SYNTHESIS **REPORT**
for Publication

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TITLE: OMEGA "NOVEL OPTICAL SENSOR 3D MEASURING SYSTEM FOR COMPLEX GEOMETRY IN ADVERSE ENVIRONMENT

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OMEGA

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2 SUMMARY PAGE

2.1 Keywords

Qualify, Measurement, Optics, Holography, Conoscopic.

2.2 Abstract

Success of industries devoted to mass-production of structural materials and semi-finished products is very sensitive to any waste-causing factors so that in-house rejection ratios must be minimized. On-1ine dimensional control of the products being obtained by a continuous process becomes critical.

The OMEGA project (Brite-EuRam 5470) intends to solve the problems arising from the lack of real time dimensional control on steel structural mill facility products. The main objective of the project is to assess the feasibility of an on-line, non-contact, measuring system, controlling complex geometry parts in adverse industrial environments. The basic technology applied in the project is Conoscopic Holography.

A lab and a plant prototype have been developed and tested. The final one incorporates four conoscopic heads and all the auxiliary equipment to perform on-line quality control in an structural profiles rolling mill plant. At the moment, the performances of the measurements are close to the specification although some additional testing in plant conditions is required to complete the work initially planned.

Clear lines of improvement have also been identified to optimize and industrialize the system. The Consortium has agreed to extend the collaboration in this new phase of the project. previous step to the exploitation of the system in the market.

Benefits arising from implementing the technology proposed by OMEGA will impact on quality assurance since one tool will be available for controlling various products, per-forming real time control of overall dimensions in a human errors free mode. This will allow an important reduction of rejection ratios which, in the case of the rolling mill, will justify the economical investment made in the project in a short period. In addition, the introduction of a system of the type developed in the project will yield an important reduction in operating cost as well as an improvement in quality and productivity of the mill.

The technology developed in the project could be applicable in a wide range of industrial situations where the type of measurement to be made, or environmental and access requirements, make other techniques inappropriate.

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3 THE CONSORTIUM

3.1 Consortium description

The Consortium is described in table 3.1.

Organization	Country	Role
TGI	E	Coordinator
CSI	E	Partner
CDO	F	Partner
ETNOTEAM	I	Partner
TIMEAT	F	Partner
Universidad de OVIEDO	E	Partner

Table 3.1. Omega Project Consortium

The partnership structure contains a supplier of optoelectronics. CDO, a company specialized on image processing (Timeat), a software house with large expertise in real time systems (Etnoteam) and an important end-user the steel producer CSI (Corporación de la Siderurgia Integral. TGI (Tecnología y Gestión de la Innovación) is the coordinating partner and the academic support is provided by the Automation Department of University of Oviedo.

CDO (Control Dimensionnel Optique, former LeConoscope), is an SME located in Paris. which developed the conoscopic holography theory and possesses the licenses of the underlying technology. During the project. CDO provided the scientific and technological knowledge of the basic optoelectronics subsystem and implemented the necessary prototypes.

Timeat. is an SME software house located in Rennes (France). specially devoted to Industrial Image Processing and Sequence: Image Processing. In the project. Timeat developed the software modules which perform the first signal processing (raw data sw).

Etnoteam, is an important Italian supplier and developer of software products including image processing in real-time in projects of medium-to-large size. It operates mainly as developer of custom software in the following four main technological areas: A) software engineering and CASE. B) software and systems technologies. C) telecommunications and real time systems. D) information systems. In the Omega project. Etnoteam designed and developed the software subsystem and carried out the integration of the sw modules developed by the other partners.

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UNIVERSITY OF OVIEDO is a technical university, with strong relationships with CSI, the end user. UNIVERSITY OF OVIEDO, provided assisstance in many aspects of the project and was in charge of: A) the robotics associated to the equipment. B) the calibration procedures. C) the thermal compensation and user interface software modules. D) the set up and developement of system lab testing.

CS [(former ENS IDES A), the end user in the Consortium. is the largest iron and-steel industry in Spain. It owns the faci I ity (structural profiles rolling mill} which offers the real conditions of the problem to be solved (fig.3.1). Thus, it led the definition of the specifications. and the tests of the plant prototype. Specifically, CSI was in charge. of A) the detailed definition of the industrial problem to be solved. B) the installation of the prototype in plant. C) the execution of the testing activities in real work conditions. D) the technology assessment by the end of the project.

TGI (Tecnología y Gestión de la Innovación, S .A.) is a technology company created to foster industrial RTD activities within the Spanish public industrial holding to which CSI also belongs. TGI was responsible. for the coordination of the Omega project. .

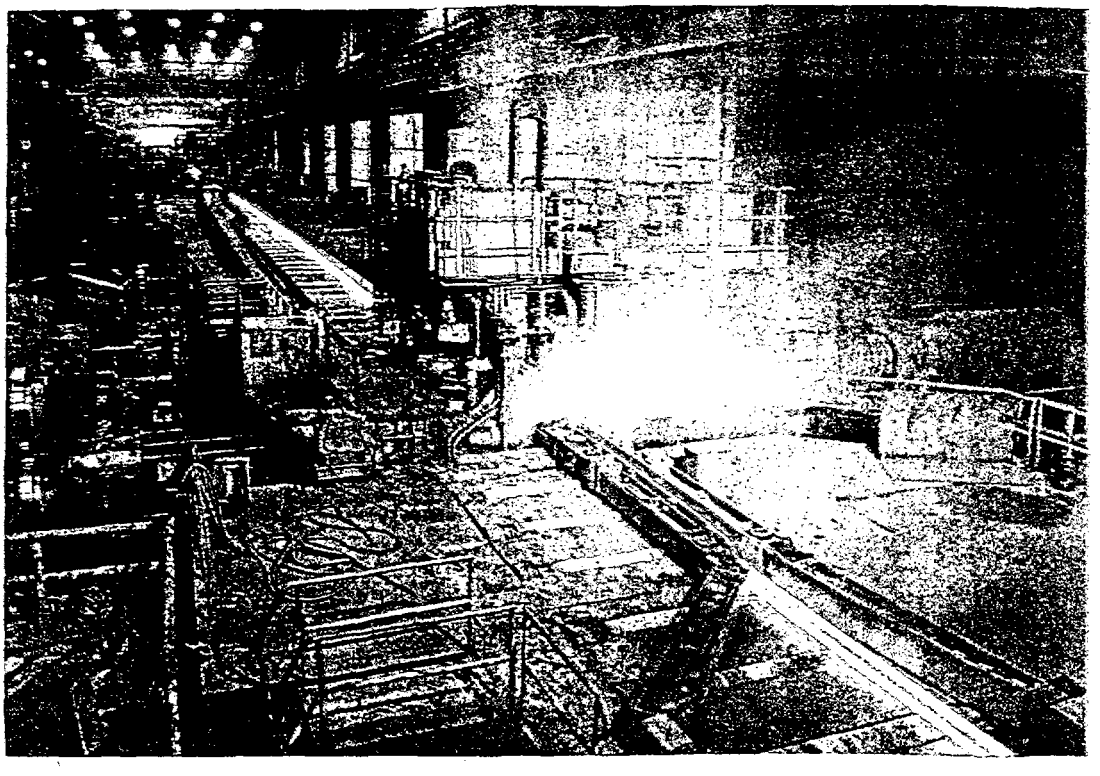


Figure 3.1. CSI's structural profiles rolling mill (Veriña, Asturias, Spain).

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4 DESCRIPTION OF THE ACHIEVEMENTS

4.1 Objectives: The industrial problem

Success of industries devoted to the production 'of massively used structural materials and semi i-finished products is very sensitive to any waste-causing factors. Generally, competence in this field is so hard that in-house rejection ratios are to be minimized. In the steel industry, as in the aluminum or plastics, processes like extrusion, lamination, etc. require rigorous application of quality control methods to reduce rejection ratios to a minimum. On-line dimensional control of the products being obtained by a continuous process becomes critical.

OMEGA intends to solve the problem arising from the lack of real time dimensional control on the products from a steel structural mill facility. Currently, this control is performed by cutting a sample which later is cooled and finally measured manually by an operator (fig. 4.1). This way, a dimensional discrepancy from specification is detected when several tons of product have already been output. All that material has to be rejected. This is a specific. costly and well defined industrial problem.

The introduction of an automatic system able to measure the profiles without interrupting the process. taking into account thermal distortions. and giving reliable information which could be used to implement a closed loop control. is the objective of the OMEGA Project. The project intends to reach its objective by means of a consistent development of an evolving vision technology, the Conoscopic Holography. This way. the basis for solving equivalent problems in other industrial activities will also be set.

In this case, the system will be developed to perform the on-line dimensional control of different types of structural profiles at the end of the rolling mill. Figure 4.2 gives an idea of the purameters to be controlled. The size of the profiles goes from SO mm. up to 600 mm., and the precision desired is 0.1 mm. for all the measurements.

A main problem in the development of the prototype is the hard industrial environment in which it must be installed, very hard in terms of noise. dust. brat. vibrations, etc. In this sense, the conoscopic head has had to meet requirements never tried before regarding adverse working conditions.

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4.2 Basic Technology Conoscopic Holography

Some other initiatives have been carried out, even in the EL' frame, trying to solve the problem mentioned above. The common denominator in all of them is the use of triangulation techniques. A new approach was adopted in the OMEGA project. The basic technology applied is Conoscopic Holography (C.H.). This technique presents an important advantage over other methods such as Interferometry, Triangulation, Dynamic Focusing, *StereosCopy,* Telemetry, etc.

C.I-i. was invented by Prof. Gabriel Sirat and Prof. Demetri Psaltis of the California Institute of Technology. *C.D.O. owns the exclusive rights* for development, production and marketing of this technology which is protected by five patents with a sixth patent now pending. The basic setup, called the Conoscope, is shown in fig. 4.3.

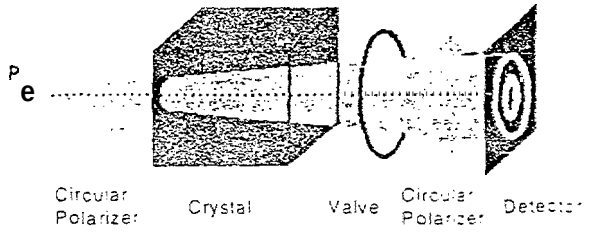


Figure 4.3. Conoscopic System

As a summary, C.H. replaces the coherent object and reference beams of conventional holography with the ordinary and extraordinary components of the same beam which pass through an uniaxial crystal. This way, some of the problems of conventional holography (i.e. the need of using coherent illumination, ultra high stability requirements, etc.) are overcome and it is possible to produce holograms using incoherent light and with a fringe period compatible with the resolution of conventional electronic devices.

The advantages of C.H. over conventional surface characterization methods are a result of the intrinsic characteristics of this new technique:

- Colinearity: the conoscopic system are inherently collinear and very simple. Indeed the emitted beam and the measurement part are on the same axis. This method has great advantages over triangulation methods which are not collinear and therefore are less accurate and have trouble measuring moving objects.

- Stability. Since both beams propagate through the same path, conoscopic holography is very stable in contrast to conventional interferometric methods. Industrial environments.

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Figure 4.1. Off-line quality control process

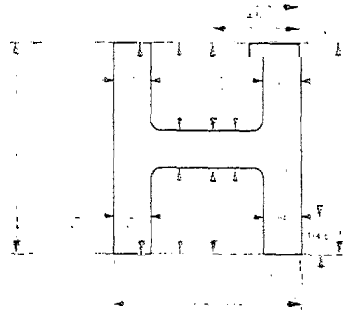


Figure 4.2. Dimensional parameters to be controlled

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vibrations or other disturbances do not perturb the measurement more than in normal imaging devices. Furthermore, it is easy to compensate for temperature effects. Conoscopic measurement systems have no moving parts and are therefore less expensive and more reliable than dynamic focusing systems.

- Compatibility to optical systems and incoherent sources. Incoherent light sources. in particular natural scene lighting and fluorescent lighting may be used, furthermore the surface measured may be preferably diffusing but some setups are able to *use* reflecting surfaces.

- Compatibility to electronic detection devices resolution as CCD camera or I D CCD array.

4.3 Omega Prototype: Subsystems

4.3.1 Conoscopic heads

The conoscopic heads are the key element in the Omega system. The industrial prototype includes four cameras each one covering an angle of 90° around the measured profile. Fig.4.4 is an schematic representation of how the corresponding part of the image of the profile is captured by the camera.

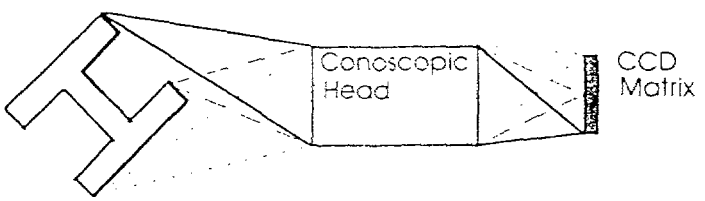


Figure 4.4 Optical setup in the profile dimension

The conoscopic head converts the incoming light from the object to be measured into an interferogram, that is recorded by a CCD camera. One point in the profile corresponds to one line in the sensitive matrix. This line yields through its number, the transversal position of this point, and through its contents the longitudinal distance.

Initially the OMEGA system was designed as a passive measuring system using the light naturally emitted by the very hot beam. However the temperature of the beams is not a fair constant during the production activity. So the consortium turns early to an active system using a dedicated laser light source. The power in the current system is ~2W with a laser pulse duration of 200 ms.

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The optoelectronic head contains some adapted objectives, an specifically developed conoscopic module and a linear laser diode array as the light source (pulsed 10W at 800nm). l-he. whole optoelectronic subsystem is covered by a sealed enclosure in order to provide a first barrier to protect them from externeal aggressions: dust, humidity, heat, mechanical shocks, etc.

The output of the cameras are four conoscopic images of the scene, that are sent to a computer, that processes this information in three stages (raw data processing. shape data computation and thermal distortions compensation) and presents the final measurements to the user.

4.3.2 Positioning device

In the industrial prototype the cameras are mounted on a positioning structure, called C frame. that will also incorporate other essential mechanical elements (blowers for dust and water, cooling system. temperature measurements, etc.) and will provide protection against heat and vibrations, etc. Within the mill. the prototype is installed near the circular saw at the end of the process. where the rolled beam is stopped and clamped to be cur. The measurements will be taken in the short time when the beam is clamped and before it is cut.

The positioning device (fig.4.5) is composed of a fixed structure and a mobile part, where the cameras are mounted. that will be able to be retired from the mill for maintenance purposes. Necessary elements inside the mobile part are: the four cameras, two air conditioning systems to cool them (the profile arrives at the saw at temperatures near to 800 °C), thermal sensors to control the internal temperature (cameras calibration is sensible to thermal changes), pyrometers to measure the profile's temperature (in order to introduce dimensional corrections), and blowers (to eliminate dust from the cameras objectives, and to eliminate water from the surface of the profile).

4.3.3 Computer subsystem

Apart from the basic processes associated to' signal acquisition, computation and presentation of measured results, a basic control of the mechanical elements in the system (blowers, cooling, movement, etc.) is needed. To solve this problem the design includes a computer subsystem (fig.4.4) composed by two separated PCS. connected in a network. The first one is an industrial PC. including a PLC slot, that is mounted in the positioning structure and controls all elements of the acquisition and signal treatment processes. The information is then sent to another PC which is placed in the control room of the mill. This PC provides the interface with the operator of the mill allowing him to introduce commands and giving him the results of the measures in different formats and on various output devices.

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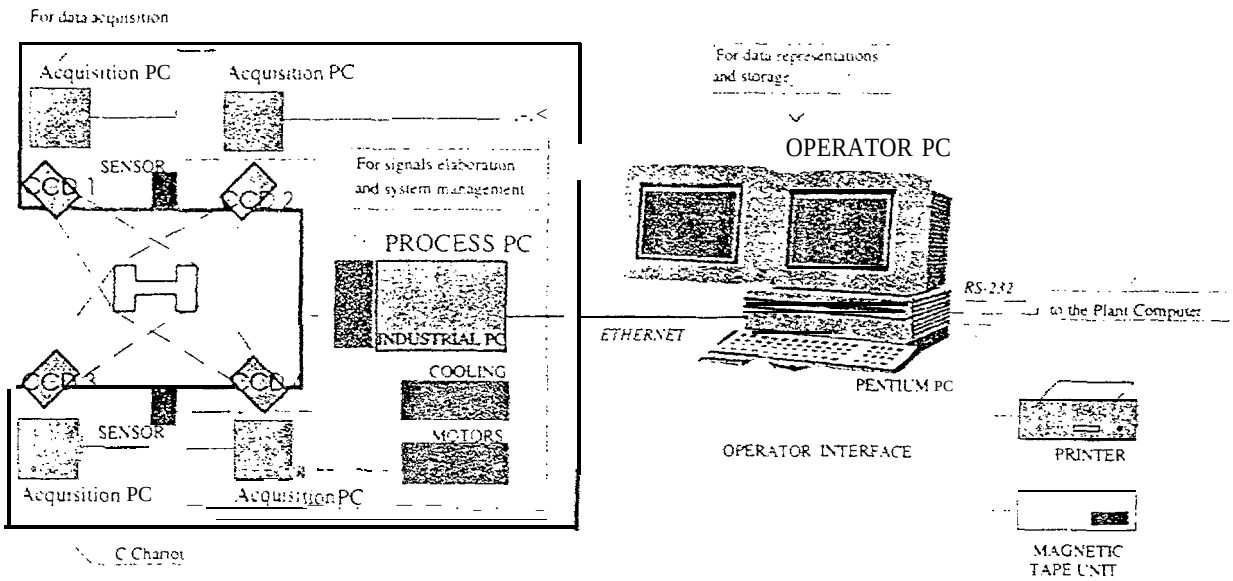


Figure 4.5. OMEGA Computer hardware components

The introduction of 4 Acquisition PC boards was decided in order to reduce significantly the data acquisition and calculation time. In the future, this equipment will be replaced by specific processing boards which will help reducing further on processing times.

4.3.4 Software subsystem

Together with the conoscopic heads, the software is a key element in the Omega system. It processes the information furnished by the Optical subsystem and the other sensors, in order to provide the dimensions in the profile of the beam, an indication of their validity and accuracy and some signals regarding the status of the whole OMEGA system. It also has to ensure all the communications among the components and with the Plant Computer, and to permit the storage, analysis, and reporting of all data collections and statistics. Finally it provides the interface with the user, presenting results and receiving operation commands from him.

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4.4 Signal processing and profile dimensions computation

4.4.1 Raw data processing

As mentioned above, the output obtained from conoscopic heads are complementary hologram images. The first goal of the raw data processing is to convert this images captured by a a CCD into a first set of related to distance values, although not yet in correct units or even linearly dependent on distances. The process, based on a fast Hartley transform (fig.4.6), is carried out for the four conoscopic heads.

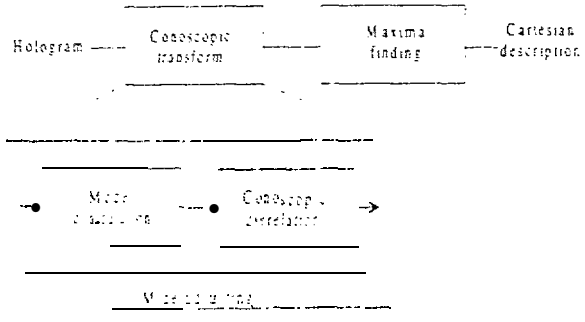


Figure 46. Raw Data Processing synoptic

As a second step. and in order to reconstruct the complete section of the objet{ and obtain a first cartesian description of the object. a co-ordinate transformation is applied. This transformation is defined by the. so-called transfer function of the camera and actually consists in applying to the initial distance values an scale transformation and a subsequent rotation and translation of coordinates. The parameters [o perform these transformations are obtained as a result of the calibration routine.

The calibration process provides the parameters to establish the functional relationship between points defined in the 3D real world coordinate system where the measure is taker-i. and their projections in camera coordinates (fig. 4.7). That is. it defines the parameters to perform the computational process described in the previous point. This relationship is called the calibration file. With the calibration file and the projections of the captured points in the cameras, it is possible, at measuring time, to perform the backward conversion and work out the corresponding real world coordinates and the desired measures.

This completes the work of the raw data processing software [he output of which is four sets of 2D coordinates, defined in a common cartesian system, and formed by the points composing the partial profiles captured by each CCD.

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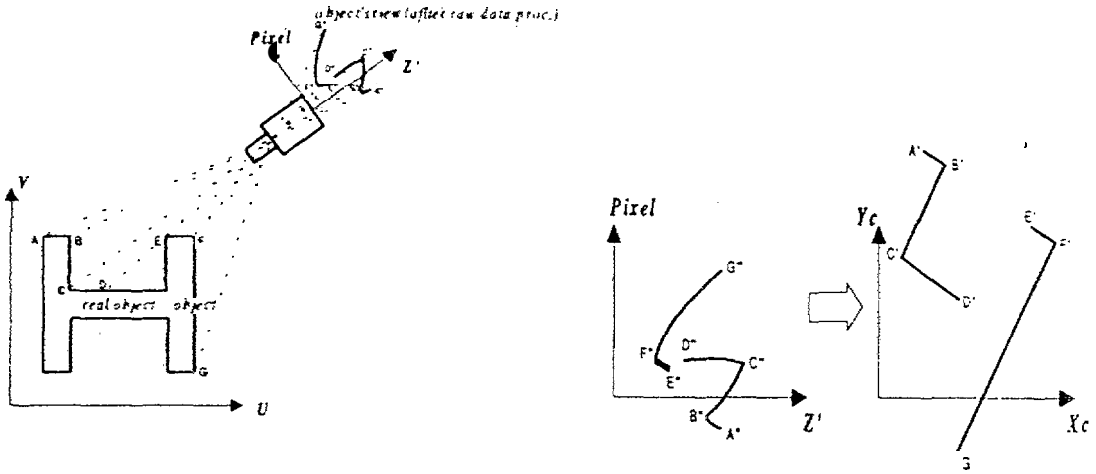


Figure 4.7. Calibration system: transformation of coordinates system

4.4.2 Shape data computation

The objective of this computation step is to translate the standard Cartesian descript ion provided by the raw data processing into a complete operational description of the profile measured by the Omega system. The shape data compilation software is basically structured in the following functions:

- Region limit identification
- Template matching (profiles composition)
- Data fitting and parametrization
- Hot measurements extraction

The result is a complete definition of the whole measured profile and its characteristics parameters (Highs. thicknesses. etc.) as defined by the end user.

4.4.3 Thermal distortion compensation "

This is the last stage in the computation process. It has the objective of calculating the final measures to be expected from the profile when it is cooled down to room conditions (the temperature in the profile when the measurements are taken is about 800° C). The input for the calculation are the values obtained from the Hot Measurements Extraction and the information

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received from pyrometers describing the distribution of temperatures in the measured profile. The values obtained from this last calculation constitute the final result of the measuring process in the Omega system.

The temperature correction process consists of the following three steps:

- Estimation of (optimization) the parameters of the exponential curve which defines the temperature distribution along the different parts of the beam (web and flanges).
- 'computation of the temperature distribution along the whole beam using the estimated parameters.
- Computation of the estimated contraction of all measurements of the beam by means of numeric integration of the differential contractions of each part of the profile.

All these calculations are per-formed by a module appropriately calibrated according to existing data as to the thermal distortion of profiles of different sizes subjected to non-uniform temperature distributions.

4.5 Results and validation

Two type of tests have been de-me:

- Functional and repeatability tests, that ensure that each hardware and software component are performing correctly, and mainly if the overall functionement is correct, (as each component is furnished by a different partner, in this case this kind of test is *very* important).
- Measurement tests, that are the core of the prototype. Accuracy of the measurements obtained, robustness and repeatability were tested. Figure 4.8 shows the temporary set up prepared for the. first, preliminary, plant testing.

All the functional tests performed have shown a correct behavior of the system in normal working mock. Also, the timing of the cycle has been measured Table 4.1 shows the approximate timing for each process (based on Pentium-90 MHz computers)

These processing times are high with reference to the specification. Nevertheless, they are not taken very much into consideration at this moment because this parameter is very much improvable by means of software optimization and upgrading of specific hardware components now used in the prototype (processing boards and CCD cameras).

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Acquisition of the 3 images (plus. minus, background)	**8 sec.**
Sent of the images to the computers	**15 sec.**
Raw data processing	**30 sec.**
Coordinate conversion	**1,5 sec.**
Sent of partial data to the process PC (Ethernet)	**0.2 sec.**
Measures extraction (hot)	**1 sec.**
Temperature correction	**O sec.**
Sent of measured data to the operator PC (Ethernet}	**0.1 sec.**

Table 4.1. - Process duration.

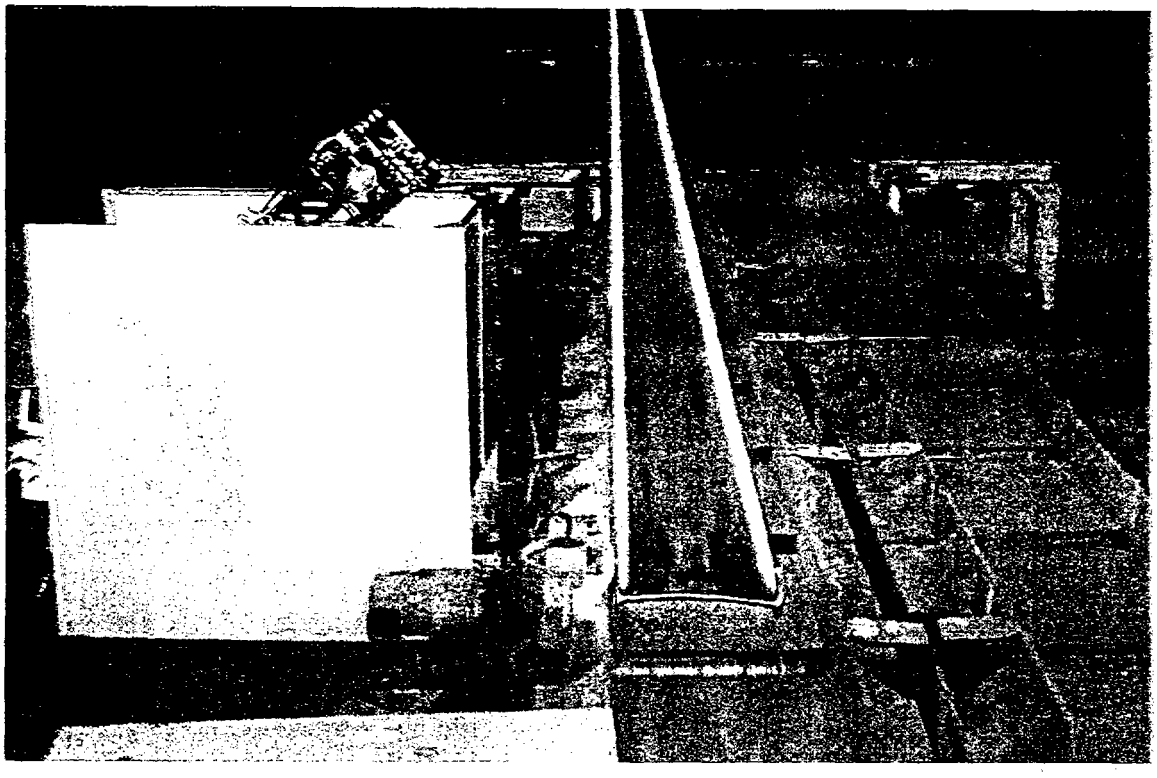


Figure 4.8.- Preliminary plant testing carried out before the positioning device was installed in the mill

Regarding measurement tests. Figure 4.9 shows the reconstruction of a two representative real profiles (HEB-160 and HEA-100). Table 4.2 presents the corresponding numerical values for different profile sizes.

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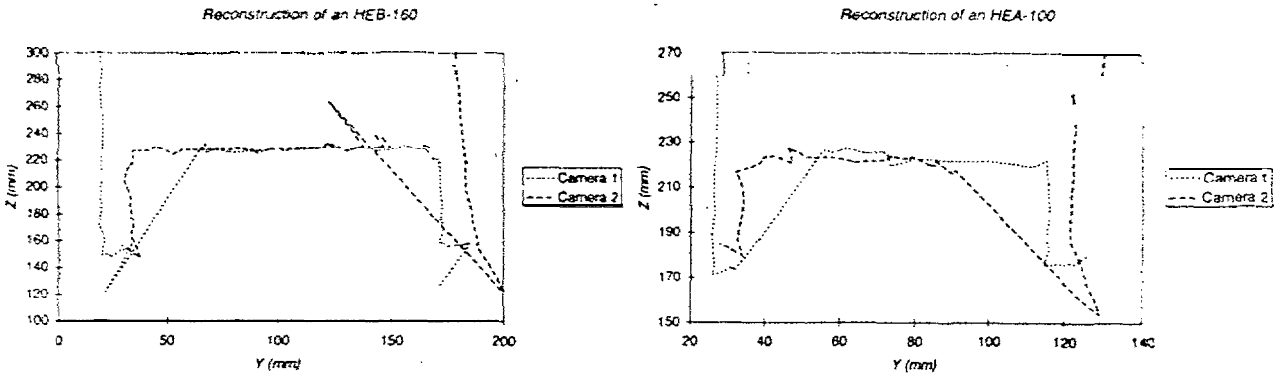


Figure 4.9.- Partial reconstruction of profiles from two cameras setup

Type of	b1			d1			d3			e		
profile	real	mean	std dev	real	mean	std dev	real	mean	std dev	real	mean	std dev
HEA-100	101.1	100.95	1,41	47.7	47.77	1.04	48.1	48.14	1.12	5.3	5.52	0.73
HEB-160	159.4	159.53	0.77	75.3	75.09	0.69	75.9	75.92	0.51	8.2	8.17	0.42
IPE-180	91.1	91.28	1.35	83.0	83.42	1.12	82.6	82.44	1.06	5.5	5.42	0.50
HEA-400	298.6	298.30	0.55	142.7	142.72	0.53	144.0	143.88	0.50	11.9	11.75	0.45

Table L?.- Measurements of profile parameters taken from different profiles.

In general, the results can be considered very positive with reference to the specification deviced by the end user. However. some problems have been detected and are currently being treated:

- A non-compensated distortion efeect makes straight lines to appear as curves.
- The extremes of the flanges have a few points very distorted because of the effects of light in that specific zones. As a result, b_i and d_i dimensions are measured with more difficulty, especially for profiles with small wings thickness.

In order to solve these problems it is necessary to complete the testing work. Anyway, the partners consider that the results achieved, being preliminary, are good enough to confirm the validity of the technology developed with the project and can be wry much improved optimizing the system now available. This opinion is also shared by the personnel in charge of quality control at the mill where the system has been installed.

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5 EXPLOITATION PLAN

The business potential of the Omega system is out of doubts. As a result of the dissemination activities carried out along the project, the Consortium has received many expressions of interest coming from steel companies and not only from the Europe.

As a result of this, the Consortium has defined three main steps in the process to industrialize and commercialize the Omega system:

- The first step is to complete the development work initiated in the project: that is. to extend the plant testing and complete the integration of the plant prototype so that at the end of the work it can be operated by the staff of CSI's mill. The milestone for this is set by the end of July or, at latest, by the begining of September this year. Then the prototype will officially be presented to the people responsible for the management and operation of the rolling mill.

- Once the first prototype is delivered and its performances absolutely confirmed. A phase of optimization and industrialization of the system will be open. To introduce the OMEGA system into the industrial market. a more robust. compact and reliable equipment is required. The objectives of this phase will be to optimize the system from the point of view of its assembly, operation and maintenance. Aspects like the upgrading of the hardware system (introduction of specific DSP boards) or the optimization of the software are considered for this phase which is expected to have a duration of around six months.

- The third phase (to be run in parallel with the previous one) is the dissemination and open commercialization of the system. initially through the steel industry. and starting with the preliminary contacts already made. Naturally, the first client for the Consortium would be CSI itself which, only in its structural profiles rolling mill, is interested in installing two Omega systems. One would replace the prototype now installed for final quality control, The second would be installed at the first part of the mill (roughing mill), with less accuracy requirements. and would be used as a first control of mill set up. Moreover CSI would be ready to show the system. in working conditions at its plant, to potential clients which would be a very convincing marketing argument.

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6 REFERENCES

6.1 Publications resulting from the project.

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