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Executive Summary

The primary objective of LearnForm is to develop, implement and verify a self-learning production system for deep drawing process that will substitute the present trial and error procedure to radically shorten the process setup times during the changing product variants and to replace a skilled operator by an automated system while preserving good quality of produced parts without cracks and wrinkles.

The goal is closely connected to four different control levels – three lower levels controlling friction, forming and clamping behaviour consolidating in an upper level energy map control. To accomplish the goal a control strategy using supervisor control scheme was proposed. The supervisory controller in the upper level collects the data from the sensors placed in different positions of the tool (temperature, sheet feed, acoustic emission), based on that determines if wrinkles or cracks occur and adjusts the set points of clamping force of segmented blank holder system accordingly. The set points adjustments are applied after each cycle (stroke). The supervisory controller is based on fuzzy logic approach and beside the process data uses information given by a human operator as well.

The proposed and implemented algorithms were tested on two different work pieces, for which two existing deep drawing tools for automotive use and white goods have been redesigned to fit project requirements. The tools have been equipped with thermocouples, pyrometers, acoustic emission sensors, distance laser sensors and a fully new designed robust sheet feed and friction sensor using a data acquisition system, which was designed to gather all the measured data and to communicate with the PLC control system. Furthermore, the tools are prepared for mounting high power piezo actuators generating oscillating clamping force.

In order to distinguish if a crack occurs or not two classifiers were implemented. The first one, which is implemented on PC, is based on the multilayer perceptron neural network and uses the information from thermocouples, pyrometers and acoustic emission sensors. Position of the temperature sensors was determined by the thermal analyses made with thermo graphic camera. The second classifier implemented in PLC adopts fuzzy logic approach and processes the information from laser sheet feed sensors that are placed in the locations where the difference of sheet position during the stroke is maximal. The rules for clamping force adjustment were obtained by fuzzy cluster analyses. The good tracking performance of the clamping control (low overshoot, short settling time) that is necessary for high quality products was achieved by PID controller with the constants being tuned by a fuzzy logic system.

Besides the self-learning system an inclination control compensating differences of the ram force in different locations using four corner cushion cylinders was implemented in the press. In order to increase energy efficiency of the hydraulic system a new concept basing on a pump with controllable motor for variable system pressure has been integrated.

Moreover, several new promising components were developed, not all of which could still show their full potential already within the project itself. These components can be further improved to finally be integrated successfully either into the LearnForm control system or any other alike industrial application. The first ones are the piezo ceramic actuators generating an oscillating force of the maximum amplitude 26 kN, frequency 200 Hz and stroke of 50 µm with the corresponding power supply and amplifiers, which also have been developed. The next ones are the friction sensors evaluating the friction force based on simultaneous measurements of axial and tangential forces. The final component developed and manufactured within the project is the robust sheet feed sensor using new physical principles which can be easily fixed inside the tool and adapted for all kinds of clamping systems.

Summary description of project context and objectives

Industrial production systems get more and more complex due to increasing demands on quality and productivity. Highly integrated automation systems constitute an essential component of production systems, which facilitate, among other things, monitoring systems and adaptive control systems within some kind of machines optimising process conditions, product quality and maintenance. Deep drawing processes are highly complex in its forming aspect itself, where adaptive systems are in demand to reduce setup time, maintenance and increasing product quality by avoiding wrinkles and cracks in industrial serial production. This is where the LearnForm project attaches the idea of self-learning production systems by combining adaptive self-learning control strategies and monitoring deep drawing process data.

The primary objective of LearnForm is to develop, implement and verify a self-learning production system for deep drawing process that will substitute the present trial and error procedure to radically shorten the process setup times during the changing product variants and to replace a skilled operator by an automated system while preserving good quality of produced parts without cracks and wrinkles.

Based on the character of the forming process, a control strategy using supervisor control scheme was supposed to be used. Using the energy model of the deep drawing process, we distinguish four control levels:

- FRICTION CONTROL to prevent the stick-slip effect using force oscillators
- FORMING CONTROL to control the velocity of the ram
- CLAMPING CONTROL to guarantee good reference clamping force tracking
- which are supervised by ENERGY CONTROL

The supervisory controller in the upper level will adjust the set points (generally time varying) of the low level control loops. The set points adjustments will be applied after each cycle (stroke). The supervisory controller will use both data from the process (mainly sheet feed and the temperature of the sheet in different spots) and information given by a human operator and will adopt fuzzy logic approach.

The FRICTION CONTROL LEVEL aimed to conceive, design and implement concepts and systems for forming-integrated friction control principally by following a combined 2-step-approach:

- Making friction measurable by new and innovative sensing concepts.
- Making friction changeable by an all new and innovative "Force Oscillator" (FO) integrated in clamping elements.

To remain flexible regarding possible work package results and their respective contribution to the overall project success, a “Plan A” and “Plan B” were foreseen, where plan A was to develop and integrate the above mentioned components to an autonomously working real time closed loop friction control sub-system. This friction control system would be embedded in the overall control concept and provide interfaces (input and output) to related quality control instances, machine components and operators. In contrast, plan B longs for friction control in a more general way by providing input to any kind of upper level control coming from friction related parameters. As an upper level control output for affecting friction conditions, the Force Oscillator (FO) would provide oscillating clamping force overly with varying amplitude and frequency.

The FORMING CONTROL LEVEL aims at a self-learning forming control based on the ram and multiple die cushion axes movements with optimal forming velocity, sheet metal feed and die gap without inclination. This work package consists of three separated tasks:

- Creation of a Sheet metal forming control model
- Die gap and sheet feed measurement and analysis of the results
- Integration of a self-learning multi-axes motion control in the machine control system.

The CLAMPING CONTROL LEVEL bases on the idea of controlling the clamping force in a way that it will be qualified for a fundament of optimised deep drawing processes. For some presses with closed-loop controlled hydraulic die cushion (like the demonstrator press PYZ250 at IWU) the resulting clamping force will never appear as a constant force. Depending on the controllers governor setting and depending on the process conditions (hydraulic and mass inertia, ram velocity, etc) the responding force can result in overshoot, undershoot as well as oscillation. This behaviour is assumed to be a very critical process condition to provide deep drawing quality.

The objective of the self learning clamping control system is the adaption of the PID controller settings by evaluating the clamping force behaviour. To get known about which PID controller settings will have impact on the force behaviour, a rational simulation model of the clamping process will facilitate. With that, a fuzzy logic model will be implemented into the PLC of the press PYZ250 at IWU.

The aim of the ENERGY CONTROL LEVEL is to develop a self-learning energy control system, where the final part quality is checked by the appearance of wrinkles and/or scratches and the final developed system will re-adjust the process parameters in order to decrease the temperature of the hot-spots. As all other sub-systems impact on the final part quality (forming, clamping and friction), which will be indirectly reflected on the thermal map, the energy control system will act as a supervisor for these other sub-systems.

For this purpose we need to, firstly, monitor how the energy is being distributed along the piece and die in order to build the thermal maps. Location of the sensors, and the selection of the technology to be used, will be fundamental for the identification of these hotspots.

Secondly, once these thermal maps are built by mean of the gathered information, the system will learn on how the energy is distributed, where the hot-spots are and its impact on the final part quality. This is, a thermal map will be obtained and the work piece energy model defined, where any change on the process variables will be reflected.

Finally, and based on the thermal map and the work piece energy model, self-learning algorithms will be developed to reduce or maintain on valid values of the hot spots by adjusting parameters to keep the final piece under the quality standards, preventing the appearance of wrinkles and scratches, minimizing manual quality checks, reducing number of attempts, waste of material and downtime.

The system will be firstly developed using off-line software tools (as MATLAB), but the self-learning control algorithms will be ready-to-apply in the press SIMOTION control environment.

Description of the Main S/T Results

As deep drawing process is a complex multi input multi output, highly nonlinear dynamic system whose mathematical description is not available a fuzzy logic based system was chosen to control the process, which was investigated by CTU PRAGUE. Controllers using fuzzy logic approach make it possible to aggregate a knowledge expressed linguistically by an experienced human operator and information extracted from measured data. A typical fuzzy control system is composed by the rules in the form IF–THEN where the IF part (antecedent) contains process variables and the THEN part (consequent) describes the corresponding control action. The rules are aggregated by an inference mechanism that guarantees smooth behaviour of fuzzy system.

In order to extract some relevant information from huge amount of multidimensional data neural networks represent a powerful tool. They are able to find a correlation which is highly nonlinear in a relatively short time thanks to the efficient learning algorithms. The learning process of a neural network has to be performed off-line before the beginning of the control process and the important features contained in the data have to be chosen in advance. Nevertheless for the purposes of application in a controller it is convenient to interpolate the resulted nonlinear surface described by a very complicated formula by a more compact nonlinear function that may be easily integrated into a control algorithm.

The global control strategy is based on supervisory control scheme with three independent control loops in the lower level – for friction control, for force control (forming control) and for clamping force control. The supervisor adjusts the set points values for each loop that are governed by local PID controllers. The supervisor is based on fuzzy logic approach and uses both data from the process (mainly sheet feed and the temperature of the sheet in different spots) and information given by a human operator.

The self-learning algorithm finds the limits of the technological window without a presence of human operator only using the measured data in the trial stage and in the process stage evaluates after each stroke whether the process runs inside that window. If the process is outside the window the self-learning control algorithm adjusts the set points for the next cycle (stroke).

Friction Control and Component Development

The initial idea of controlling friction within the forming process was to establish a control loop able to directly influence friction conditions within the press. This concept was supposed to be based on friction data measured directly within the press as an input and friction-affecting force oscillation applied to the clamping area as an output.

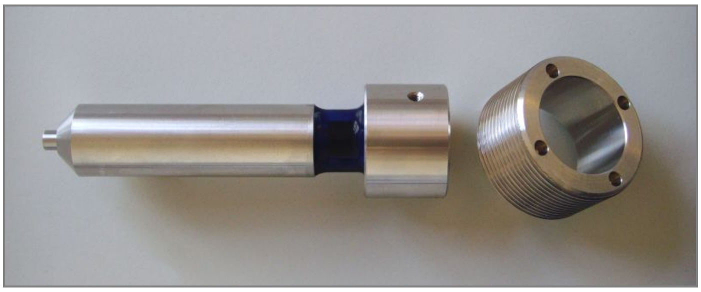
Therefore two all new components were designed, built, integrated and tested: a sensor named friction measuring interface (FMI) from ERAS and an actuator named force oscillator (FO) from CEDRAT. As representatives for the process parameter “friction” up to 3 values were intended to be provided by the FMI: the static friction coefficient, the dynamic friction coefficient and the actual status of movement (“stick” or “slip”).

At a very early stage it was still intended to perform friction control as a stand-alone closed-loop control on sub-system level within one forming cycle. This idea was then rejected mainly due to the fact that there are too many other influences on friction that are driven by other instances (like clamping force, ram speed etc.). It was decided to integrate the friction control aspect to the upper level control and to provide friction data (by the FMI sensor) as well as force oscillation (by FO actuators) as input resp. output to this control. The design was realized by elaborating, evaluating and providing a dedicated mechanical layout that is able to separately apply axial and tangential forces to a “deforming area” that is equipped with strain gauges. A dedicated way of application of the strain gauges together with dedicated electronics allows having axial and tangential forces as separate outputs of the sensor system "FMI".

In addition, a new sheet feed sensor "SFS" was engineered, designed, manufactured and tested within LearnForm to measure sheet edge movement directly within the forming tool. The designing of the sensor was motivated by two ideas:

- Sheet edge movement is corresponding to sheet feed as well as to friction and it is supposed to be one of the main relevant parameters representative for the overall forming process (and, in consequence, for work piece quality).
- Sheet edge movement is a parameter that to date still cannot be provided by both simple and affordable measuring technology. Thus a concept was searched and found to provide an affordable and still precise measuring system.

The sensor design features a simple and robust housing, easy to handle and to integrate in all kinds of clamping systems by simply cutting a notch with the dimension of the sensor. The sensor can be fixed inside the tool resp. the notch by a dedicated easy-to-handle clamping mechanism.



New design of Friction Measurement Interface (FMI)

New design of Sheet feed Sensor

The design of the so called "force oscillator"(FO) aims at reducing stick slip effect during deep drawing process in providing sufficient dynamic force to avoid any crack in the sheet metal forming. Simulations including Finite Element Method are performed in order to optimize the actuator performances. The force oscillator displays 50µm of stroke and 26kN of blocked force. Thanks to the integration of flexures and the use of suspension, the FO allows a backlash of +/- 1mm and withstands a parasitic angle of +/- 0.1 degree. Four force oscillators are delivered, in addition to the dummy FO.

Large low voltage piezo stack

Force Oscillator

Dummy FO with strain gauges

For driving the force oscillator actuators, ERAS developed dedicated power electronics suitable for providing power with proper sinusoidal waveform (as well as saw tooth wave forms at a later design stage) at different amplitudes and frequencies. The electronics specifications of this all new power electronics of course were supposed to be suitable for the FO designed by CEDRAT.

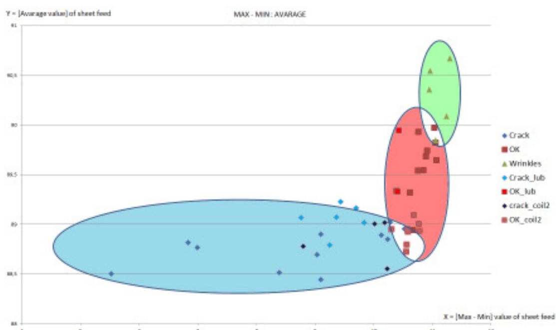
Another approach to expand maximum power of FO has caused CEDRAT to develop a separated set of amplifiers, where the driver topology is built around a full bridge output stage. As the piezo actuator is a reactive element, the input power range is only 200W instead on the output side, more than 2kVA is delivered to the load. The power supply is built around a standard Fly back providing high voltages and auxiliaries' voltages.

Forming Control

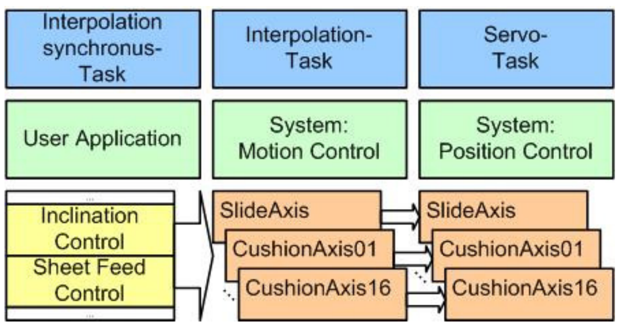
Deep drawing processes especially identify with the fast transformation from an initial shape of the work piece to its desired finished shape. In spite of the short forming time, the process depends on a multiplicity of parameters. Those are used to configure the process and those should ensure a high quality result of the work piece and process stability. Within forming control, deep-drawing velocity and other process variables are used to control the sheet feed, which was not able to simulate by a MATLAB model due to the high complexity of the process. The forming control supervisor strategy is built on different measurements.

In order to improve the process quality, the self learning system can define the set-velocity by a five point ram velocity profile based to the position of the ram. The variable ram velocity influences the clamping force control which is normally based on a constant ram velocity. The force profile definition was changed to a ram position based profile to avoid this influence. The control concept is completed by a supervisory control that implements the self-learning algorithm. Forming control also requires sheet feed measurement, for which a sensor is exposed to rough environment conditions. It has to be robust and insensible to resist shocks and vibrations but has to provide precise measured values with high resolution and sampling rate during the deep-drawing process, which was finally running with a laser triangulation sensor tracing the sheet edge through the gap between the upper and lower tool.

The results of deep drawing tryouts results in a classification showing the dependencies between the process parameters clamping force, drawing velocity, temperature etc and its corresponding results in deep drawing quality. Basing on this information, a supervisory control basing on fuzzy logic has been implemented into the PLC, tracing, recording and evaluating measured data with adaptive feedback to the set values of the PLC cycle by cycle. Once identified all critical values to feed the fuzzy rules, the system reacts on changing process conditions (e.g. lubrication) increasing or decreasing the set clamping force straight to a valid process window.

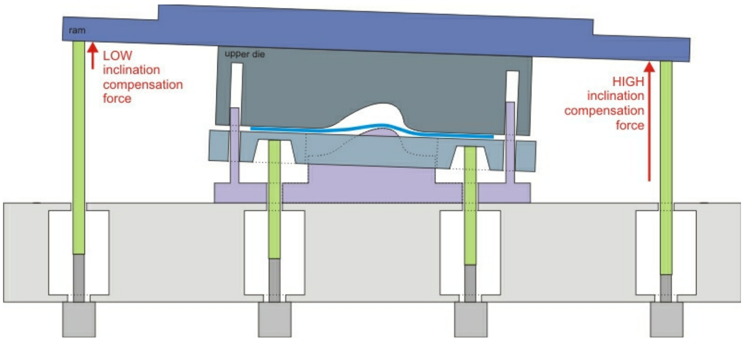


Quality classification of deep drawing cycles relating on measurement data



Forming Control (Sheet Feed & Inclination) PLC implementation as ready to apply programs

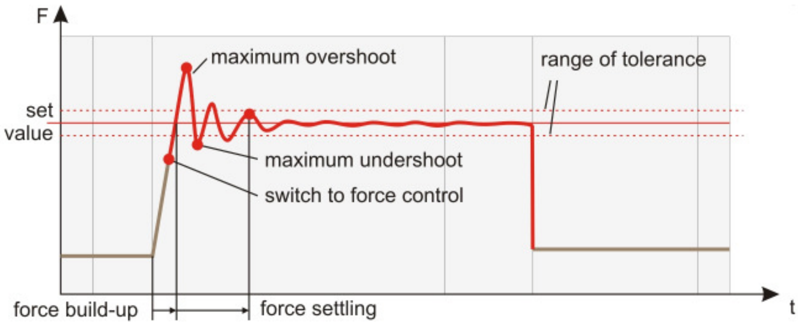
Within the appearance of asymmetric forces, keeping good forming quality means the tool planes have to be kept parallel. Therefore a new special design of an integrated inclination control will ensure the parallelism, where four of 16 sixteen die cushion axes are used to affect compensating forces to the ram directly. A patent application for the developed inclination control functionality has been filed by SIEMENS in February 2011.



Using hydraulic multiple die cushion within the blank holder clamping and the ram inclination compensation

Clamping Control
From the knowledge of operators and engineers, the force behaviour of a close loop controlled die cushion system can be described by a set of relevant criteria. Considering these values to be within their limits, one needs to set relating hydraulic PID controller settings. In the first instance, the modelling of the clamping control has been realised for one hydraulic axis. Therefore, the following points have been implicated for consideration of the deep drawing simulation:

- motion sequence of the ram
- process of hydraulic system
- open and closed loop control systems
- evaluation of achieved procedure (criteria calculation)



Clamping force behaviour with criteria to not exceed their margins

All used parameters, of which the most are not of relevance for this study, can be set or changed before a simulation cycle. After one simulation cycle, the characteristics of the process values and their derived criteria are available for evaluation in the MATLAB environment. In this way, the mode of operation of the parameters, which are of relevance for the clamping process, can be determined without experimental effort and can be clarified simulative over a wide area.

With the help of the simulation model, it was able to study the dependencies (influences) between the parameters and the criteria. Thereby some assumptions were made for the non varying parameters, what leads to the dynamical and controlled behaviour of the demonstrator press PYZ250. By a combination of those parameters, a large number of solutions have been provided within a four dimensional domain of definition. The dependencies between the parameters and the criteria could be visualised with the help of the display format of multidimensional characteristic diagrams, resulting in a clearly-arranged consolidated result [Priber, U.: Smoothed Grid Regression].

The fuzzy algorithm derived from the simulation model, has been implemented into the simulation model implicit. With that, presetting untypical values for PID controller settings leads to exceeding the criteria of clamping force behaviour. Regarding the relating hypothesis, the deep drawing process will result in less part quality.

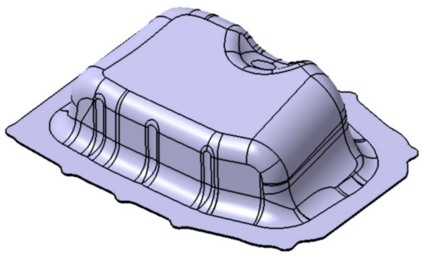
Finally, running the simulation model within a couple of cycles, the clamping control system suggest to increase or decrease PID controller settings aiming to not exceed the clamping force behaviour criteria. In summary, one can say, that the average number of necessary cycles to optimise the process is about six deep drawing cycles. The algorithm also has been implemented into the PLC Simotion P350 for one die cushion axis. It has been tested without any tooling inside. For test setup, the die cushion axis was in contact with the ram directly running with similar results like in the simulation.

The idea of the clamping control system has been validated by IWU to work correctly with one axis optimising the force behaviour within its criteria. The utilisation of this system for a coupled multi axis die cushion system could not be validated due to unsteady behaviour and requires further studies on interrelating control systems.

Deep Drawing Tools

GOREJNE was in charge for design and production of the sheet metal forming tool for the white good industry. For this purpose the Front Panel work piece from the cooking oven was chosen and new intelligent tool for this work piece was designed and produced, for which the work piece has to be from two different sheet materials with totally different characteristics, mild steel and stainless steel. For that matter we designed new blank-holder system with segment inserts to allow the control of blank holder force by segments totally separately with the multiple die cushion axes of the press demonstrator at IWU.

Segmented Blank Holder of Cooker Front Panel (Gorenje)



Oil Pan (CIE Automotive)

The work piece selected for the automotive demonstrator is the Oil Pan from CIE AUTOMOTIVE, which stamping process consists on a transfer stamping process, which forms the part to the final geometry within seven operations, but focusing on the step with highest drawing height.

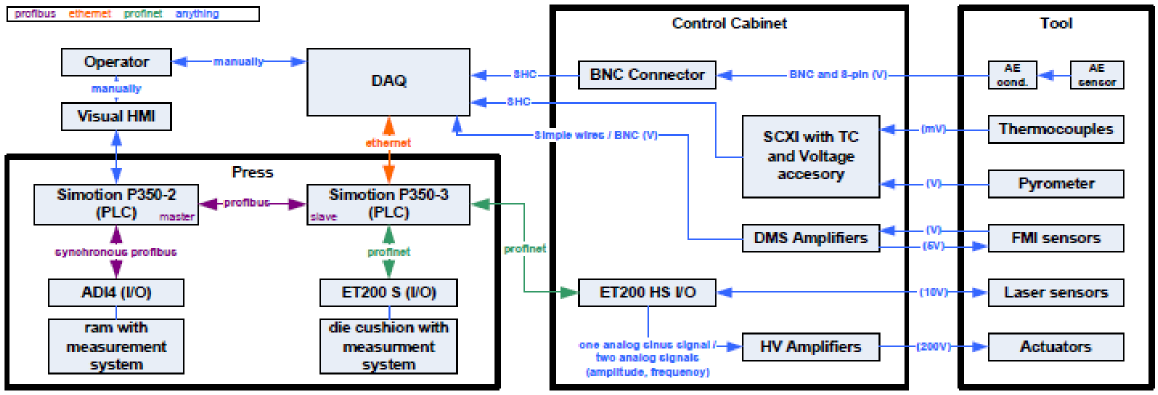
Both tooling have been designed to integrate all necessary sensors that are requested to get a lot of deep drawing process information and the energy map of the part as well as actuators to extend the margins of set parameters.

Control and Measurement Interfaces

Data mining activities, required for the Energy Control System, are very dependant on data quality and correct identification. Where time stamp it's critical for data traceability. Hence, a dedicated Data Acquisition System (DAQ) was used for sensors data acquisition by TECNALIA.

The DAQ was also integrated with the press PLC, as some of the information required for the analysis was there. For both applications synchronization a communication protocol was implemented, and a simple user interface application developed. There, some static process parameters were provided for its storage and use in the analysis.

LearnForm: Communication concept for data aquisition



Energy Control as Self-Learning Upper Level Control

The implementation of an energy control system for a deep drawing operation is based on the thermal modelling of the operation. This involves the acquisition of thermal maps of the work piece, the forming tools and the environment. The energy distribution map, as an output of the sensors acquired information, should provide information on how the other process variables, friction, forming and clamping forces, behave. In other words, how a change on one of these controlled outputs could impact in final piece quality (crack, tiny crack, scratch…) and how it could be identified (and measured) at the work piece energy model.

If these relations could be extracted, and impact on the quality quantified, then it should be feasible to identify process deviations and, hence, provide the new parameters for the next punch so that the process can be re-adjusted within the expected process window.

For the Energy Control system completion and, hence, for the self-learning concept implementation is mandatory to, somehow, know the quality of the produced part after the stroke to finally change the process parameters to fix part quality within the process window.

The use of an Artificial Neural Network (ANN) helped us to classify the quality of the part and its deviation for the process parameter quantification. For its definition and training, we have:

a) Made a characterization of the sensor signals, in order to decide which are the most relevant characteristics for the classification model.

b) Identify the significant (statistical) parameters for its consideration.

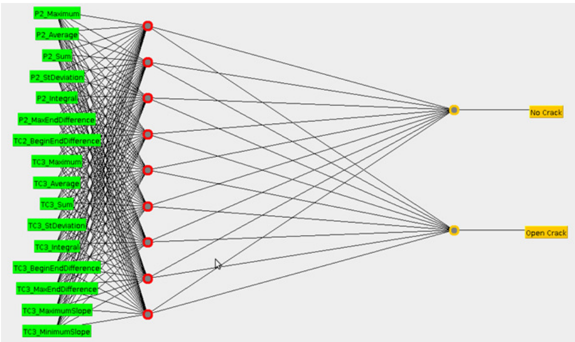
c) Configured the ANN to process each sensor with the proper characteristics that provide meaningful information for classification purposes.

As a result of the previous analysis, a Multilayer Perceptrom (MLP) Neural Network has been developed by TECNALIA for a classification problem of five categories and also for a classification of two categories (open-crack and No-crack). Where the second experiment has obviously a better result, achieving an error minor than 1%. This result has been achieved with only some trials thus, we need to make a generalization of the algorithm.

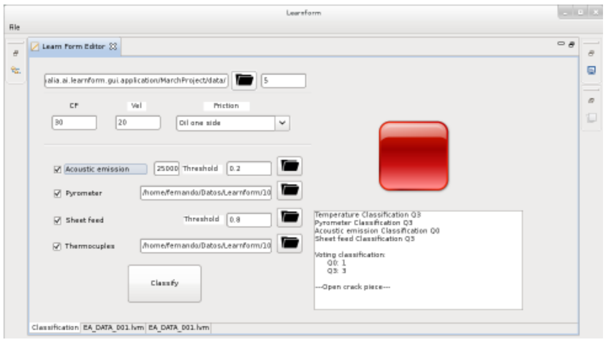
Considering the data from different workshops, we have implemented a general classifier applicable for different workshops and different conditions (different process parameters). As signals provided by thermocouples and pyrometers have a drawback, because of their low stability between workshops, our approach has been to use as many sensors, not only those related to the Energy Control System, as we have to improve the classification capability.

Therefore, a Multi-classification solution has been proposed in order to fully exploit the benefits of different type of sensors. Multi-classification is a paradigm which tries to join different classifiers with a decision function. In this case each classifier uses features coming from different types of sensors: thermocouples, pyrometers, acoustic emission and sheet feed sensor.

The multi-classification solution has been implemented in Java, EclipseRCP and Weka. The visual result of the implementation is an interface which executes the Multi-classification process providing the result for each of the classifiers and an overall classification result.



Neural Network classifier for quality classification of deep drawing process



Visual user interface of classification software tool with online interface to sensors and PLC

Potential Impact and Main Dissemination Activities and Exploitation Results

The LearnForm® Product

It is a complete **solution** for sheet metal forming process based on a mechatronic die, sophisticated sensors, and advanced self-learning control algorithms/software

It displays the following advantages:

- It is a complete solution
- Shorter setup time/try out time can be realized
- The tryout process can be simplified
- Improvement of the process stability in different environments
- Positive economic aspects (save material, save energy, …)
- It is self-learning : thanks to the sensors and fuzzy-logic control, the system adapts itself without human interaction
- No expert technological knowledge is required to handle the press while using the LearnForm solution
- Adaptable to old and new presses
- Adaptable to other applications

Quantified Data on the Dissemination and Use of the Project Results

All partners have been invited to contribute to the "socio-economic follow-up" of LearnForm by means of a Chart covering several issues relevant here, such as:

- Communication/marketing issues
- Employment issues
- Economic/commercial issues
- IP issues

Hereafter a chart gathering the figures of all partners is presented, and enables a quick and easy overview and analysis of the situation. It is followed by the charts for each partner, for a more detailed analysis. Consortium's chart is in the attachment

We expect positive effects on employment; advanced training of personnel; but also on manufacturing costs, delivery times, and product quality. As a result, although quantitative impact of the LearnForm project results are difficult to predict at this stage, it has been clearly shown (from the analysis of the above results) that the LearnForm consortium sees many positive impacts of the project and interesting opportunities for its exploitable results.

We can draw the following summary given the different data gathered from all the partners:

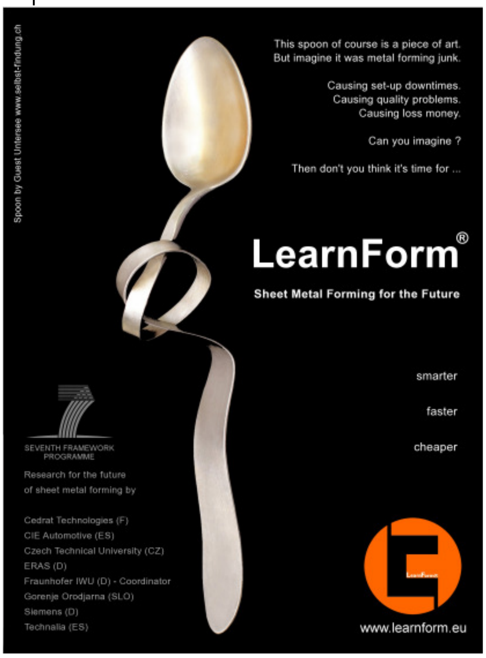
- Regarding training & employment issues, both internal & external trainings are planned. 1 PhD has been created and 2 more could be possible. 2 work placements have been opened and one more could be within the 3 years following the project. 1 job has been created and 2 more could be contemplated. 5 jobs have been safeguarded so far and 7 could be in the future.
- Regarding IP issues, the LearnForm® trademark has been registered. An application for a European patent has been filled by SIEMENS on 23/02/11. The patent is for "Vorrichtung zum Tiefziehen eines Werkstücks" (Mechanism for the deep-drawing of a workpiece)
- Fields of application: Deep-drawing process. Maybe also other machining/manufacturing processes, other sheet metal forming processes (hydro forming, hot/warm forming, forging, plastic injection, aluminium die casting, rheocasting, co-stamping of different materials in a single operation, thixoforming…)

- Potential customers: Press manufacturers, producers of stamped parts, tool makers, sensor suppliers for sheet metal forming, engineers, numeric control suppliers, automation companies
- Markets: large-scale: automotive & white goods, medium to small scale: airspace industry

The LearnForm® Image

The image of a brand and product is a very important component of the marketing, hence of a commercial strategy. The partners have decided during the Dissemination meeting in Dresden, that:

- LearnForm® is the name of the final solution
- The logo
- The motto is either "Sheet metal forming for the future" or "Smart sheet metal forming"
- Communication material has been created and made available to all the partners through the collaborative website:
    - A poster



It has been agreed among the partners that the poster will not focus on technical information but will rather act as an "eye catcher" to draw people's attention.

- A leaflet

The leaflet uses all the components of the LearnForm® image: name, motto, logo, eye-catcher, but it also gives technical information and customer's benefits.

- Video : A one-minute promoting video could be developed
- The LearnForm® website is regularly updated www.learnform.eu
- Fairs/conferences: so far the partners have disseminated about LearnForm® during the events shown in template A2.

SWOT Analysis

- Strengths:
  - shorter and easier tool training
  - operator replaced by autonomous control system
  - standardization of operator's knowledge

- decreased lead times in manufacturing
- increased productivity
- decreased default parts
- improved quality of drawn parts
- flexibility to adapt to changing environment conditions (demand, product type, specifications…)
- repeatability
- better holding system, hence better forming
- process control optimization
- process efficiency
- uses technologies that have demonstrated their robustness and reliability to be used in industrial environments
- tooling cost (set up tome, maintenance)
- innovative (many new ideas)
- high-tech, technological image
- strong experience of the partners in each field
- shared experience between partners
- good European coverage
- potential worldwide market

- Weaknesses:

  - only a prototype, testing not yet completed
  - far from bringing to the market
  - Nearly impossible to produce a universal autonomous control system without the necessity to tune it for different stamped parts
  - results too ambitious,
  - tests only carried out on 2 types of workpieces so no guarantee of its functionality on different ones
  - specific stamping press needed
  - tooling cost (additional components)
  - risk of process stops due to system failure

- Opportunities:

  - no equivalent solution available from competitors
  - current process highly dependent on extensive trial-and-error experiences and the operator’s experience
  - sheet metal products are a growing trend due to increasing demand from emerging countries
  - additional industrial applications to be analyzed

- Threats:

  - hydraulic market very conservative (changes in machine automation 10 to 20 yrs.)
  - Machine-tool manufacturers reluctant to changes?
  - Flexible forming process
  - Low-cost drawn products from emerging economies
  - Evolution of the existing applications