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Trends in Metrology

P. H. Osanna, N. M. Durakbasa

Vienna University of Technology , Wien, Austria

1. Introductory remarks

Tens of billions of Euro of sales depend world wide each year directly on measurement instruments and techniques. The appropriate laboratory research provides the measurement bedrock upon which modern society stands. Pocket cellular telephones, air bags, heat-seeking missiles, fax machines, video game players – these products require length measurements many times smaller than the eye can see, as well as precision measurements of voltage, frequency, velocity, pressure, radiation, and temperature. Laboratory research continually improves how these basic quantities are measured, a process that is inseparable from each government's constitutional responsibility for maintaining the nation's weights and measures.

Since 1970 we see increasing importance of computer aided measurement techniques as a means to control industrial manufacturing and the quality of all kinds of products. At the same time precision engineering developed as important trend in instrumentation and metrology. Tactile, optical and electronic methods are preferred tools in computer integrated production plants. Besides those newly developed not conventional instruments are of increasing importance for practical industrial application. Their efficient use and correct calibration are crucial requirements for quality management in this environment.

2. Production metrology for quality management

Competition and cost consciousness on the one side an increasing demand for quality and reliability on the other side are contrary requirements in present production engineering. This must be considered also from the point of view of the international standards about quality management and quality assurance [1]. Last but not least the very important fact of the protection of environment must be taken into consideration [2].

The international standardisation on quality management systems references to the fundamental and general trend to higher expectations on the quality of products. General experience confirms it also 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 upright. The quality of the prepared products can thus be seen thoroughly as fundamental element for just this productive power of economic enterprises and in general also of other organisations.

Quality control and quality management consist of a diversity of tasks, measures and activities, which extend over the entire product life cycle for each product must be accompanied in all phases through corresponding quality relevant measures and activities. This is presented very vividly through the idea about the quality circle or the quality spiral [3]. Thereby quality management includes certainly essentially more than measurement technique but on the one side quality control in connection with products or with processes is impossible without measurement technique and on the other side measurement technique forms the fundamental basis and it is one of the main parts of every quality management systems associated with the manufacture of products as well as the operation of technical plants.

The term product is to be understood here in a very general sense as result of activities and processes in the meaning of the present international standards [1]. A product can be thereby material or immaterial e.g. in the form of service or an arbitrary combination from both. At material products the effect of measurement activities can be understood easily and recognised evidently. In connection with other types of products measurement technique is only conceivable with difficulty. But it was always a basic target of the science measurement technique, since we speak of this science, to try to measure what was not measurable up to now.

3. Micro and nano technology

3.1. Recent developments

Precision Engineering is an important trend in present instrumentation and metrology. To achieve surface finishes and part tolerances in the sub micrometer and nanometer region it is necessary to incorporate very sophisticated instrumentation and metrology into the design. This trend was developing in the electronics industry where the drive was towards miniaturisation for higher packing densities and faster switching.

Since approximately 1975 we speak about “Nanotechnology”, a term introduced by T a n i g u c h i [4] to describe manufacture to finishes and tolerances in the nanometer region (Fig. 1).

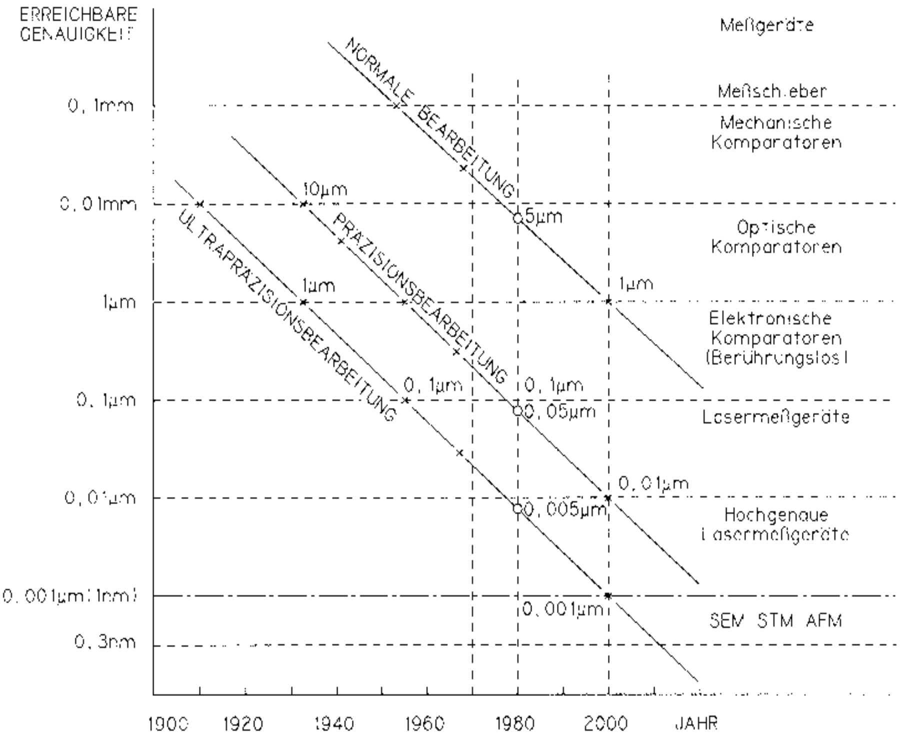

Fig. 1. Development of achievable manufacturing accuracy [5]

Extrapolating the specifications from existing and past machine tools, such as precision lathes and grinders, to the new generation of machine tools it was concluded quite correctly that before 2000 accuracies of between 0.1 µm and 1 nm will be needed to cater for the needs of industry. Taniguchi was too pessimistic for this has been already state of the art before 1995 [5]. This goal can be reached only through the development and application of high precision manufacturing processes and by the application of high precision measurement technique of apart conventional methods.

In production engineering tolerances of workpieces decrease continuously. On the one side this can be seen in close connection to increasing demands of customers and consumers in reference to the quality of products and to quality management of processes. On the other side this development can be traced to the beginning of the twentieth century [6] and it lies in one line with the perspective of nanotechnology. The accuracy improvement of one ISO tolerance grade every decade still continues [7] and also recent reports give evidence on the effect of constantly tightening workpiece tolerances [8]. As the tolerances of workpieces and their features decrease the interaction and correlation between dimensional tolerances and surface finish becomes more important [9].

Extremely high accuracy demands deposit presently already at highly developed instruments for everyday use as there are video cassette recorders, CDplayers, pocket telephones, air bags, fax and copying machines, further on 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.

3.2. New methods and materials

The meaning of nanotechnology shows itself first of all together with production and measurement technique, but it encompasses far more than engineering and it finds application in very different sciences and disciplines, as there are biology, physics, medicine and electronics.

Just in electronics nanotechnology stands in close connection with the tendency to micro miniaturisation started by the growing needs at electronic circuits especially in aviation, space and military technique. The goal is to design smallest electronic instruments with highest possible reliability and service life which contain nevertheless a multitude of electronic circuits and elements and which can be manufactured in large numbers very economically. Thereby very extensively automated processes stand in the foreground.

The importance of nanotechnology in the engineering domain shows itself in the need to raise the precision of manufacturing processes considerably [10]. For the production of high technology goods it was necessary to develop new manufacturing processes under application of novel raw materials. Such new techniques are for instance ion beam machining and thin film production. Innovative materials are silicon and glass ceramics. That joined with the interest in miniature sensors and actuators and accurate slideways to make possible the control and supervision of processes with highest possible accuracy and moderate expense.

4. Nanometrology

4.1. Methods in nanometrology

Nanotechnology is not restricted only to the production in the nanometric range. It is evident that one will be endeavoured in future to utilise multipurpose instruments with high flexibility, which should operate fast and insensitively as much as possible against environmental influences like thermal drift and vibrations.

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]. Fig. 2 shows a 3-D image topography of a sample surface of a copper alloy “atomic” structure.

More and more we see the growing importance of those developments. The resolution of the measurement instruments has been improved to an atomic level. This will be pursued in future still increasingly, further on however also to reduce measurement time as well as uncertainty and to increase precision will be of important interest.

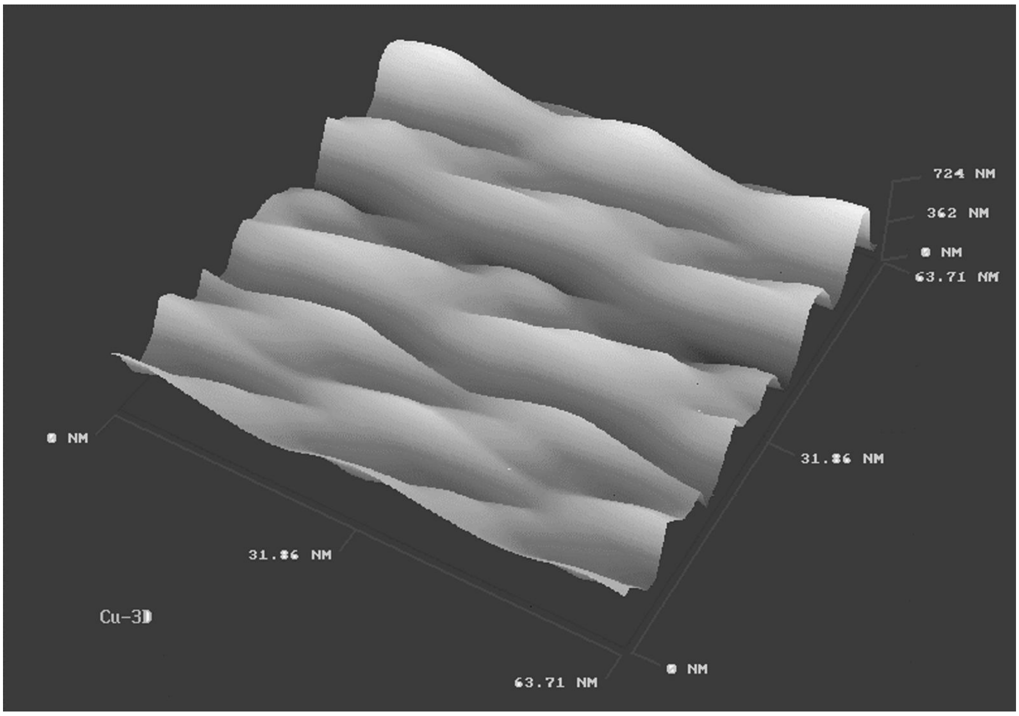

Fig. 2. 3-D image topography of the surface of a copper alloy atomic structure

4.2. Metrological characteristics

The search for the spatial correlation of features as well as the appropriate identification are very important in general in dimensional metrology. Atomic structures or the order of molecules are typical points of interest in the field of nanotechnology.

For a measuring device the capability to make possible the visualisation of the surface or workpiece feature to be investigated and the quantification of this visual information are essential characteristics. In this connection we speak about a “metrology gap” [5]. The reduction in the scale of features or details to be investigated has not necessarily been accompanied by an increase in the ability to quantify. Due to the inability to calibrate at the atomic level of nanotechnology there are difficulties to quantify with sufficient accuracy.

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 both lateral and vertical to the investigated surface because of the need for information of the shape of small structures and the shape of for instance cells, molecules or atoms. With scanning tunnelling and atomic force microscopes lateral resolutions up to 10 nm and in vertical direction up to 1 nm are achieved. So these measuring devices achieve a ratio of resolution of nearly 1 showing an important advance over the above mentioned conventional methods.

In any case the described developments in manufacturing technology, metrology and instrumentation are fully on the way. They will continually improve in the future and it is not possible to foresee the end. The already by Kienzle, Taniguchi and Whitehouse demonstrated trend will continuously lead from nanotechnology to “Picotechnology”.

5. Metrology for production automation and control

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 [13].

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 [14]. Multi-Functions Integrated Factory (MFIF) is an innovative concept and model for future enterprises and 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 (Internet) making possible the application of intelligent metrology at world wide distributed factories on the basis of advanced engineering data exchange techniques. Fig. 3 illustrates the integration of intelligent computer aided quality control (ICAQ) and metrology into the model of MFIF. In [15] an example is given for an appropriate Internet based application of production metrology and ICAQ.

Automated measurement technique closes quality control loops in production, in that an early recognising of 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 therefore the demanded workpiece accuracy can be achieved under an economic point of view.

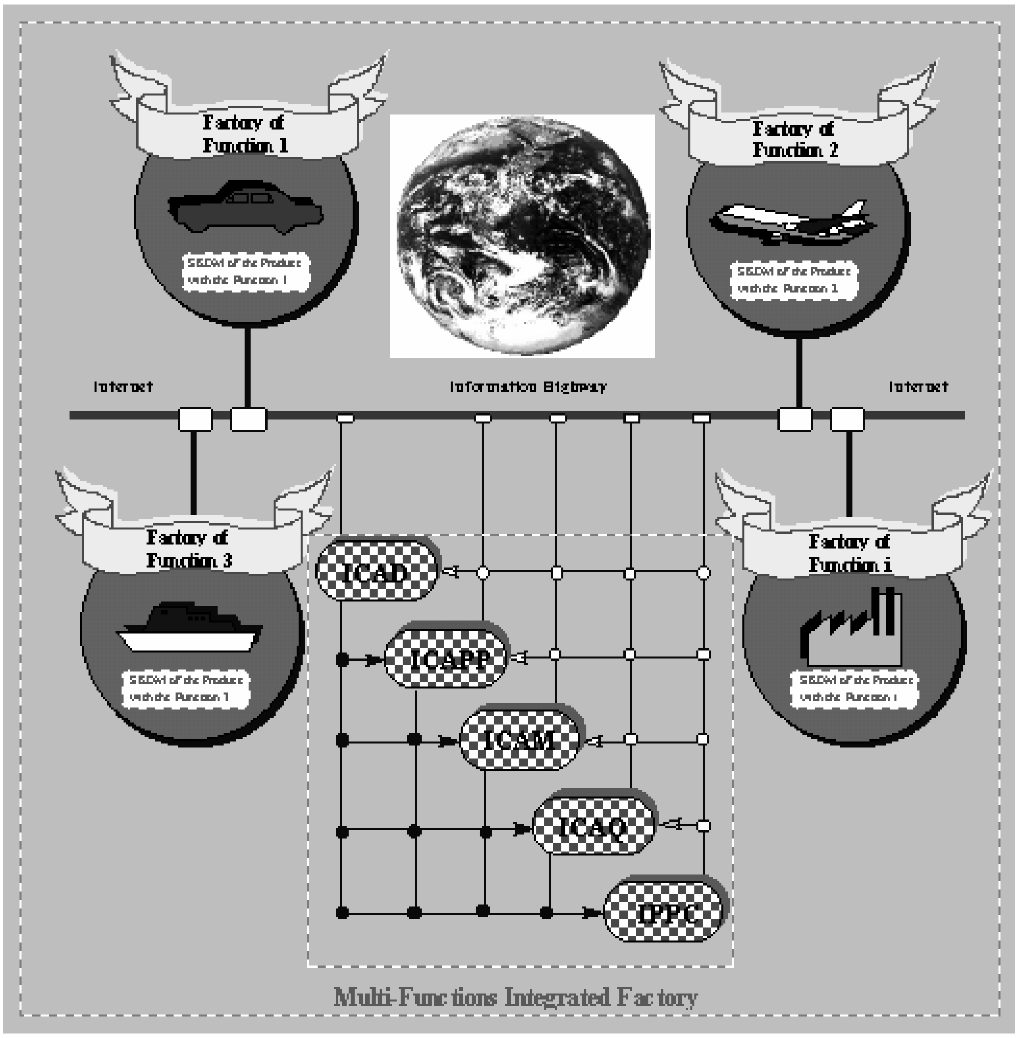

Fig. 3. Integration of Intelligent Computer Aided Quality Control ICAQ and precision metrology into MFIF model

6. Precision metrology for biomedical applications

There exists rapid development in biomedical technique and this demands the application of modern computerised precision measurement technique and measuring devices. This can be applied to evaluate the shape of non technical structures as there are human joints or limbs with high accuracy. Fig. 4 illustrates the measurement of the shape of an artificial tooth used for implantation in human jaws. The results of such measurements form the basis for the improvement and optimisation of future work for implantation and in endo prothesis.

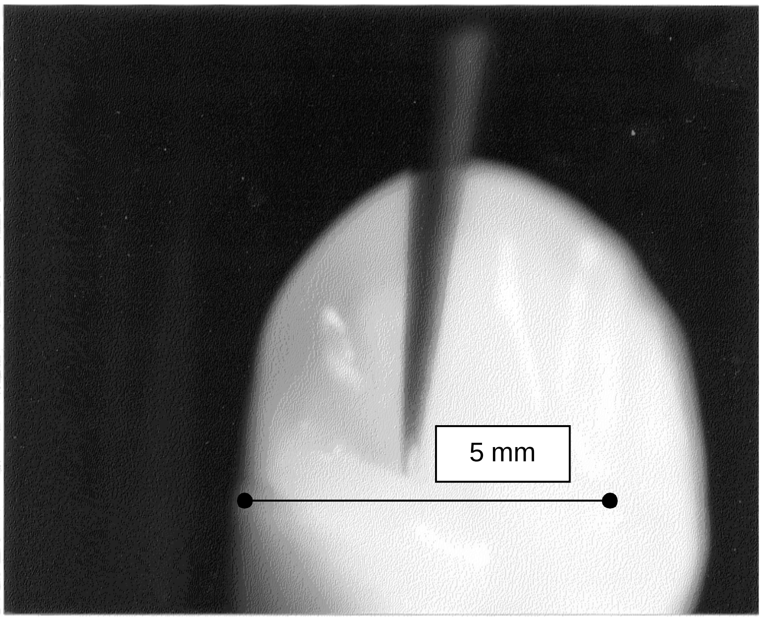

Fig. 4. Measurement of an artificial human tooth for implantation

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 geometric and kinematic principles of movements of human joints where the general degree of knowledge seems to be remained at a similar level as more than one hundred years ago.

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.

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

New biomechanic researches of A. M e n s c h i k [16] and F. M e n s c h i k [17] come to the result that the shape of a rotational conchoid would be an optimum solution for artificial joints. A conchoid form can be evaluated from measured data when form measurements on real human femur heads are carried out by using a CMM in scanning mode [18]. Fig. 5 shows the graphical evaluation of measurement results of a human femur head. The CMM only works as measuring system and digitizer. The evaluation is done by using data transfer of measuring data to an evaluation computer and using table calculation software for optimisation.

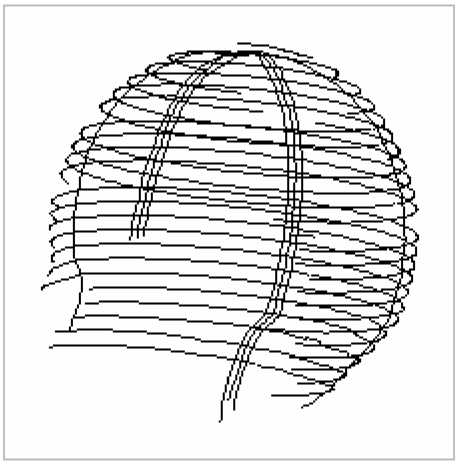

Fig. 5. Measurement data of a human femur head

7. Concluding remarks

There exist close interactions between precision metrology and newest industrial and technological developments. Focal points of interest for nano technology and nano metrology are production automation, increase of products quality and biomedical technique.

The already described developments in manufacturing technology, metrology and instrumentation are fully on the way and they will continually improve in the future. It is not possible to foresee the final end and this trend will continuously lead from Nanotechnology to "Picotechnology".

Quality control and quality management are far more than practical application of precision measurement technique but it is not possible to achieve high quality and environmental compatibility of technical products without appropriate and intelligent metrology.

References

1. ISO 9000: Quality Management Systems – Fundamentals and Vocabulary. 2000.
2. EN ISO 14001: Environmental Management – Specification and Guidance for Use. 1996.
3. Juran, J. M. Juran on Planning for Quality. New York, The Free Press, 1988.
4. Taniguchi, N. On the basic concept of nanotechnology. – In: Proc. Int. Conf. Prod. Eng. Tokyo, 1974, part 2, Tokyo: JSPE, 18-23.
5. Whitehouse, D. J. Nanotechnology instrumentation. – Measurement + Control, **24**, 1991, No 2, 37-46.
6. Kienzle, O. Genauigkeitsansprueche des Konstrukteurs und ihre Verwirklichung durch die Fertigung. – Industrieanzeiger, **82**, 1960, No 62, 26-42.

7. O s a n n a, P. H. Dreidimensionales Messen. Future 80, Frankfurt: Ingenieur-Digest-Verlag, 216-218.
8. S w y t, D. Challenges to NIST in Dimensional Metrology: The Impact of Tightening Tolerances in the U.S. Discrete-Part Manufacturing Industry. NIST report IR4757, Gaithersburg: National Institute for Standards and Technology, Precision Engineering Division, 1992.
9. T a b e n k i n, A. Effects of form and finish on tolerances. – Quality, **9**, 1993.
10. T a n i g u c h i, N. Current status in and future trends of ultra precision machining and ultra fine materials processing. – Ann. CIRP, **32**, 1983, No 2, 573-582.
11. B i n n i g, H., H. R o h r e r. Scanning tunnelling microscopy. – Helv. Phys. Acta, **55**, 1982, 726-731.
12. I c h i d a, Y., K. K i s h i. Nanotopography of ultraprecise ground surface of fine ceramics using atomic force microscope. – Annals of the CIRP, **42**, 1993, No 1, 647-650.
13. O s a n n a, P. H., N. M. D u ra k b a s a, R. O b e r l a e n d e r. Low Cost Solutions for Quality Management in Flexible Automated Production Systems. – Manufacturing Systems, **23**, 1994, No 1, 77-81.
14. O s a n n a, P. H., L. S i. Multi-functions integrated factory M.F.I.F – a model of the future enterprise. – In: Conference Proceedings: Internet Device Builder Conference, Sta. Clara, May 2000.
15. F u, S., J. R a j a. Internet Based Roundness and Cylindricity Analysis. M. N. Durakbasa, P. H. Osanna, A. Afjehi-Sadat (Eds.) – In: IMEKO 2000 Proceedings. Vol. VIII. Wien: Abteilung Austauschbau und Messtechnik, ISBN 3-901888-10-1, 2000, 83-88.
16. M e n s c h i k, A. Biometrie. Berlin, Springer Verlag, 1987.
17. M e n s c h i k, F. The shape and kinematics of the hip joint. – In: Proceedings of 3rd Conference of the EORS, Paris, Abs. No 220, 1993.
18. O s a n n a, P. H., F. M e n s c h i k, K. R e z a i e, N. M. D u r a k b a s a, R. O b e r l a e n d e r. Utilization of form measurements in biomechanics and endo prosthesis to improve the kinematics of human joints. – State and Advances of Measurement and Instrumentation Science, – IMEKO TC1/TC7 – Colloquium, London, Sep. 1993, ISBN 0-9522111-0-6, 389-394.

Направления в метрологии

П. Х. Осанна, Н. М. Дуракбаса

Технический университет, Вена, Австрия

(Р е з ю м е)

Показано значение измерительной техники в научных исследованиях и в индустриальном производстве, и особено влияние метрологии на качество и на качественый контроль, нанотехнологию и биомедицинскую технику. В современном производстве нужно увеличить роль измерительной техники. Повышение качества можно достичь путем целенасоченного применения измерительной техники. В настоящем учитываются и экологические аспекты тоже.