INNOVATION IN PRODUCTION METROLOGY FOR PRECISION ENGINEERING AND TO SUPPORT SUSTAINABILITY AND IMPROVEMENT OF PROCESS AND PRODUCT QUALITY IN MODERN MANUFACTURING INDUSTRY

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ABSTRACT: High accuracy workpieces are created nowadays by a large variety of modern manufacturing processes and techniques such as: CNC turning and milling, broaching, grinding, polishing, honing, electro chemical etching, etc. The problematic of the high accuracy of the work pieces in modern industrial production technique gained in the last years more and more importance through constantly increasing demands on the quality of the produced parts. On the other hand important charge of the environment, reduced availability of natural resources, necessity to improve energy efficiency and the increasing growth of waste require new concepts and strategies to recycle technical consumer goods as there are household instruments, consumer electronics and passenger cars - instead of land filling, burning or steel production a high potential of recycling is necessary. In view of the large quantity and high personnel costs, an advanced disassembly technique is needed working more rational than traditional manual processes and cheaper than highly sophisticated fully automated highest technology machines and devices. This trend develops presently continuously further on because of the development from microtechnology to nanotechnology as well as from nanotechnology to picotechnology, which means particularly special metrologies and production methods for the realization of manufacturing accuracies in the nanometric range. This paper shows actual trends and developments in Industrial Metrology today.

KEY WORDS: Precision Engineering, Industrial Metrology, Nanometrology, Sustainability, Multi-Functions Integrated Factory

1. INTRODUCTORY REMARKS

Measurement technique can be named as an "enabling science" meaning that it is a science which makes other developments first of all possible and it forms the basis for inventions. In operational and industrial environment production metrology delivers essential information for the completion of products and about working condition and status of processes. To survive economically also at the today thoroughly usual short-term changes of the state of the market under world wide competition, a high quality level of the prepared products together with effectiveness and productivity must be guaranteed, furthermore must be secured the reliability at application and employment, for an avoidance of energy losses must be carried likewise as for thrifty consumption of raw materials care, and final are aspects with regard to protection and conservation of the environment of essential meaning.

As the tolerances of workpieces and their features decrease the interaction and correlation between the dimensional tolerances and surface finish becomes continuously more important [1]. Technical surfaces are created by a large variety of manufacturing processes. Precision manufacturing has been helped in the last few years with CAD-CAM systems applying casting or machining (milling, grinding, lapping, polishing).

2. PROCESS, PRODUCT QUALITY AND ACCURACY - TECHNICAL PRODUCT SPECIFICATION

With the rapidly increasing globalization of the market worldwide, in which the outsourcing of productions and production fields that occupation of subcontractors as well as the establishment of plants of an enterprise in geographically different fields became usual and increase still continuously, the standardization became the necessity in the field of the Geometrical Product Specification and Verification (GPS).

Due to this narrow international economical interlacing also knowledge and application of worldwide harmonized technical norms on the field of the requirements and inspection of the geometrical and material qualities of parts become a demand which the enterprises must set themselves up for. In this case the homogeneous application of the fundamental standards in the field of the length and angle, deviations of form and position as well as the surface roughness can help, that a high level functionality as well as quality and reliability of the products can be achieved in a wide scale both at development and design and at production and control of the products without regarding for the location of the plant.

The future economical evolution stands in narrow combination with a sped up increase of the quality in the production field. The quality of the products influences the continuity and the rhythm of the production, the production costs, the production extent, the job productivity and the efficiency of these products with their application or their consumption in diverse manner. A high product quality adds to satisfy the needs of the population increasing constantly, stabilizing international cooperation and to enlarge as well as to increase the export ability of the products.

In the first place the extraction of high-quality information is a task of the measurement technology. High product quality can be achieved only there, where the measurement technology is integrated into the production event as far as possible strongly. On the other hand, however, continuously new orders are made through increasing quality onto the capability of the measurement technology. Quality protection and measurement technology form an inseparable unit from that in the process of manufacture.

3. INNOVATION IN PRECISION ENGINEERING AND INDUSTRIAL METROLOGY

The trend in instrumentation and metrology was already developing in the electronics industry where the drive was towards miniaturization for higher packing densities and faster switching. As a result, highly controllable and stable processes such as lithography were introduced. This meant a need arose for the very accurate positioning of specimens. In turn this resulted in an interest in miniature actuators, motors and accurate slideways for which new technologies have required development. In particular new materials and thin film research were pre-eminent. In electronics and manufacture, new developments on the nanoscale are taking place. The appropriate laboratory research provides the measurement bedrock upon which modern society stands. Pocket cellular telephones, air bags, multifunctional office printers, video game players these products require length measurements many times smaller than human eyes can see, as well as precision measurements of voltage, frequency, velocity, pressure, radiation, and temperature.

The European and international standardization on quality management systems references to the fundamental and general trend to higher expectations on the quality of products. General experience confirms again and again that it is only possible through continuous efforts and improvements to achieve high productive power as well as high quality production processes and to receive the upright. The quality of the prepared products can thus be seen thoroughly as a fundamental element for the productive power of economic enterprises and in general also for other organizations.

A high product quality adds to satisfy the needs of the population that are increasing constantly, stabilizing the international cooperation and to enlarge as well as to increase the export ability of the products. In the first place the extraction of high-quality information is a task of the measurement technology. High product quality can only be achieved if metrology is integrated tightly to the production process as close as possible. Because of the quality, the assurance and metrology form an inseparable unit in the process of manufacture.

To achieve surface finishes and part tolerances in the submicrometer and nanometer level it is necessary to incorporate very sophisticated instrumentation and metrology into the design. This development started in the electronics industry but micro miniaturisation is also now of high priority for mechanical engineering. This fundamental is based on the development and application of high precision manufacturing processes (Figure 1).

Generally dimensional surface measurement technique has the task to recognize at explored surfaces corresponding details and magnifies greatly in most cases especially perpendicularly to the tested surface to make possible distinctions between individual lateral details. In nanotechnology and precision machining however very often smallest or even crystalline structures and molecular assignments are of special interest.

Increasingly those developments have attained since about 1980 at meaning to improve the resolution of the measurement instruments to an atomic level. This will be pursued in future still increasingly, further however also to reduce measurement time as well as uncertainty and to increase precision.

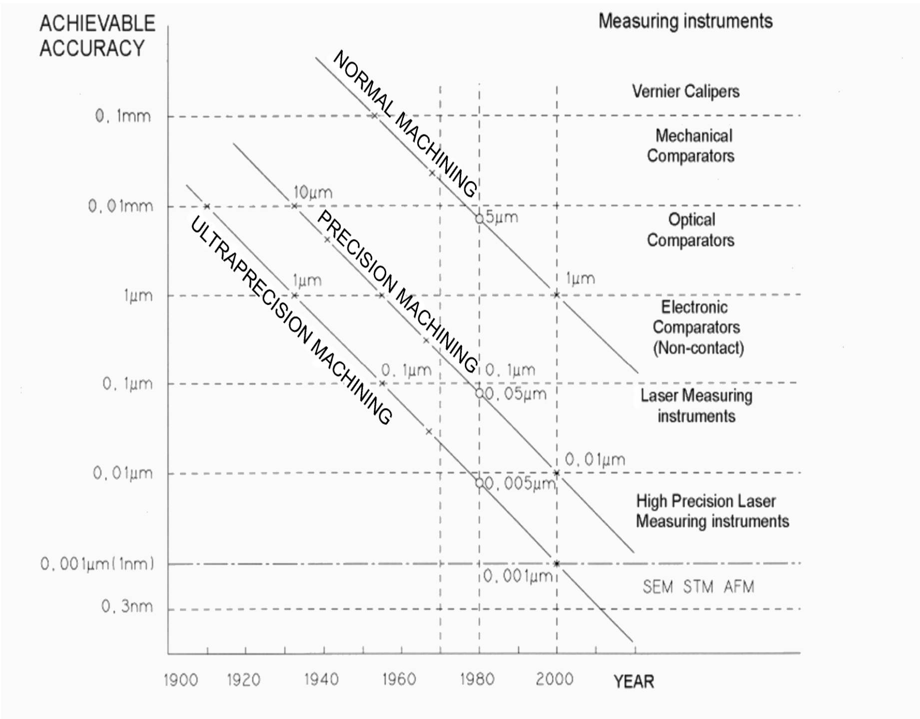


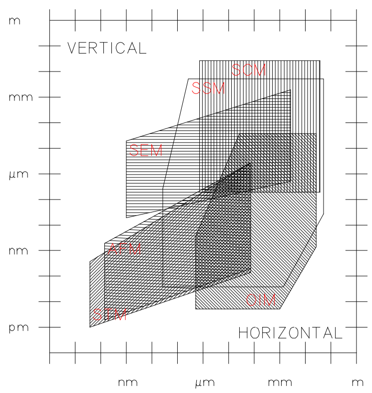
Figure 1. Development of dimensional metrology and achievable manufacturing accuracy [2]

The production of very precise components goes hand in hand with the development of the necessary metrology, and a wide range of measuring instruments has been devised to cater for the evaluation of surfaces and structures down to the 0.1 nm level (Table 1). This powerful array of instruments provides a measuring capability in nanometrology.

Table 1. Measurement techniques related to measuring capability

Limit size	Measuring techniques
>10 µm	CMM, mechanical and pneumatic comparators, optical systems
10µm-1µm	CMM, fine mechanical comparators, optical and electric comparators spin resonance
1 µm–100 nm	CMM, Electromagnetic and electrostatic comparator, optical interferometer, phase microscopes, dark field microscopes
100nm-10nm	CMM, Laser interferometers, roughness measuring devices, fluorescence microscope
10nm-1nm 1nm-0,1nm	Laser confocal microscope, X-ray microanalyzer, SEM, SPM (STM, AFM), electron and X-ray diffraction system

When we consider existing optical or stylus methods and also scanning electron microscopy the typical value of the ratio of vertical resolution to lateral resolution is about 0,01. This depends typically from conventional machining with typical cutting depth to width ratio. In the field of nanotechnology at the atomic scale there are similar demands for resolution because of the need for information of the shape of small structures and the shape of for instance cells, molecules or atoms (Figure 2).



AFM Atomic Force Microscopy
STM Scanning Tunneling Microscopy
SEM Scanning Electron Microscopy
OIM Optical Interference Microscopy
SCM Scanning Confocal Microscopy
SSM Scanning Stylus Microscopy

Figure 2. Measuring resolution and measuring range for different methods

With scanning tunnelling and atomic force microscopes lateral resolutions up to 1 nm and in vertical direction up to 0,1 nm are achieved. So these measuring devices achieve a ratio of resolution of nearly 1 (Figure 3) showing an important advance over the above mentioned conventional methods.

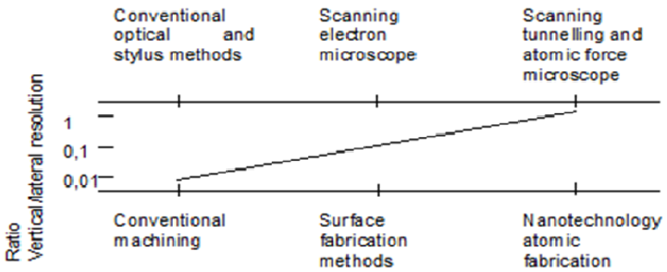


Figure 3. Development of resolution ratio [2]

During the last few years nanotechnology has changed from a technology only applied in semiconductor industry and in research laboratories to a technology that becomes also interesting to many applications in traditional branches of mechanical engineering. The dramatic improvement of ultraprecise manufacturing machines and the invention of new production techniques like Focused Ion Beam Technology has made the production of features and functional elements with micro- and nanometer size possible and economically reasonable. In metrology, the further development of the above mentioned microscope techniques and especially special variants and related techniques has helped to establish nanometrology in research institutes and meanwhile industrial application has been taken into consideration too. Although both manufacturing technology and measurement instrumentation fulfill in principal several of present demands in nanotechnology, international measurement standards in nanometrology are still missing. These standards, including the calibration of instruments, the toleration of form and functional elements in the nanometer scale, new parameters and measurands for nanometrology and guidelines for reproduceable and comparable measurement results are vital for the acceptance of an industrial nanometrology in industry.

The needs of the industry for ultra-high precision engineering and workpieces with a surface roughness less than few nanometers call for measurement instrumentation that can be applied reliably in modern production processes, together with international standards defining parameters and tolerances in the nanometer scale. The requirements on the measurement systems and the measurement strategy to determine suitable parameters, time, costing and the guarantee of a predetermined process stability by means of measurable and correlated parameters come into focus.

On basis of industry needs, the demands on industrial nanometrology can be subdivided into three major scientific attributes (Figure 4):

- Reliability: Measurement results have to mirror the real surface structure and statistic and systematic errors may be reduced to an absolute minimum.
- Comparability: Measurement results must be comparable when they are measured with different measurement systems of the same kind. Ideally measurement results taken with different systems should be comparable too.
- Reproduceability: Several measurements of the same sample under the same conditions must result in the same results. Changes in measurement conditions must result in comprehensible changes in the measured parameters.

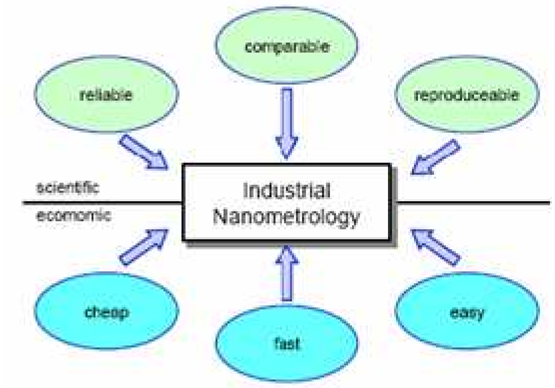


Figure 4. Demands on Industrial Metrology

4. METROLOGY FOR SUSTAINABLE DEVELOPMENT

Today the general principles of quality management are introduced in very different organisations in which partly measurement technique is to be found in the real sense hardly, but productive power joined with reliability stands thoroughly in the foreground. Criterion is the establishing of arbitrarily modelled products together with a supplier-customer-relationship. Completely actual transformations can at first of all very abstractly appearing applications as necessarily prove [3].

The various efficient tools, methods and techniques of modern quality management can be utilised however also in connection with environmental management. Quality management systems according to International Standards of the EN ISO 9000 [4, 5]series are a good basis for building environmental management as well as energy management practice [6, 7, 8]. This offers the opportunity to apply well known systems and well known tools in a modified form to solve a company's environmental problems and to increase the efficiency [9]. Additionally, this will put the environmental question far beyond national boarders maybe throughout the world.

Additionally, the advantages of an environmental management system based on a quality management system is not only the application of a widely accepted and approved system. In this way it is possible to find an effective but low cost solution for an environmental management system especially under the point of view of small and medium sized enterprises [10].

Thereby important tasks emerge for the measurement technique at the implementation of effective measures of the environmental protection. Surely the measurement technician is not summoned from the beginning to take position to questions of ecology and it is very difficult being able to give answers about this on full width. But it would be very dangerous to do not take in principle these problems into consideration for there we find the perhaps most important questions and problems of the time being.

5. METROLOGY FOR AUTOMATION AND CONTROL AND BIOMEDICAL APPLICATIONS

The automation of measurement technique is particularly under the point of view of the productive power of essential meaning whereas flexibility must be considered as an important boundary condition. In an industrial environment of computer integrated and intelligent manufacturing it is necessary that measurement technique can be adjusted flexibly to changing task designations. Appropriate solutions can be found with the help of flexible intelligent measuring cells and their components [11].

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 need to be investigated. "Multi-Functions Integrated Factory - MFIF" [3] is an innovative concept and model for future enterprises. It is initiated with the aim to provide cost-effective, agile and optimum ways to produce customer-driven "Multi-Functional Products - MFPs" in the near future, based on intelligent production technology and especially the information highway making possible the application of intelligent metrology at world wide distributed factories on the basis of advanced engineering data exchange techniques (Figure 5). Fu, S., and Raja, J., gave an example for an appropriate application for engineering metrology and ICAQ [12].

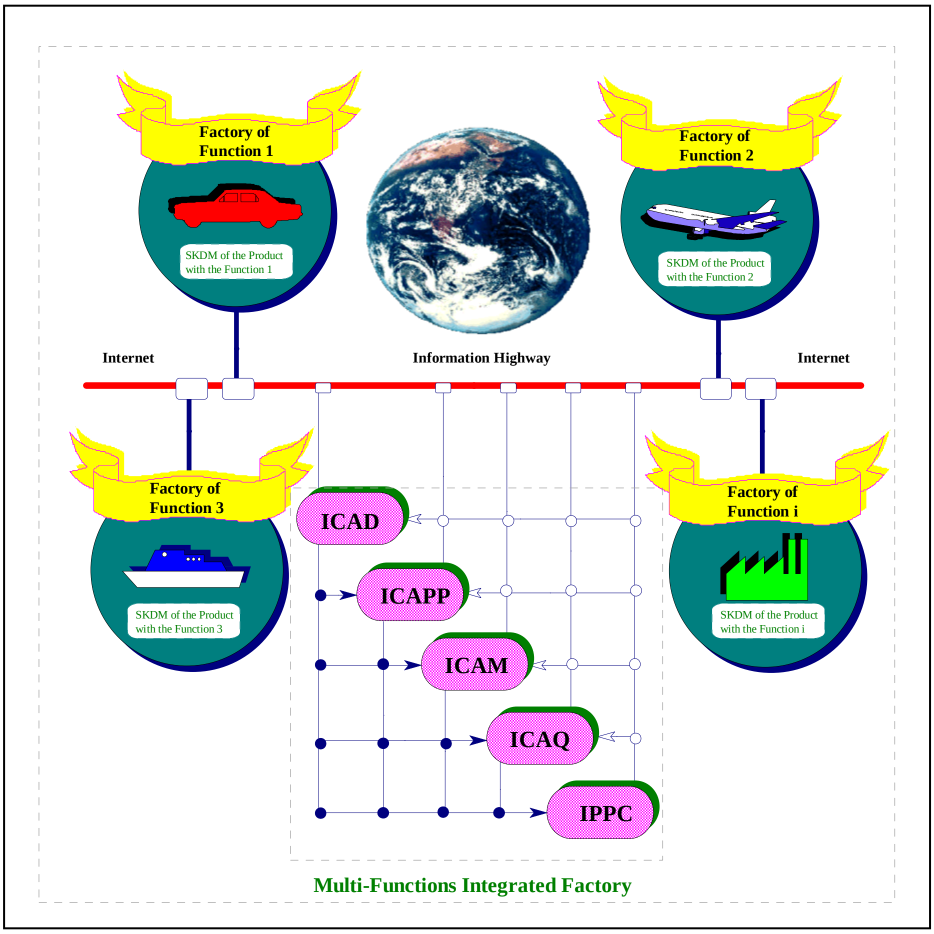


Figure 5. Integration of Intelligent Quality Control and Metrology into the Model of a Multi-Functions Integrated Factory MFIF

Automated measurement technique closes quality control loops in production, in that an early recognising possible reasons for rejections together with an analysis results the improvement of manufacturing processes and preventive corrections can be introduced. For the draft and the completion of workpieces experimental values and expert knowledge of geometric deviations facilitate the discovering of meaningful strategies [10, 13] therefore the demanded workpiece accuracy can be achieved under an economic point of view.

There exists rapid development in biomedical technique and this demands the application of modern computerised measurement technique and measuring devices [18]. This can be applied to evaluate the shape of non technical structures as there are human joints or limbs (Figure 6) with high accuracy. Figure 7 illustrates the graphical analysis of a hip joint implant after measurement with a digital microscope [17]. Figure 8 illustrates surface structure evaluation of an of a precision endo prosthesis for the femoral head of a human hip joint. The results of such measurements form the basis for the improvement and optimisation of future work for implantation and in endo prosthetics.

In this scientific area there have been considerable advances during the last fifty years as far as used materials are concerned. Nevertheless there is still lack of knowledge about geometrical and kinematical principles of movements of human joints where the general degree of knowledge seems to be remained at a similar basis of more than one hundred years ago.

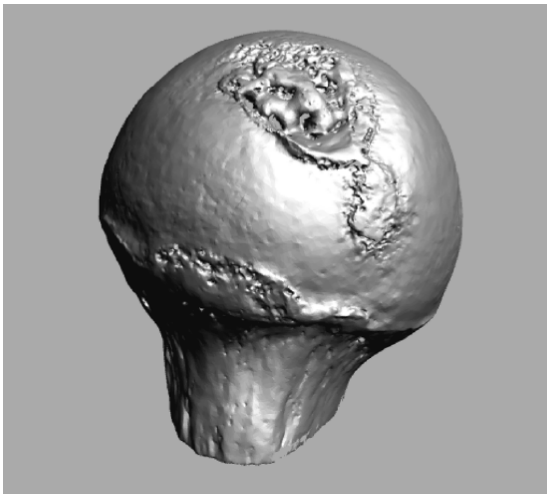


Figure 6. Graphical evaluation of measurement results of a hip joint implant.

In technical instruments accurate and reproducible movements are carried out only when exactly predefined elements are used. So the conclusion from analogy is possible that the kinematics of human beings works on a similar basis of exact regulations which mostly are unknown up to now. Artificial links and joints would work better if we would have more exact information about the original human elements.

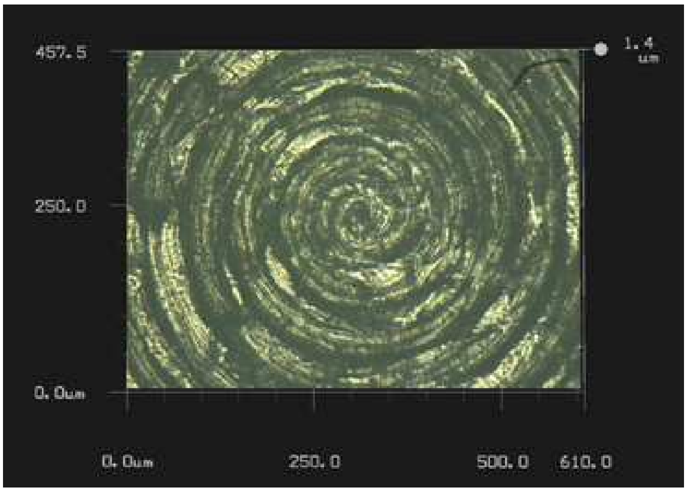


Figure 7. Graphical analysis of a hip joint implant using digital microscopy system

It is presupposed that joints of creatures must be constructed according to defined geometric kinematic regularities elsewise it would not be possible that those elements will stay in correct function during whole lifetime of up to hundred years. These rules and laws are preconceived by men within technical motion systems and must be testified stepwise for each joint.

The presented overview about the research area metrology in the fields of biomedicine and bioengineering demonstrates clearly the great importance of this development and it goes directly into the direction of nanotechnology. This is fully in line with the general ideas of production metrology, nanometrology and engineering of technical surfaces (figure 8) [14].

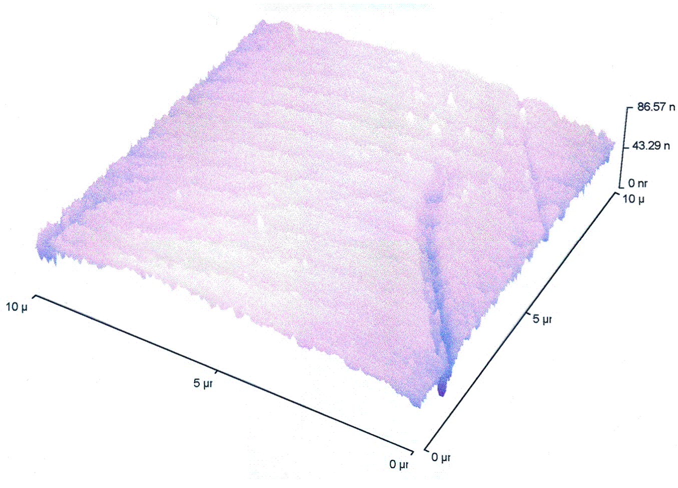


Figure 8. Detail of the surface of a precision endo prosthesis for the femoral head of a human hip jointwith a 40 nm deep scratch

New breakthroughs by the instrumentations have been made in recent years, to establish high-tech instruments which can acquire a 3D surface structure of the precisely machined surfaces to fulfill the requirements for the application in industrial environment [15].

These measuring techniques are typically used for surface characterization. For 3D measurements it is often more advantageous to use a CMM. Such Nano-CMMs have been recently introduced achieving an uncertainty of 100 nm or better and enabling three-dimensional measurements as well as scanning of high precision parts.

The concept of the ultra high accuracy coordinate measuring machines is based on the linear scales to measure the position of the probe tip and measuring heads for the scales in the horizontal plane. The design also features air bearings for high repeatability and small power dissipation in the slides. Measurements with resolutions less than 50 nm in industry and less than 1 nm in national metrology institutes are desired today.

6. CONCLUDING REMARKS AND OUTLOOK TO FUTURE DEVELOPMENTS

There exist close interactions between measurement technique and industrial and technological developments. Special points of interest are quality and environmental management, automation, sustainability and micro and nano technology.

It is correct that quality and environmental management are much more than practical application of measurement technique but it is not possible to achieve high quality and environmental compatibility of technical products without appropriate and intelligent measurements.

In modern metrology it is possible to use instruments capable of creating atomic resolution images of the surfaces of different specimens. SCM, AFM, STM and Scanning Probe Microscopy (SPM) are such advanced measurement technologies. At the atomic level metrology and fabrication are closely related. STM has made possible the first steps of atom manipulation which may lead in the future to fabrication at the atomic level [16]. As a still more futuristic development this may perhaps make possible the design and production of miniature measurement instruments or devices for medical treatment or operations in human beings that might operate autonomously in the micro- or even nanoworld. The speed and reliability that can be achieved make any idea of mass manufacturing, now, or in the foreseeable future, preposterous. But in any case nanometrology has become technical reality and pico- and femtometrology will not be impossible in the future.

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