# INTELLIGENT METROLOGY, QUALITY ASSURANCE AND QUALITY MANAGEMENT AS BASIS FOR TECHNICAL DIAGNOSTICS IN GLOBAL COMPETITIVE PRODUCTION

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**Abstract:**
Intelligent metrology, quality assurance and quality management play an important and basic role in modern cost-effective customer-driven design and manufacturing. To meet market demands in present and future global industrial world, manufacturing enterprises must be flexible and agile enough to respond quickly to product demand changes. With support of artificial intelligence and modern information technology it is possible to realise modern cost-effective customer-driven design and manufacturing taking into account the importance and basic role of quality management and metrology and building up the basis for simultaneous concurrent quality assurance and technical diagnostics

These basic ideas are integrated into an innovative concept and model for modern enterprises that makes possible agile and optimal industrial production. The core part of this proposal is an intelligent measuring cell for quality assurance, data collection and data evaluation. This new approach is already realized at the Department of the authors.

Key words: Quality engineering, quality management, metrology, information technology, technical diagnostics, artificial intelligence, factory integration.

## 1. INTRODUCTORY REMARKS

Quality management and quality assurance system is a essential part in manufacturing enterprises and especially in advanced computer integrated manufacturing production environment. Such system will also play a basic and most important role in multi-functions integrated factory (MFIF). Quality management and quality assurance in individual activities of different function enterprises in MFIF must be investigated to ensure the realisation of MFIF e.g. through intelligent production systems (IPSs) based on quality management and quality assurance in MFIF to create, to realize and to present the features, such as, concurrent, interactive, collaborative, modular, integrative, learning, autonomous, self optimising and self organising functions.

## 2. ENVIRONMENT OF MODERN INDUSTRIAL MANUFACTURING

### 2.1 Possible Developments in Factory Automation and Integration

To meet high-level demands for comfortable daily life in the future, manufacturing enterprises must be flexible and agile enough to quickly respond to product demand changes, and new models and configurations for future manufacturing systems and enterprises in which are usually applied need to be investigated.

Multi-functions integrated factory is an innovative concept and model for future enterprises which is initiated with the aim to provide cost-effective, agile and optimum ways to produce customer-driven multi-functional products (MFPs) in near future, based on intelligent production technology, information highway, distributed computing environment (DCE) technology, parallel-processing computing and advanced engineering data exchange techniques [1, 2].

By means of information highway (internet), DCE and parallel-processsing technologies and advanced product data representation and exchange model STEP [3, 4], factories which produce cars, aircrafts and ships respectively, for instance, could be linked to each other to form a new kind of factory with all three functions according to needs. The product - MFP - will be produced in such a way that the different function tasks of the product should be manufactured in adequate function factory, and then assembled and integrated to realize the combination of the functions. The factory works by using its advantages of multi-functions, and produces high efficiently and agilely low cost customer-driven multi-functional products.

Such MFIF has the potential to improve industrial competitiveness, fully manufacturing automation and optimally to manufacture the customer-driven MFP worldwide. Intelligent manufacturing systems (IMS) are the basis for realization of MFIF. In MFIF individual functional enterprises are functionally and configurationally integrated with other functional enterprises located in different parts of the world to produce MFPs respectively. This concept of MFIF will come into existance in the near future and will be realised step by step.

### 2.2 Possibilities of Collaboration, Improvement and Optimisation in Production

One feature of MFIF is the use of cross-functional design and manufacturing production teams, in which engineering staffs with different skills and expertise work concurrently, collaboratively and interactively together on a MFP project.

MFIF is based on the assumption that it works only under the condition that the each single-functional factory has a possible full-scale IMS working environment and is an integration of intelligent manufacturing machines, cells and

systems. Concurrent, interactive, collaborative, modular, integrative, learning, autonomous, self optimising and self organising functions are the main features of MFIF.

The factories are reconfigurable to take advantages of agile manufacturing production for the MFPs. The MFIF provides a function-business-shared feature to create new customer-driven markets. MFIF is controlled and arranged by collaborative activities between the individual factories. Cooperative activities between all units of the factories can also be concurrently on-line carried out. Learning is carried out step to step by using the methods of evolution, and used to optimise process control. It is possible that all the systematisation knowledges for design and manufacturing (SKDM) of each factory in MFIF and all production information between ICAx systems of MFIF can be exchanged simultaneously on-line.

Failurefree concurrent exchange of production information and data, concurrent processing and executing of production processes through distributed computing environment DCE, STEP or new standard, and learning of the all collaborative production processes are also features of MFIF.

## 3.  QUALITY MANAGEMENT AND METROLOGY IN MODERN INDUSTRY

The quality assurance process will be used in all product production processes and steps in MFIF - from the design to the assembly. In order to realise automatic quality assurance and to deal with complex, variable and dynamic quality control problems of the production processes in this environment, the quality assurance system will be enhanced comprehensively through self-optimising processes thrust in the design system and all manufacturing production processes in MFIF. Quality management (QM) and quality assurance (QA) with intelligent, associative, concurrent, interactive, collaborative, modular, integrative, learning, autonomous, self optimising and self organising functions will be realized in MFIF.

### 3.1 Intelligent Computer Aided Quality Assurance System (ICAQ System)

The assembly process is the final manufacturing step for MFPs in MFIF. This process will be carried out in one of the individual factories which is near to the customer. The coupling areas of the different function parts of MFP are produced for ease-assembling, and they can be very easily combined and put together. By means of quality management and quality assurance used in all manufacturing steps - from design to assembly - it will not be necessary to arrange a final quality assurance for completed MFPs.

Learning with self improving ability makes possible the way to "Zero Error" production. A method has been developed enabling the supervision of quality in the process chain as well as its optimization by means of a knowlwdge and neuronal-network-based learning management system, and a self-learning system with neuronal networks has been realised [5]. The method can be used in MFIF and permits

to learn stepwise from deviations and to improve the processes continously.

In the ICAQ system Fuzzy Logic will be applied for Quality Function Deployment (QFD) and for monitoring and forecasting of maintenance of measuring instruments, furtheron for CAD and for a high-level knowledge-based expert system for tolerancing and quality planning.

In order to get concurrent, interactive and associative quality management and quality assurance and to optimise the quality assurance process through itself, learning method for quality assurance processes must be used, and the ICAQ components of the factories in MFIF link all process steps to each other from design model to all  other systems, so the quality management and assurance informations for MFP´s production are automatically regenerated when the design is changed or quality assurance activities are modified in one of the processes for MFP production.

### 3.2 Linking of Qality Management to Intelligent Design and Intelligent Production

In MFIF, the design tasks of MFP can be carried out intelligently, interactively, concurrently and collaboratively. The quality and quality assurance data exchange of the design work of MFP can be guaranteed by using the following technologies. Distributed design system [6] can be used for multi-functional product design and quality assurance for the design. Using DCE and parallel-processing technologies, the Engineers can work on parts of a design task, but the content of the design as a whole is a corporate resource to be managed and secured. This system makes it possible that the product designers of different function factories can work parallelly on the all subtasks of the product.

Collaborative working method in MFIF has the goal to realize not only electronic data exchange function but also an interactive working function on-line, and to work at the different places and at heterogeneous systems out the same product model. Transmission of words, figures and sound by means of multimedia will also be integrated in such interactive CAD systems which could recognise manual drawings, learn the design process of the product, even understand the natural language instruction for the design, and optimise the design process and design quality. This kind of process would be guaranteed by modern data communication technoligies and intelligent quality management and quality assurance as described in above. The design quality and quality assurance data exchange of the design work of MFP can be guaranteed by using the already mentioned techniques.

An effective use of analysis, simulation and visualisation tools gives several advantages for MFP design and quality assurance of the design. In this system the designers from the different single-functional enterprises use typically parallel-processing, virtual reality and virtual prototyping technologies, to design and simulate the customer-driven MPFs and their systematical function activities as well as to create a fully digital MFP production and programs for theentire manufacturing process.

In the ICAM system, the quality management and quality assurance information and programs will also be on-line concurrently, interactively and collaboratively exchanged and modified. It runs autonomously according to the adequate functional qulity assurance tasks and organises all manufacturing quality activities and units optimally in adequate factories. Learning the processes from the processes, the quality assurance parts of the ICAM units improve the all manufacturing process quality assurance parameters continously.

The implemetation of all these properties in an intelligent quality management and assurance architecture is a great challenge, and distributed, decentralised, self-organised and self-optimised concepts will be the main approach for this goal.

## 4. QUALITY MANAGEMENT SYSTEM IN GLOBAL FACTORIES

### 4.1 Intelligent Sophisticated Metrology and Intelligent Quality Assurance

Every enterprise in MFIF has a computer-integrated and intelligent manufacturing environment, and utilises the integrated ICAQ system with intelligent metrology with e.g. ICMM (intelligent coordinate measuring machine) to test the product or to scan and digitise complex product models with freeform surfaces, in order to obtain the digital model of the product and to modify it in ICAD system and then to create a new modified freeform surface model and CNC programs for manufacturing the end product by machine center in the workshop.

ICM (Intelligent Coordinate Metrology) in MFIF is a very important tool to solve various problems of quality management and quality assurance in MFP production especially when high flexibility and high accuracy are demanded. This way of metrology is the uptodate measuring method for complex dimensional and geometrical measuring problems (see Figure 1).

In MFIF, CNC-controlled ICMMs are connected by using networks with design and manufacturing. The goal is to mutually use the data stored in ICAD, ICAM and ICAQ systems, and to realise data parallel-processing. For the concurrent production and the system, it is suitable to use off-line programming technique, through which CNC inspection programs can be worked out without using the CMMs and the products. By means of this technique, the quality assurance data and inspection NC program for ICMMs can be simultaneously generated during the product design.
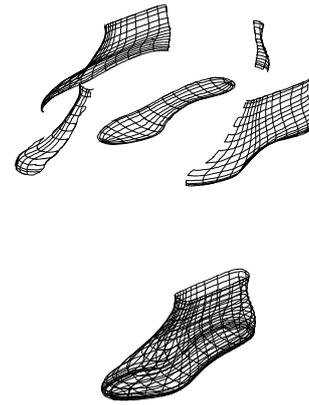


**Fig. 1.** Complex dimensional and geometrical measurement model based on coordinate metrology.

Because of world wide needs for customer-driven MFPs, a global concurrent quality assurance system must be used with the support of internet and parallel processing computer technology. Internet makes it possible to establish a global quality assurance information highway for simultaneous on-line MFP quality assurance data exchange in MFIF environment, nd to interact with suppliers and customers world wide.

Off-line programming for ICMM in ICAD system and in special programming software is the basis for simultaneous quality assurance in the individual enterprises but also in global MFIF. Many off-line programming packages as well as ICAD/ICAM/ICAQ system architechture are typical combinations in the integrated factory. ICAD/ICAQ data communication technique will be widely used in MFIF. On the basis of computer aided measurement technique and especially coordinate metrology quality management is integrated into the production information network.

An off-line programming package based on 3D-CAD model that represents nominal data of products can be used for the application. The probe configurations can be selected through the created probe database. The operator can call all regular element measuring functions and the actual data evaluation functions, using main dialog menu of the package. On this basis measuring programs and the probe paths can be simulated, edit and optimised. During the simulation a CNC measuring program is generated in a specific format. Additionally a collision control function is realized through simulating the measuring processes on the computer monitor.

### 4.2 Application of Optoelectronic and Nanotopographic Methods

Besides coordinate metrology modern optoelectronic methods are important measurement tools in computer integrated production plants and also as basic tools for quality management and assurance activities in MFIF. Their efficient use and correct calibration are crucial requirements for quality management in this environment. Figure 2 gives an overview on optoelectronic methods [7] for dimensional and geometrical measurements.
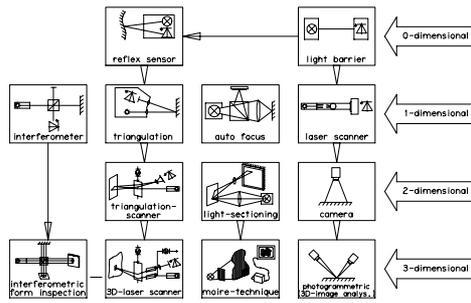
**Fig. 2.** Optoelectronic measuring methods, overview.

Presently exists the general development from microtechnology to nanotechnology. Nanotechnology describes new innovative manufacturing technologies, finishes, tolerances and especially measurement technique and instrumentation in the nanometer range [8, 9, 10]].

In persecution of this aim since about 1982 new high resolution and high precision measuring devices have been developed, especially Scanning Tunnelling Microscopy (STM) [11] and Atomic Force or Scanning Probe Microscopy (AFM, SPM). For highest demands these methods make it possible to explore atomic structures and in general very accurate and small industrially produced parts and structures [12]. Figure 3 shows a 3-D image topography of a sample surface of a copper alloy "atomic" structure.

It is emphasised, that in this respect applications in micro electronics do not stand in the focal point. Rather instruments of mechanical engineering and particularly precision engineering are addressed in the first hand. Extremely high accuracy demands deposit presently already at highly developed instruments for everyday use as there are VCRs or CD-players and in the sensor technique in automotive engineering and even in the home appliance if we think on one-hand mixing taps which demand ultra precision form tolerances.
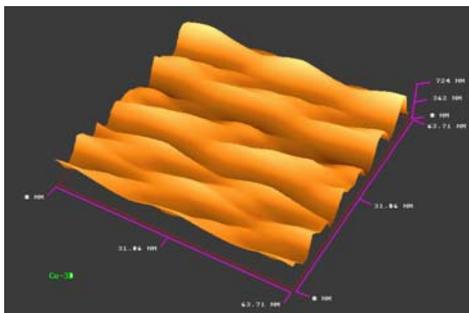


**Fig. 3.** 3-D Image Topography of a Sample Surface of a Copper Alloy Atomic Structure

## 5. PROPOSED CONCEPT FOR AN INTELLIGENT QUALITY ASSURANCE CELL

For the intelligent flexible automation of quality management and assurance, data collection and evaluation

in single functional enterprises an intelligent measuring cell (IMC) or intelligent quality assurance cell (IQAC) is proposed. With such a system the following tasks can be solved:
- automatic intelligent measurement by using CNC measurement programs,
- off-line CNC programming of measurement devices,
- automatic changing of workpieces,
- automatic probe changing,
- automated evaluation of measuring results.

Figure 4 shows the principal structure of such an intelligent measuring cell or intelligent quality assurance cell according to the above given definition which is already partially realized at the authors' Department. It consists of a series of devices and components:
- a local area network of various PCs especially for ICAD, ICAE and ICAQ evaluation,
- a precision intelligent CNC dimensional measuring instrument with control computer,
- a probe changer with interface and control computer,
- a robot for workpiece manipulation,
- various measuring instruments, for instance a small CMM and other devices,
- a scanning probe microscope to evaluate surfaces in the submicrometer and atomic range,
- printers for data and graphic output,
- database systems for construction data, measuring results and quality data etc.
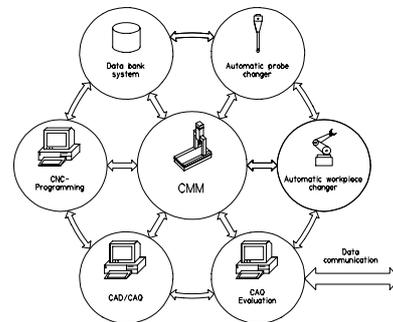


**Fig. 4.** Configuration of an Intelligent Quality Assurance Cell.

The proposed solution can be seen as a further step with the goal to achieve intelligent and economical MFP manufacturing, inspection and quality management in MFIF, especially in small and medium sized multi-function integrated entprises, and to find flexible solutions for all kinds of measurement problems in an automated intelligent manufacturing environment in MFIF.

As already mentioned such a system is partially realized at the authors' Department with success.

## 6. GLOBAL CONCURRENT QUALITY MANAGEMENT AND DIAGNOSTC SYSTEM

A data communication model as described in paragraph 2.1 is the ideal solution for future solutions in global and intelligent manufacturing environment. By means of a common data model and powerful communication network established among ICAD/ICAQ and all other manufacturing processes, it is possible to realise the concurrent quality management and quality assurance activities and other production activities in MFIF, e.g. all production processes, for example design and development, process planning, manufacturing, quality assurance and management etc., which are traditionally carried out sequentially, can be parallelly carried out in MFIF. The quality management and assurance production knowledge can be stepwise parallelly established and refined. If a modified quality activity is made in a process, a correspondent quality assurance activity change will be simultaneously carried out in all other intelligent CAx systems.

Internet makes it possible to establish a global information highway for simultaneous on-line exchange of production data for collaboration on the design, quality assurance and all the production processes, for concurrent communication of all the systematization knowledges for design, manufacturing and quality assurance of global and intelligent production, and to interact with the factory's suppliers and customers worldwide. In [13] an example is discribed for an appropriate internet based application of production metrology and ICAQ. Basic studies for that system have been carried out in the course of an intercontinental University collaboration [14].

A global information system has to be investigated to fulfil the global information connection in MFIF environment. The development of information highway, DCE technology and advanced engineering data exchange technique (STEP) make global information systems possible. Such systems can be realised by utilising the mentioned technologies, by means of which whole collaborative, interactive and concurrent design and manufacturing processes of products in global and intelligent production environment can be achieved. STEP provides an unambiguous representation and an exchange mechanism for computer-interpretable product data throughout the whole life cycle of a product, independent from any particular system.

Through global information connection a quality assurance process could be so carried out, that during the CAD modelling the quality assurance planning, modeling, programming and simulating processes which cooperate with the customers and suppliers could also be simutaneously carried out. The design, quality assurance planning and the quality assurance programming can be carried out at one place and the quality assurance simulating, measuring and evaluating processes can concurrently be carried out at another place in the world.

## 7. CONCLUDING REMARKS

Multi-functions integrated factory is a innovative concept and a new model for future enterprises developed to meet demand for cost-effective customer-driven design and manufacturing, to realize agile and optimal manufacturing production. The quality assurance process will be used in all product production processes in MFIF - from the design to the assembly. QM and QA in individual activities of different function enterprises in MFIF play a basic role to ensurse the realisation of MFIF, e.g. through the intelligent production systems based on quality management and quality assurance in MFIF to create, to realize and to present the features, such as, concurrent, interactive, collaborative, modular, integrative, learning, autonomous, self optimising and self organising functions.

In this manuscript, the intelligent quality assurance system in MFIF, an off-line programming technique for ICMM as basis for simultaneous quality assurance and an intelligent measuring cell for the flexible automation of quality assurance and management, data collection and data evaluation in multi-function integrated factory was proposed and discussed. Optoelectronic and nanotopographic quality assurance methods and a global data communication model for the future that is investigated to realise the concurrent quality management and quality assurance activities and other production activities in MFIF, e.g. all production processes, for example design and development, process planning, manufacturing and quality assurance and management etc., which are traditionally carried out sequentially, can be parallelly carried out in MFIF in global and intelligent manufacturing environment, are introduced. Additionally such a system can be also applied for the international cooperation and collaboration of small and medium sized companies as are typical in the European Union [14].

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