XXI IMEKO World Congress "Measurement in Research and Industry"
August 30 – September 4, 2015, Prague, Czech Republic

DEVELOPMENTS IN PRECISION ENGINEERING: HIGH PRECISION METROLOGY APPLICATIONS TO IMPROVE EFFICIENCY AND QUALITY

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Abstract – Current economic development shows that more and more pressure is exerted on the industry in terms of flexibility, efficiency and high quality of production processes and the products. Nanotechnology has settled in recent years as a crosscutting technology with many applications in different areas. This study provides existing applications, moreover proposing novel approaches, which essentially corresponds to the ever-continuing miniaturization so that functional structures are formed with a case study of testing the limits in the production of a conventional planetary gear.

Keywords: geometrical product specifications and verification (gps), micro/nanometrology, quality, top-down approach, miniaturization.

1. INTRODUCTION

Nanotechnology as a cross-cutting technology with many applications in different areas of life lays down the ground work of our research. The size range is assisted by one nanometer to 100 nm, ie a ten-thousandth of a millimeter, and creates a common feature.

The nanaotechnology applications offer various outstanding properties in miscellaneous products that make these objects successful on the market. Often the nanoworld touches and leads in the areas of micro and macro precision technology. Macroscopic products are equipped with nanotechnology and influence to some extent their quality.

By the top-down approach, which essentially corresponds to the ever-continuing miniaturization, smaller structures are always prepared, so that functional structures are formed that are smaller than 100 nm. The goal of our approach is to test the limits in the production of a conventional planetary gear.

We go through the various techniques in the field of macro-, micro- and nano-technology. Where even the macro techniques with cm / m dimensions have challenges in the precision engineering, the microtechnology mm / micron and nanotechnology components have been generated with dimensions in the nanoscale range.

In times when everyone is much thinking and writing about smart factory (industrie 4.0), it is worth to give a working example of the development of production in the field of mechanical engineering. This paper presents an example of the methods of additive manufacturing, which allow the production of parts in the nanoscale and examine them with the proven methods of measurement.

This will be especially possible on the basis of the innovative concept and model for modern enterprises the so-called "Multi-Functions Integrated Factory - MFIF" that makes possible an agile and optimal industrial production in any kind of industry and especially in up-to-date SMEs. Those new models can be developed on the basis of intelligent production technologies and extensive use of the information technology, parallel-processing computing and advanced engineering data exchange techniques [1].

2. HIGH QUALITY - PRODUCT DEVELOPMENT - PRODUCTION EFFICIENCY

Energy efficiency and environmental protection have the essential impact on production systems especially on the product development and design processes.

In the advanced production systems the design tasks can be carried out intelligently, interactively and concurrently. The system for collaborative working method has the goal to realise not only electronic data interchange (EDI) function but also an interactive working function on-line, and to work at the different places and at heterogeneous systems FOR the same product model. Transmission of words, figures and sound by means of multimedia will also be integrated in such interactive intelligent design systems that 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 on the base of integrated management systems.

2.1. Smart design

There is a need for companies to fundamentally change or develop their approach to design with the aim to make sure that the final product meets the functional needs of its application. In order to realize this concept, a considerable amount of expense needs to be expended in functional testing that fulfils the required parameters to ensure that the design and its manifestation through manufacture presents the desired conditions taking into account the materials selected and its fabrication yields. During these processes, function related data collections [2] and handbooks [3] support design engineers. According to the functional specification of a workpiece, which are derived from the functional need, the geometrical specifications are set up during the design stage (Fig. 1). To communicate geometric requirements the manufacturing staff and machines, the ideal shape has to be translated in the language of ISO GPS, which bases on standard geometrical elements [4].

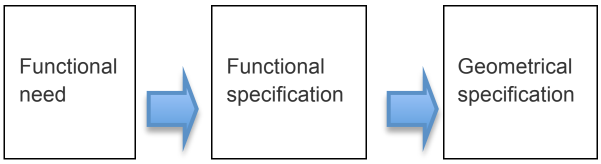


Fig. 1. Functional need, Functional specification, Geometrical specification [3]

In order to establish this relationship between design, production and measurement and to clarify the mutual importance, standards have been developed in the area of the Geometrical Product Specifications and Verification - GPS. Comprehensive knowledge in this area is an important presupposition to achieve economic design, construction, production, metrology within integrated management systems of quality and environment.

The new international standards about quality assurance, quality management and environmental management [5, 6, 7, 8] have been adopted. In this respect the general term GPS has become recently well-known for the area of mechanical engineering. It defines the characteristics of the workpiece such as the shape (geometry), dimensions and surface topography that are also indicated on the specifications and technical drawing of the workpiece. In this way the optimal function of the respective part is supposed to be guaranteed considering certain manufacturing tolerances. Greatest emphasis must be placed at the definition of the technical drawings on strict compliance with appropriate normative regulations. To represent a work object in an enlarged scale is not a challenge for today's CAD programs. To produce it in a manufacturing process shows the limits of the manufacturing methods.

In this study, a planetary gear will be taken as an example. The application of the scaled rows has not been considered here for size gradation. For the choice of the transmission size and the ratio, the ranges that suit both technical and economic aspects generally prevail [9]. In this study the focus is on the production possibilities of small and minimized parts and their determination by means of the geometrical product specification requirements, hereinafter referred to as GPS. If there is a not so great emphasis placed on the required functionality of the reduced parts, in the first approximation it is possible to focus on the production of the gear box limited by production itself. In the tooth flanks of the individual gearing mechanism components, perfectly designed surfaces and shapes are necessary that are defined in the nanoscale (see Figure 2).

2.2. Additive manufacturing

The nanoscale can be accomplished by two methods in the production process. The bottom-up and top-down methods offer the possibility to approach the nanoscale.

Additive manufacturing (AM) is a tool that streamlines and expedites the product development process. In an effort to reduce time to market, improve product quality, and reduce cost, companies of all sizes have come to rely on AM as a mainstream tool for rapid production development. As a visualization tool, AM processes help companies reduce the likelihood of delivering flawed products, or the wrong products, to the marketplace [10].

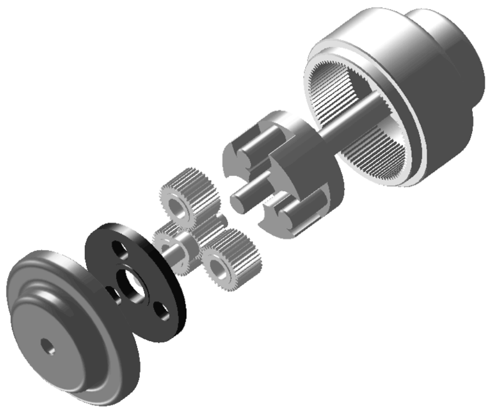


Fig. 2. The gearbox modelled to be manufactured by size gradation

At first, the manufacturing process will be taken into consideration, which are divided into six main groups and numerous lower tiered subgroups according to the German standard DIN 8580 [11]. In Anglo-Saxon, a coarser classification is common and that is better suited for further discussion. It is based exclusively on the geometry [12].

- Subtractive manufacturing method
- Formative manufacturing method
- Additive manufacturing method

The subtractive manufacturing provides the desired geometry by removing of defined regions. Thus it falls into the area of the top-down technology.

Additive manufacturing processes produce the desired geometry by the joining of volume elements. This method is clearly added to the bottom-up section. This is called layer process if the geometry is made up of individual layers.

In generative manufacturing not only is the layer by layer process applied to a geometry, but also they are produced as individual layers one above the other. In practice the two general definitions are used interchangeably.

The increasing demand for functionally sophisticated workpieces at an economical price forces the designers to state the exact specifications of the workpiece. Any neglect or non-unique representation regarding the description of the specification makes the compliant manufacturing of the product difficult [13].

While attempting to downscale the planetary gear and during preparation, the generative methods have shown to be suitable. Attention is paid not only to the complexity of the shapes but also still referred to resources for this gentle production of the object considered. Therefore it has already taken on the aspect of the production lifecycle consideration.

The stereolithography (SL) process is available in this example. One of the most popular among currently applicable rapid prototyping processes is stereolithopgrapy (SL). This relies on a photosensitive liquid resin which forms a solid polymeric when exposed to ultraviolet light. Due to the absoption and scattering of the beam, this reaction only takes place near the surface. As with a line printer PolyJet, the print head moves back and forth along the x-axis and leaves the building platform on an ultra-thin layer photopolymer. Each layer is cured immediately after application by means of UV-lamps that are installed directly on the printhead. Thus, the finished model does not need to be cured as is conventional printing with other technologies.

3. ADVANCED MICRO- / NANO-METROLOGY APPLICATIONS

The most important parameters in determining the suitability of a technical part are its compatibility, functionality, performance and corrosion resistance. The precise assessment of wear, friction and miniaturization demands creation of nanometer scaled surface structures, surfaces with thin film deposition and ultra precision surface treatment with the utilization of new manufacturing and measurement instrumentation and techniques. These include micro and nanofabrication of surface patterns and topographies by the use of laser machining, photolithographic techniques, and electron beam and colloidal lithography to produce controlled structures on technical surfaces in size ranging from 10 nm to 100 µm.

A planetary gear designed for a measuring robot is an example of advanced technology implementation. In this respect the general term "Geometrical Product Specifications and Verification - GPS" has become recently well-known for the area of mechanical engineering. It defines on a technical drawing the shape (geometry), dimensions and surface characteristics of the workpiece under discussion. The optimal function of the respective part is supposed to be guaranteed considering certain manufacturing tolerances.

The manufacturing industry as developing in micro and nano-scale production requires assessment tools that can be applied and proved in the global market. Hence, important tasks emerge for the measurement technique at the implementation of effective measures. The intelligent measurement process which can be carried out simultaneously in all product realization steps in modern factories - from the design process to the assembly procedures as well as from the after use to the recycling and reuse is the future of the assessment in manufacturing industry. In order to realize automatic measurement and to deal with complex, variable and dynamic quality control problems of the production processes in this environment, the intelligent measurement system will be enhanced comprehensively through self-optimizing processes thrust in the design system and all manufacturing production processes of this environment. Integrated management system with intelligent, associative, concurrent, interactive, modular, integrative, learning, autonomous, self optimizing and self organizing functions will be realized in modern manufacturing industries.

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. As presented in the Fig. 3 and Fig. 4, the surface topography as well as the geometrical assessment is the key solution to develop high precision components in the advanced manufacturing industry. The requirements on the measurement systems and the measurement strategy to determine suitable parameters, time, costing and the guarantee of predetermined process stability by means of measurable and correlated parameters come into focus.

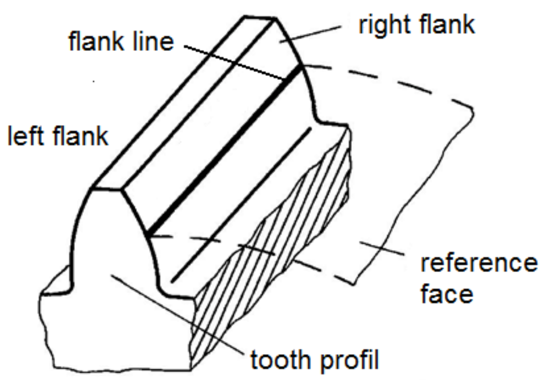
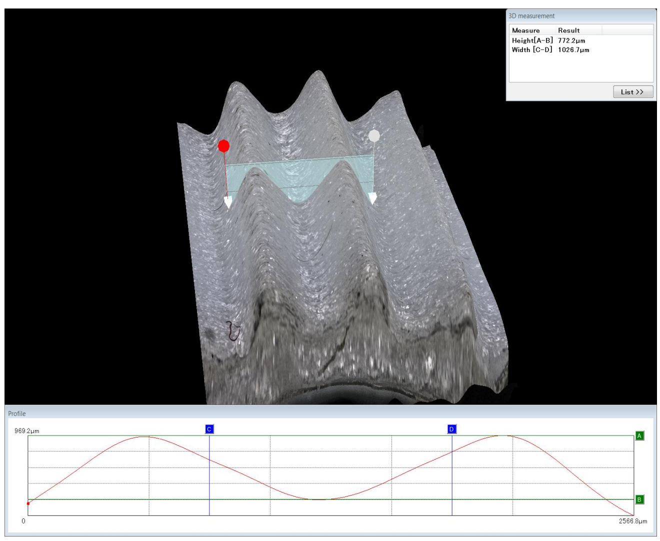
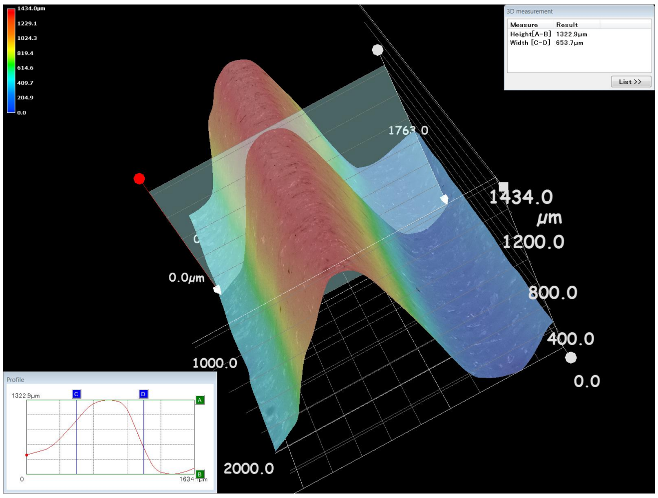


Fig. 3. The cut-out profile of a gear-wheel



(a)



(b)

Fig. 4. a) and b) The assessment of the surface and geometrical topography of the gear-wheel profile by high precision laser microscopy

4. CONCLUSION AND FUTURE WORK

Today the fast-changing market needs require manufacturing processes, which allow rapid adaptation. The topic of generative production in particular with rapid prototyping using advanced metrology methods is essential in the advanced manufacturing industry. The motivation of this implementation work assessment is the need for higher cost efficiency in production and economical operations. To create quick and easy prototypes has been an increasingly important process for businesses. The use of the rapid technology and the correct method provides fast customization. Using an example, a planetary gear, results and experiences could be gained correspondingly.

This paper investigates and analysis the needs of the nanotechnology for ultra-high precision engineering and micro/nanosacle workpieces by further providing an example of a functional planetary gear. The need of high precision metrology applications is focused to improve efficiency and quality in order to fulfil a reliable modern manufacturing process of such micro/nanoscale workpieces together with international standards defining parameters and tolerances in the nanometer scale.

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