XVIII IMEKO WORLD CONGRESS
Metrology for a Sustainable Development
September, 17 – 22, 2006, Rio de Janeiro, Brazil

FORMA3D – AN EDUCATIONAL PROGRAM FOR THE QUALIFICATION OF TECHNICAL PERSON INVOLVED WITH COORDINATE METROLOGY IN BRAZIL

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Abstract: The fast dissemination of coordinate metrology in Brazil has not been followed by the necessary qualification of human resources. Because of its flexibility, complexity and great integration with the whole manufacturing system, Coordinate metrology demands an in depth qualification of the technical person. This paper describes an educational program developed by professionals from Universities and Industries in Brazil for the qualification of technical person involved with coordinate metrology. The program, called FORMA3D, has been active since 2004 with more than 100 3D Metrologists graduated. The motivations, the technical background, the pedagogical structure and the preliminary results are related in this paper.

Keywords: Coordinate Metrology, Education in Metrology.

1. COORDINATE METROLOGY IN INDUSTRY

Coordinate Metrology is the most powerful technique of dimensional metrology in industry and has been widely used. Its qualities regarding geometrical capability, automation, flexibility and accuracy have motivated more and more industries to employ it all phases of the product life cycle.

At product and process developments, and quality control of the production, coordinate metrology plays an essential role for the quality of the product and the productivity of processes. In the development of the product, the 3D measurement is used in tasks as (figure 1):

- Digitization of models
- Analysis of prototypes
- Investigation of problems
- Certification of parts from suppliers

Fig. 1 - Measurements in development phase [1]

In the phase of development of the serial processes, the Measurement is used in activities as (Figure 2):

- Tooling approval
- Approval of devices
- Analysis of first sample
- Adjust and validation of processes

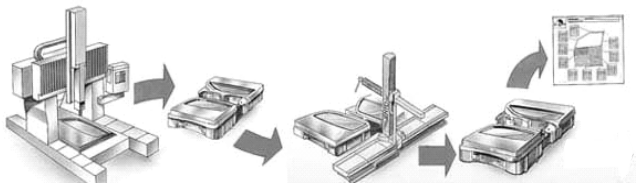

Figure 2 – Coordinate metrology in process development

Finally, in the phase of serial production (figure 3), coordinate metrology is a key instrument to evaluate capability of machines, to maintain the processes under control and avoid losses, keeping and improving the quality of components.

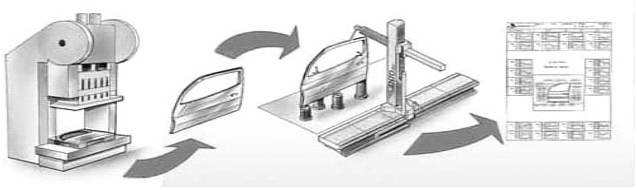

Fig. 3. Coordinate Metrology in the Control of Production

2. THE REQUIREMENT OF THE METROLOGICAL RELIABILITY IN MEASUREMENT PROCESSES

In all those phases, it is evident the necessity of great metrological reliability in the results. Wrong measurements are the cause of countless problems in products and inefficiency in processes. The 3D measurement is powerful

but, if not correctly used, can be problematic. There are many parameters to be adjusted in the measurement process and several sources of uncertainty influencing the result.

In all those phases, the coordinate metrology has the basic objectives of avoiding that dimensional problems goes ahead, and also of supplying precious information that will indicate the corrective action to be taken for the solution of those problems. It is the coordinate metrology that approves or it reproves a injection mold, or a supplier, or a lot of pieces. Its influence in aspects as the development time of a product, the costs of production and the functional performance of a component are enormous.

It is, then, evident the great need that the results of the measurements are reliable, in other words, that its uncertainty is small when compared to the tolerances of products and processes.

To illustrate this, the figure 4 display the result of a simulation of losses (for millions of pieces) caused by errors of classification in a serial process, compared to the increase of the measurement uncertainty. The tolerance of the measured piece is of ± 0,02 mm and the production process would have a Cpk of 1.33 without the influence of the measurement.

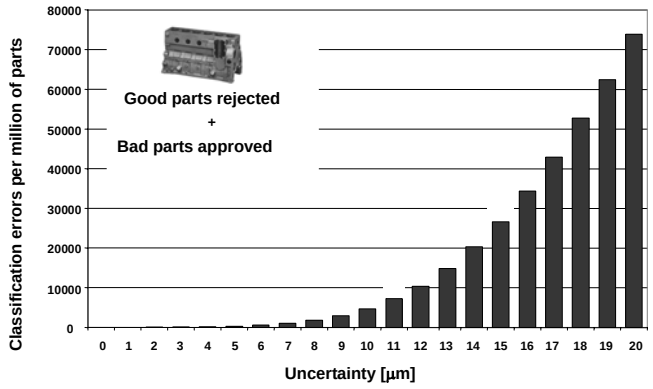

Fig. 4 - Effect of the Measurement Uncertainty of in the serial dimensional control

In the area of coordinate metrology, this reality is found in a lot of companies. The Technology is very powerful, but also quite dangerous. The technological sophistication of the measuring machines and softwares has generated some myths regarding to the errors of measurement, such as:

- The measurement uncertainty is always very small and appropriate for any piece;
- The operator doesn't have any influence on the results, as the measurement is automated;
- The acquisition of the machine is the only investment necessary to use the technology.

Obvious these are false. As any other measurement method, the coordinate metrology is not perfect. In fact, in our material world nothing is perfect. Different influence factors (figure 5) cause imperfections to the measurement process increasing the measurement uncertainty [2].

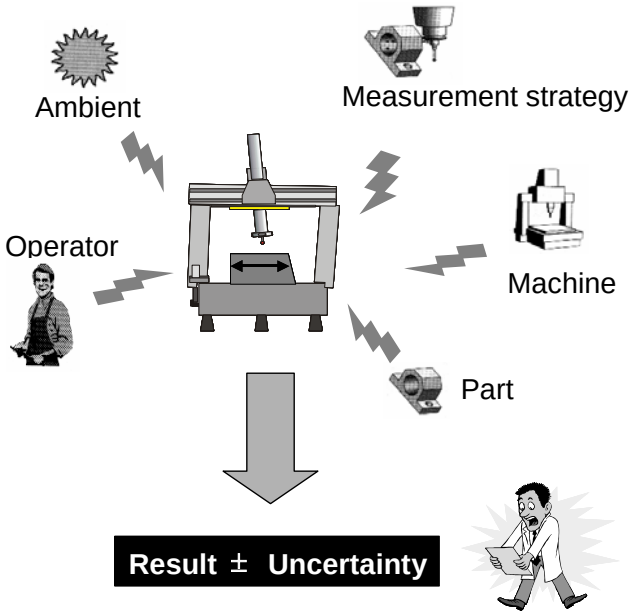

Figure 5 - influence Factors in the Measurement 3D [3]

In that context, the qualification of technical person is fundamental for the obtaining of reliable results.

3. QUALIFICATION OF HUMAN RESOURCES IN COORDINATE METROLOGY

Although the coordinate metrology is quite automated and computerized, it depends on the operator skills to define the whole measurement strategy. In coordinate metrology the measurement strategy is particularly more critical, because some characteristics intrinsic to the method. Many are the parameters that can provoke measurement errors and incorrect diagnostics about the conformity of products and processes.

Then, besides being competent in the operation of the machine and measurement software (operational qualification), it is necessary a *metrologic qualification*. The sum of the operational qualification with the *metrologic qualification* enables the professional to carry out their activities with efficiency and reliability.

However, the situation in Brazil and in many parts of the world is deficient. The very fast dissemination of coordinate metrology in industry was not accompanied by the offer of metrologic courses dedicated to 3D measurement. Usually, the qualification programs are directed to the operational qualification, supplied by the manufacturers of the coordinate measuring machines.

As a consequence of this lack of a greater metrologic background, it is often the existence of operators that are expert in the machine and measurement software, but ignore

basic criteria to avoid measurement errors, or how to estimate the measurement uncertainty of the results. Unfortunately, in many situations the operator is the weak part of the measurement process.

The persons employed in the measurement operations should be competent, appropriately qualified and well informed on the whole process in that the measurement is inserted [4].

Competent and well trained people, that understand the principles involved in the measurement, not only measure with more efficiency and accuracy, but also tend to be more motivated and to accept the responsibility more easily for challenges that improve the quality and reliability in the measurements.

In the coordinate metrology this is particularly critical, because some intrinsic characteristics, such as:

- Measurement essentially mathematic;
- Sophisticated equipments;
- Computerized and automated operation;
- Intense integration with other areas of the company;
- Pieces usually of higher value;
- Geometries complexes and tight tolerances;
- Great variety of geometries;
- More complex drawings;
- More complicated measurement tasks;
- Etc.

From the operator of a coordinate measuring machine is required not only in the operation of the machine, but a series of activities involved in the quality control process. These are attributions usually demanded of the technical personnel of the measurement 3D:

- To participate, in an environment of simultaneous engineering, of the development of the products and of its geometric specification;
- To understand the drawing of the piece and the geometric specification (dimensions, tolerances and references);
- To establish correct measurement strategies to the requirements of the piece;
- To operate the machine and the measurement software efficiently, exploring their full potentialities;
- To apply careful procedures to preserve the reliability of the measurements and the measuring machine;
- To evaluate the reliability of the measurements and to verify the correction of its uncertainty compared to the tolerances of the product;
- To analyze the results and extract useful information for the correction and optimization of processes and products;
- To interact with teams of quality assurance to indicate dimensional non conformities and propose solutions.

Because of this, besides being competent in the operation of the machine and of the measurement software (operational qualification), there is the need of a wide qualification (metrologic qualification). The sum of the operational qualification with the metrologic qualification provides to the professional the necessary background to carry out with efficiency and reliability their activities (figure 6).

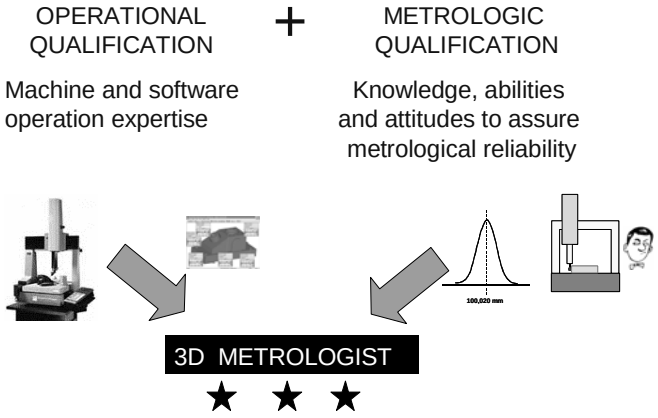

Fig. 6 - operational Formation and metrológica

However, the panorama in Brazil and many parts of the world is different. The very fast spread of the coordinate metrology was not followed by the offer of metrologic courses specific to the measurement 3D. The training courses offered are basically the operational qualification, supplied by the manufacturers of the coordinate measuring machines.

In this aspect, the metrologic qualification is practically inexistent. As a consequence, is very frequent the existence of operators that dominate the machine and the measurement software very well, but that ignore basic criteria to avoid measurement errors, or that don't know how to estimate the measurement uncertainty. In other words, they pilot the equipment very well, but the results of the measurements can present a high uncertainty. There is therefore a difference between a "Pilot of measuring machines" and a "3D Metrologist".

This reality is not exclusive of Brazil. In several of the industrialized countries of the world the reality is similar. There is not a formation directed for the function of 3D Metrologist, in spite of the great presence of that activity and its great importance inside many productive chains**.**

3. THE EDUCATIONAL PROGRAM FORMA3D

Motivated by the need of metrological background to the technical persons involved with coordinate metrology in Brazil, a group composed by specialists of Faculties and Industries have idealized and structured an educational program dedicated to the area of 3D measurement: FORMA3D.

FORMA3D is a training program focused in the knowledge and abilities necessary to the technical personnel

involved with coordinate metrology to carry out, with efficiency and reliability, their activities. Its main objective consists of offering a wide and independent training program for the professionals involved with the 3D Measurement in the Brazilian Industry.

The structuring of the program is multi-institutional and it was accomplished by professionals of companies and teaching institutions with up to 20 years of experience in Coordinate Metrology, knowing deeply the necessities and reality of Brazilian industry.

The first step was to analyze the Brazilian market, studying the use of coordinate metrology. Based in this observation of the Brazilian reality, the main competences and abilities necessary to the execution of the functions of a 3D Metrologist[1] were identified. This research revealed three different profiles of professionals involved with coordinate metrology:

- The professional that executes manual or automatic pre-defined measurements, having a profile of machine operator;
- The professional that, besides the previous competences, defines the measurement strategy and it elaborates measurement programs;
- The professional that, besides the previous competences, coordinates measurement rooms, interacting with personnel of engineering (products and quality) in the development of products and processes.

Based in these profiles the structure curricular of FORMA3D was built, composing three levels, corresponding to the three modules of the course, designated for:

Module 1: 3D Metrologist – Level C: Professional with competence to understand the functional principles and sources of errors of coordinate measurements and execute a measurement efficiently.

Module 2: 3D Metrologist – Level B: Professional with competence to define solid measurement strategies, to elaborate programs CNC, to evaluate the uncertainty of the measurement and to verify his/her reliability in relation to the tolerances.

Module 3: 3D Metrologist - Level A: Professional with competence to coordinate teams with operators and programmers, to participate of teams for definition of references and functional dimensions in the development of products, besides interacting with project and process specialists to correct dimensional non conformities in the pieces.

For each one of those profiles it was listed the knowledges, abilities and necessary attitudes to the efficient and reliable execution of their functions.

[1] The structure of FORMA3D is organized by competences, in accordance with the new guidelines curriculares of ministry of Education for the technological teaching. In agreement with the opinion 16/99 of National Council of Education, competence is understood as " the capacity to articulate, to mobilize and to put in action: values, knowledge and necessary abilities for the efficient and effective acting of activities requested by the nature of the work ".

Finally, based in this list of competences, it was defined the technical contents, the didactic materials, evaluation system, besides other operational aspects of the course. FORMA3D was, in that way, structured by competences, being in accordance with the most current guidelines of Brazilian federal council of education. Figure 7 shows the whole process of FORMA3D structuring [5].

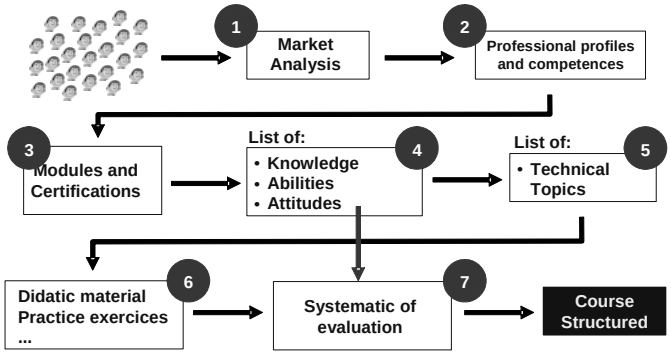

Fig. 7 – Activities in FORMA3D structuring

The evaluation of each Module is based on the defined competences for each level of the course, and not only on the subjects. With this systematic, more than to know if the participant knows statistics (content) or not, it is evaluated its capacity in evaluating the metrologic reliability of a measurement process (competence).

The table 1 displays the list of each student's evaluation, containing the competences to be proven for the module 1.

Table 1 - Competences evaluated in the Module 1

Student: XXXXXX	
Personal Competences (attitudes)	**Evaluation**
Autonomy	
Cooperation	
Criativity	
Iniciative	
Leadership	
Quality of work	
Technical Competences	**Evaluation**
To know the foundations of Metrology and its insertion in manufacturing processes	
To know coordinate metrology technology and its mathematical background	
To know the theoretical and practical aspects involved in the dimensional control of pieces	
To know the sub-systems that compose the coordinate measuring machine and their operation forms	
To know the practical procedures that precede the measurements	
To apply consistent measurement strategies and to process and report results	
To know the disturbing factors that prejudice the accuracy of the measurements and to practice strategies to minimize the influence of those factors on the results	

According to this curricular structure, the participants should study, in the sequence, the modules 1, 2 and 3. Once

evaluated and approved in the Module 1, he will be certified as 3D Metrologist – Level C, being able to study the next Module. The sequence of the course is visualized in the figure 8.

With that operation, FORMA3D offers to the participants a formation directed to the reality and the demands of the market, and the course is adapted to the reality of the Brazilian industry and the educational level of its professionals.

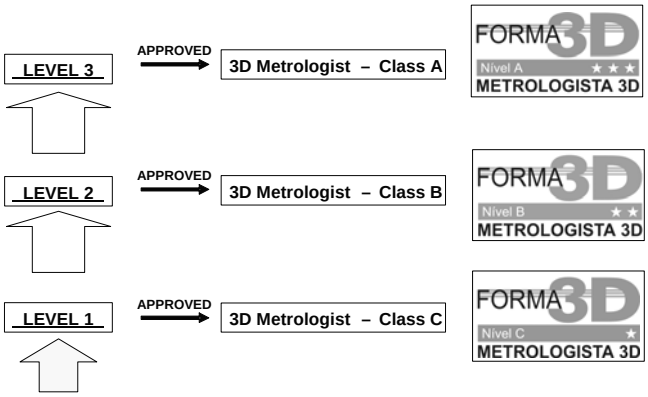

Fig. 8 - Sequence of the modules of FORMA3D

PARTIAL RESULTS

The program was implemented in 2004, promoted by Mitutoyo South America Inc., and has been executed in many companies in Brazil. Figure 9 shows some moments of theoretical and practical classes during the courses done in companies (e.g. DaimlerChrysler and Volkswagen) and at Mitutoyo Training Center.

Fig. 9 – Classes of FORMA3D

More than 130 technicians have been graduated as 3D Metrologists with FORMA3D, indicating the great necessity of metrologic training for Coordinate Measuring Machines operators.

FORMA3D began to be executed in the year of 2004. On that year the Level C of the program was offered only in company, in DaimlerChrysler Brazil and in Volkswagen Brazil. In 2005 the course started to be offered open, promoted nationally for Mitutoyo South America.

In 2006 it was also implemented the second level of the course (Level B). Both are promoted by Mitutoyo South America in its Metrology Institute in Sao Paulo.

In 2007, FORMA3D will be completely implemented with the offer of the Module A completing the curricular structure curricular of the program. Along 3 years of implementation, a total of 135 professionals of the industry, metrology laboratories and faculties were formed by FORMA3D.

A short description of these participants can be seen on figure 10.

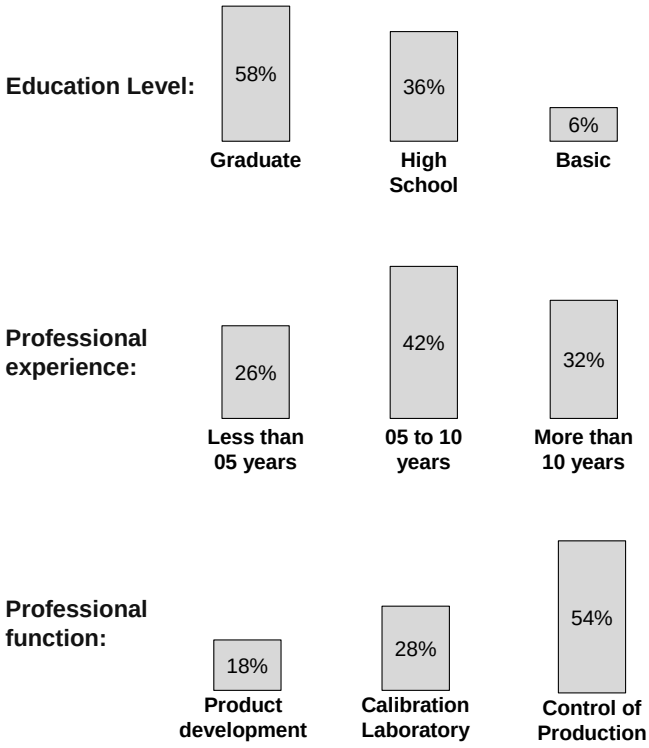

Fig. 10 – Profile of Participants of FORMA3D

At the end of each course the participants evaluate the course with opinions about technical and operational aspects. The graphs on figure 11 show the condensed results of that evaluation

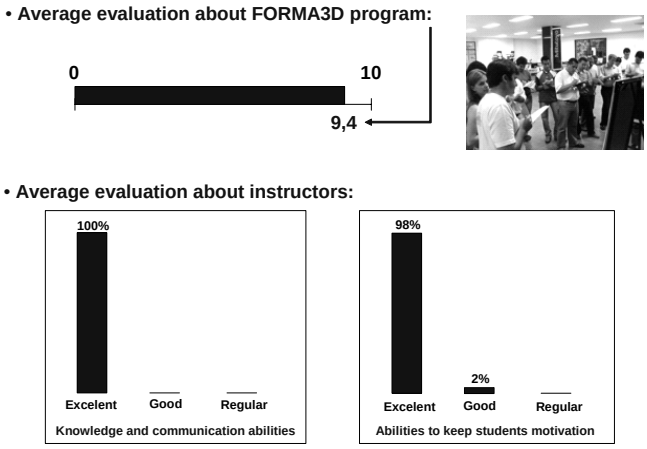

Fig. 11 – Evaluation of FORMA3D by participants

Up to the moment, the following companies in Brazil have already 3D Metrologists graduated by FORMA3D:

Actaris	**MWM**
Altona	**Pecval**
Arim	**PETROBRÁS**
Arvin Meritor	**Peugeot-Citröen**
Axe	**Rempel**
Bitzer	**Renishaw**
Black and Decker	**Romi**
Confab	**Saintgobain**
Cummins	**Sandvik**
DaimlerChrysler	**Senai**
Dana	**Sew**
Estil	**Shaeffler**
FE Fundição	**Soma**
FIAT Powertrain	**Soriani**
Honda	**Teksid**
IVECO-FIAT	**TRW**
Knorr-Bremse	**Turbomeca**
Kostal	**Unicamp**
Luk	**Unipac**
Mahle	**Vibracoustic**
Mitutoyo	**Volkswagen**
Musashi	**Wibra**

3. CONCLUSION

The metrologic background of the technical person involved with coordinate metrology is a requirement to the reliability of measurement results. More than being experts only in the operation of hardware and measurement software, it is necessary that the operators have a complete knowledge also in the metrologic aspects of 3D measurement.

In this sense, an educational program called FORMA3D was structured and has been conducted in Brazil since 2004, promoted by Mitutoyo South America. The preliminary results indicate the success of the program and its importance to the Brazilian Industry. More than 130 professionals have been graduated in 03 years and the preliminary results have demonstrated a very good acceptance.

ACKNOWLEDGMENTS

To all the people that have contributed directly and indirectly to construct and execute the FORMA3D in Brazil, and to all the companies that have believed on it, graduating their Metrologists in this program.

REFERENCES

[1] Manganelli, M. *Multifunction CMM systems speed up the design of free surface car bodies.* Mfg Maganize, Vol. 5-1, 1998.

[2] Sousa, A.R. *Garantia da Confiabilidade Metrológica na Medição por Coordenadas.* Apostila da Fundação CERTI, 2001.

[3] Pfeifer, T. *Fertigungsmesstechnik*. Ed. Oldenbourg, 1998. ISBN3-486-24219-9

[4] Metrologia – Conhecendo e Aplicando na sua Empresa. Cartilha Técnica da CNI - Confederação Nacional da indústria, 2002.

[5] Sousa, A. R. *FORMA3D – Formação Regular de Metrologistas 3D – Módulo 1*. Didatic material of FORMA3D program, 2004.