. This presentation allowed us to let other researches know about the project and was in fact an officious kick-off of the project.

During the two and a half years of the project, the research team has made a considerable effort in order to spread as much knowledge and experience in both the academic and industrial world. Next a list of the papers presented in international conferences, the articles published in scientific journals and the technical reports presented in industrial journals are listed.

The papers presented in international conferences are the next:

1. Sáenz de Argandoña, E., García C., Arana N., Izaguirre A., Aztiria A. “Control de proceso en tiempo real y aseguramiento de la calidad en operaciones de embutición y corte mediante adquisición de datos y técnicas de visión artificial”. XVI Congreso de máquinas-herramienta y tecnologías de fabricación, Donostia, España, October 2006.
2. Fillatreau P., Bernard Fx., Ardanza A., Arana N., Sáenz de Argandoña E., Izaguirre A., Garcia C., Mugarza J.C. "Calibrating Camera Position Parallel to a Surface for Dimension Calculation of Flat Parts", 8th International workshop on Electronics, Control, Modelling, Measurement and Signals 2007& Doctoral School (EDSYS, GEET), Liberec, Czech Republic, May 28-30, 2007.
3. Aztiria A., Saénz de Argandoña E., García C., Arana N., Izaguirre A. “Application of Artificial Intelligent Technique for Sheet Metal Forming processes global control”. 40th CIRP International Seminar on Manufacturing Systems, 2007, Liverpool, England, May 2007.
4. Saénz de Argandoña E., Aztiria A., García C., Arana N., Izaguirre A., Fillatreau P., Terzyk T. “Control of forming processes by means of artificial intelligent techniques”. The 17th International Conference on Flexible Automation and Intelligent Manufacturing, FAIM 2007, Philadelphia, USA, June 2007.
5. Saénz de Argandoña E., Aztiria A., García C., Arana N., Izaguirre A., Fillatreau P., Bernard F.X., Terzyk T. “Cooperation Strategies between Artificial Vision System and Force-Acoustic Sensors for Sheet Metal Forming Global Control”. The 17th International Conference on Flexible Automation and Intelligent Manufacturing, FAIM 2007, Philadelphia, USA, June 2007.
6. Aztiria A., Saénz de Argandoña E., García C., Arana N., Izaguirre A. “Aplicación de técnicas de Inteligencia Artificial para el control global de procesos de conformado”. The 2nd Manufacturing Engineering Society International Conference, MESIC 2007, Madrid, España, July 2007.
7. García C., Sáenz de Argandoña E., Aztiria A., Arana N., Izaguirre A., Pop R., Galle M., Terzyk T., Fillatreau P. “Automatic detection of burrs in sheet metal cutting processes by a combination of a Sensor based Monitoring System, an Artificial Vision System and an Intelligent Control system”. 57th CIRP General Assembly, Dresden, Germany, August 2007.
8. Pop R., Saenz de Argandona E., Liewald M., Wagner S., Garcia C. ”Mit Prozesskontrolle zum Erfolg/ Künstliche Intelligenz zur Regelung von Stanzprozessen“ In: wt Werkstatttechnik online, 97th age-group (2007), 10th edition, SPRINGER-VDI-VERLAG.
9. Fillatreau P., Arana N., Sáenz de Argandoña E., Izaguirre A., Zuriarrain I., García C. “FPGA based Smart Camera For Industrial Production Control Applications”.

Submitted to The 18th International Conference on Field Programmable Logic and Applications, Heidelberg, Germany, September 2008. (Waiting for acceptance.)

And the articles published in scientific journals are:

1. Saénz de Argandoña E., Aztiria A., García C., Arana N., Izaguirre A., Fillatreau P., Terzyk T. “Forming Processes Control by means of Artificial Intelligence Techniques” (accepted in Robotics and Computer-Integrated Manufacturing, accepted and to be published in summer 2008).
2. Saénz de Argandoña E., Aztiria A., García C., Arana N., Izaguirre A., Fillatreau P., Bernard F.X., Terzyk T. “Cooperation strategies between Artificial Vision System and Force-Acoustic sensors” (accepted in Robotics and Computer-Integrated Manufacturing, accepted and to be published in summer 2008).
3. Saenz de Argandoña E., Aztiria A., García C., Arana N., Izaguirre A. An Intelligent Controller using Expert Systems for Sheet Metal Forming Processes. Manufacturing Department, Computer Science Department, Mondragón University (submitted to Expert Systems with Applications).

And finally two technical reports have been published in Spanish Journals.

1. Control de procesos de conformado en tiempo real published in the Journal Adimendun (related with Intelligent Materials and Processes), nº12, July 2006, pages 1-4.
2. Control de procesos industriales de conformado en tiempo real published in the Journal Información de máquinas-herramientas, equipos y accesorios IMHE, nº 329, October 2006, pages 10-15.

As it was stated in workpackage 8, with the aim of spreading the state of the art of monitoring and artificial vision systems and the knowledge generated in the project, a workshop took take place in Mondragon on 28th of February 2007. In this workshop researches from the University of Mondragon (Dr Carlos Garcia and Dr Alberto Izagirre), researchers from Brankamp (Mr. Juan Figueras) and researchers from Delta Technologies (Philippe Fillatreau) explained the attendants how monitoring systems (Brankamp), artificial vision systems (Delta Technologies) and artificial intelligence (Alberto Izagirre) can improve the performance of forming processes. And finally Dr. Carlos Garcia explained how the combination of all this systems to develop an intelligent controller can give greater results than the use of the systems separately.

At the meeting more than 40 attendants from all over the Basque Country and Spain listened about these control strategies and about the middle term results achieved at the present project.

A brief description of the Workshop is next shown:

Title of the workshop:
Workshop on process monitoring and quality control in metal forming processes.
Date:
28-02-2007
Objectives:

- To learn about the possibilities of sensors based monitoring systems in metal forming processes.

- To learn about the possibilities of artificial vision based monitoring systems in metal forming processes.
- To learn about the possibilities of intelligent control strategies in metal forming processes.

Agenda:
9:30 Welcome.
Xabier Sagarna, Continuous Training Manager, MGEP
Carlos Garcia, Metal Forming Processes, MGEP
09:45 Introduction: Why process monitoring?
Carlos Garcia MGEP
10:15 Metal forming processes: process monitoring and quality control by means of sensors and artificial vision systems: state of the art
Carlos Garcia, Metal Forming Processes, MGEP
10:45 Coffee break.
11:00 A commercial solution. Brankamp: experiences in monitoring of metal forming processes
Juan Figureas Brankamp
11:30 A commercial solution. DTSO: artificial vision in quality control.
Philippe Fillatreau, DTSO
12:00 Intelligent control of metal forming processes.
Alberto Izaguirre, Information and Communication Technologies, MGEP
12:30 Closing remarks
Carlos Garcia, MGEP

At the final meeting of the project that took place in April 2008 at Mondragon, it was stated that another workshop will be made in autumn 2008 in Industrias Alzuaran. The main purpose of this second workshop will be to show people from industry the capabilities of the complete control system developed during the project. In this way, people from industry will be able to see the complete system, composed of the monitoring system, the artificial vision system and the controller based on artificial intelligence tools is working in a blanking facility at Industrias Alzuaran. The main idea is to explain engineers from industry the improvements that Industrias Alzuaran has got since the installation of the system.

And finally, from the beginning of the project a web site was developed by the coordinator of the project (University of Mondragon) with two purposes. The first purpose was to facilitate the communication between all the partners and the second purpose was to disseminate the knowledge generated in the project. The link to the web site is the next one: http://www.pro2control.net/

6.2.1 Section 3 - Publishable results

See in section 1 Publishable Executive Report at the present report.

The electronic version of the Periodic activity report must be submitted as follows
A complete file containing the whole report, including the Annex on the Plan for using and disseminating the knowledge
A separate file containing the Publishable Executive Summary
A separate file containing the Plan for using and disseminating the knowledge
A separate file containing the Publishable results of the Plan for using and disseminating the knowledge