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THE ANALYTIC DESCRIPTION AND DESIGN OF WORKPIECE GEOMETRY FOR MECHANICAL ENGINEERING

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ABSTRACT

The prescription and consumption of material and energy to achieve the necessary and required workpiece accuracy in series manufacturing depends to a great extent from the geometrical workpiece tolerances of any kind (roughness, form, position, dimension) which are prescribed for the production and the realisation of these tolerances and therefore for the function of the produced workpieces and their fitness for practical application and none the less of the economy of production altogether. This requirement is of great importance at the time being which is characterized by shortage of energy and raw material.
Adequate knowledge in this area is an important presupposition to achieve wastefree production and low costs of manufacturing with high as possible quality and accuracy at the same time. This is of extreme importance in present time of worldwide international competition in industry and production.

Keywords: *Manufacturing, Workpieces, Tolerances, Design, Economy, Metrology.*

1. INTRODUCTION

If the geometry of machined parts is considered as a whole there exist interactions between the different features forming the periphery of the part. But also within the surface of every single feature there exist interactions between geometrical deviations of different kind and different order. If we take these deviations of dimensions, roughness, form and position collectively the existing interactions are significant for the accuracy and the functions of the parts that should be accomblished during practical application.

2. DESIGN AND MANUFACTURING ACCURACY

Since about 1970 computer-aided production metrology has been of continuously increasing importance for the comprehensive analysis of the workpiece geometry used in modern production technology.
Depending on whether macro geometry or micro geometry is the focus of the analysis, in general distinction is made between geometrical deviations of different order. It is common practice to collectively consider the more or less short-wave geometric deviations of third or higher order as surface roughness, on the basis of internationally established parameters [1].
As already described in former research reports there is evidence for the existence of “inherent interrelations” and "so to speak a natural relationship" , as it were, between the different kinds of form errors or geometric deviations [2]. First and foremost it has been in [3] where the term of a "uniform approach to geometrical deviations of different order" has been coined [3]. This uniform approach and way of analysis has been translated into reality in particular through the development of coordinate metrology. Its applicability to microgeometry measurements has been pointed out successfully [4, 5].
Extensive industrial investigations have been carried out as support for practical industrial application and appropriate correlations and guidelines have been worked out [6-8]. Especially the already mentioned developments of computer-aided metrology supported in building up the basis for correlating permissible and function oriented geometrical deviations with workpiece accuracy [9, 10]

3. COMPREHENSIVE DESCRIPTION OF THE WORKPIECE GEOMETRY

For the geometrical description of workpieces GPS ("Geometrical Product Specifications and Verification") defines the shape (geometry), dimensions and surface characteristics of workpieces on technical drawings. In this way the optimal function of the respective part is supposed to be guaranteed considering certain manufacturing tolerances. Nevertheless workpieces will be produced, which do not fulfil these requirements. Therefore workpieces are measured and inspected in order to be able to compare the finished parts with the specifications. There is a need to relate between actual workpieces and:

- the workpiece imaginated by the designer,
- the workpiece as manufactured,
- the knowledge about the workpiece as measured.

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 Geometrical Product Specifications and Verification.
A set of requirements concerning the geometry of a workpiece (or of an assembly of several workpieces) is known as the “Geometrical Product Specifications and Verification” covering requirements of size and dimension, geometrical tolerance and geometrical properties of the surface.
Comprehensive knowledge in this area is an important presupposition to achieve economic design, construction, production, metrology and quality management.

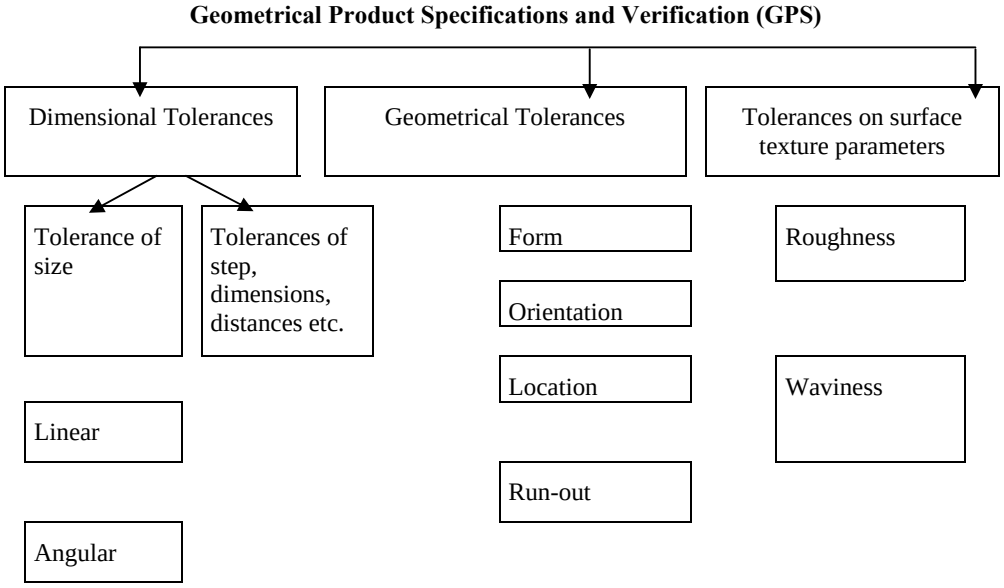


Figure 1 - Geometrical tolerances and tolerances of dimension and geometrical properties of the surface [11]

The concept of the Geometrical Product Specifications and Verification includes:

- several types of standards, some are dealing with the fundamental rules of specification, some are dealing with global principles and definitions and some of them are dealing directly with the geometric characteristics;
- different geometric characteristics such as size, distance, angle, form, location, orientation, roughness;
- workpiece characteristics as results of different manufacturing processes and the characteristics of specific machine elements and
- occurs at several steps of the product life cycle, in the development of a product, design, manufacturing, metrology, quality assurance, etc.

This concept is represented in Figure 2, showing four different types of GPS standards and designated as the "GPS-matrix-model" (Figure 2).
According to the original idea, the group of fundamental GPS standards should contain such standards which establish the fundamental rules for dimensioning and tolerancing. However, in this group there are only two documents - ISO 8015:1985 [12] and ISO/TR 14638 [13] - which contain the outline of the Masterplan [13].
Global GPS standards are closely related to many other GPS standards - first of all those contained in the General GPS Matrix. Global standards influence general GPS chains of standards directly (being referenced to) or as default documents. A very important global GPS standard is ISO 1 [14] which defines and prescribes the standard reference temperature. Another global GPS standard is for example ISO 14660-1 [15] which establishes terms and definitions of geometrical features.

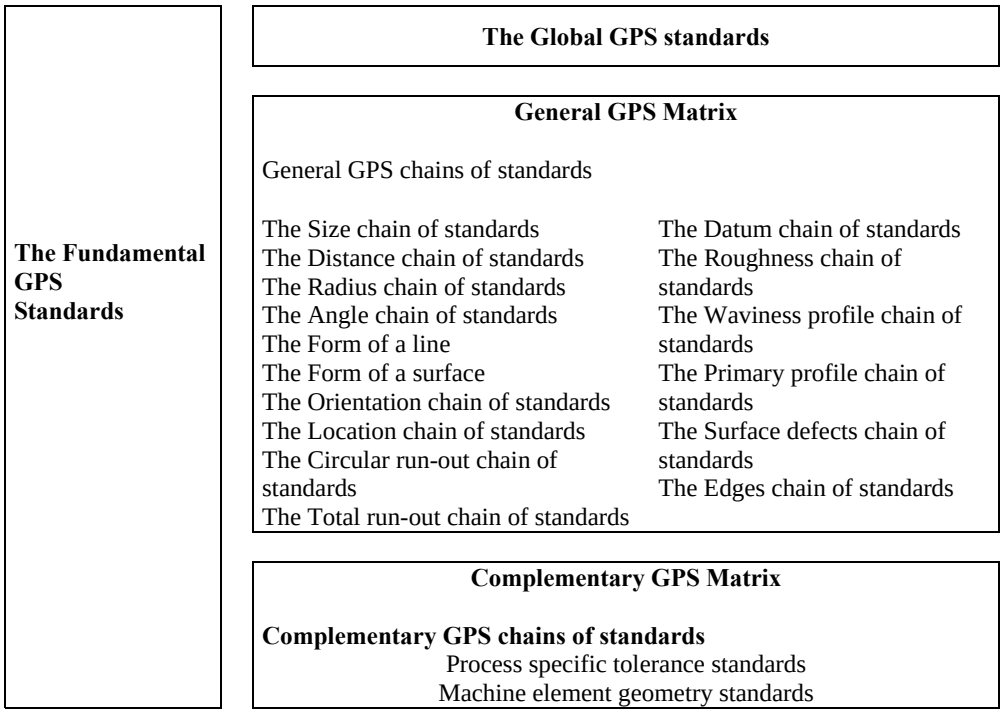


Figure 2 - The GPS-matrix-model – GPS Masterplan – Overview [13]

Complementary GPS standards contain technical rules for drawing indications, definitions and verification principles for specific categories of features or elements. Some of the rules depend on the type of manufacturing process (machining, casting, welding, forming); other rules affect the geometry of specific machine elements like screw threads, splines, or gears. Most of the big number of Complementary GPS standards have been prepared by different ISO Technical Committees; only a few are the direct results of activities of TC 213.

The Complementary GPS standards are divided into:

- Tolerancing standards for special production methods (e.g. casting, cutting)
- Geometrical standards for mechanical parts (e.g.: gears, screw thread)

4. INTERNATIONAL HARMONISATION AND STANDARDISATION IN THE AREA OF GPS

Since the 1930's it has been tried hardly by Technical Committees (TCs) of national and international bodies for Standardisation (especially the International Standardisation Association ISA before World War 2 and the International Standardization Organisation ISO since the late 1940's) to develop generally understandable and as far as possible harmonized international standards in this area of engineering.

So quite a long time the GPS standards have been developed by committees in ISO and published as soon as that there has been a specific requirement. However a comprehensive survey of all GPS standards was sometimes missing. This led to standards with different aims and representations and sometimes also to inconsistent determination. Furthermore there are gaps between the GPS standards. Since 1996, the Technical Committee ISO/TC 213 on “Dimensional and Geometrical Product Specifications and Verification” has been working towards harmonizing previously standardized practices in tolerancing (specification) and related metrology (verification). The Technical Committee ISO/TC 213 works in close collaboration with a similar committee in the European organisation CEN/TC 290. According to the Vienna Agreement all projects are processed in parallel by these two technical committees - so documents on GPS prepared by ISO and CEN are identical.

5. GPS AS BASIC REQUIREMENT FOR WORPIECE ACCURACY

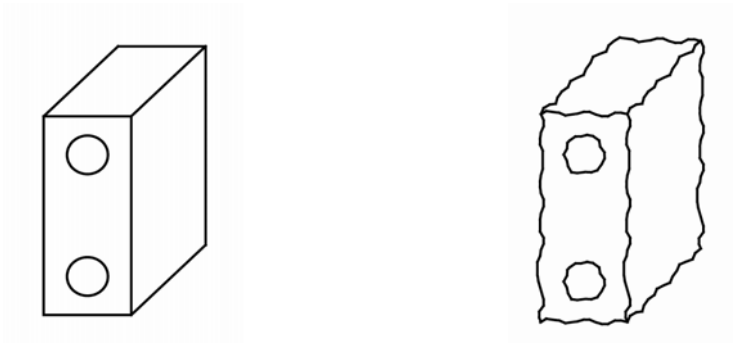
In general it is the intention of the manufacturer to satisfy all requirements that are demanded for a product. Every manufacturer is looking forward to satisfy all the criteria that its product must have. Technical means, tools and methods are used to ensure the consistency of product characteristics. One of its important characteristics or features is the geometrical specification or - it is better to say - Geometrical Product Specifications (GPS).
Geometrical Product Specifications are a means to transform function dependent demands into produced workpieces and parts based on:

- mathematical rules and methods,
- consideration of macro and micro geometry,
- possibilities for measuring of quantities and especially toleranced quantities and
- evaluation of uncertainty, etc.

In general there exist various definitions and concepts in Geometrical Product Specifications and Verification (GPS) but one of them which has been presented a few years ago named "Skin-Model" [9] was studied in the frame of some research projects. The "Skin-Model" presents a new description for Geometrical Product Specifications and Verification (GPS) with its associated details and on its basis every workpiece can be geometrically defined and considered by applying manipulations of the workpiece geometry. This determination is based on mathematical rules and definitions. It means that according to this determination every workpiece can be designed and on the other hand according to the design it can be measured very clearly.

6. THE SKIN MODEL AND COORDINATE METROLOGY FOWORKPIECE CHARACTERIZATION

The "Skin-Model" is a geometric model of the physical interface between a workpiece and its environment. It defines non-ideal features with consideration of ideal features at the workpiece circumference. A real feature is a non-ideal feature the shape of which depends of the production process and its conditions whereas ideal features exist only in theory (Figure 3).



Ideal features Non-ideal features

Figure 3 - Ideal model and "Skin-Model" of a Workpiece

The Skin-Model is based on some general and basic definitions and it uses some tools which are named "Operations" which can be compared with mathematical operations as in mathmatics and especially in arithmetic.
Operations which are applied within the Skin-Model are:

1) Partition,
2) Extraction,
3) Filtration,
4) Association,
5) Collection,
6) Construction and
7) Evaluation.

Figure 4 shows the parallel procedures which are given by “Design Intent” and the “Verification of Manufactured Workpieces” so that they comply with the design intent [16].
By application of appropriate avaluation software he measuring results can be transformed into suitable data format that can be used for further calculation and study. In the next step the measuring results will be evaluated with applying computer programs, which are available for statistical evaluations. Now the quality control department will be able to analyse this phase easily and can give necessary advice or notice to relevant other departments especially in the developing and planning domain.
This gives principal ideas in respect of the evaluation of measurement results with regard to GPS.

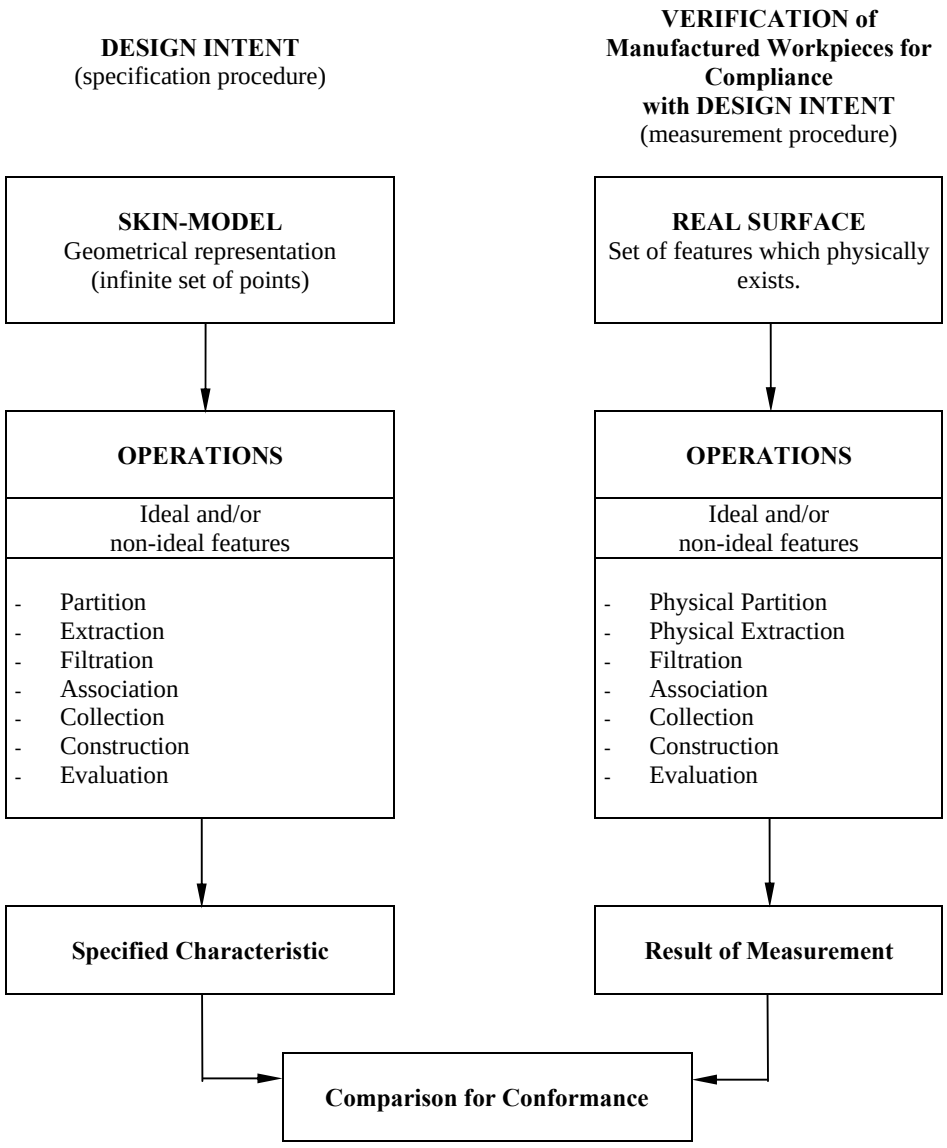


Figure 4 - Comparison of design intent and verification of manufacturedwWorkpieces

7. OUTLOOK ON FUTURE DEVELOPMENTS AND CONCLUDING REMARKS

The presented ideas explain in principal the correlation between different geometrical deviations and the manufacturing conditions. This can help to achieve lower manufacturing costs and at the same time higher quality in modern production. The presented study can be seen as a further step in the direction of a comprehensive analysis of workpiece geometry and it is fully in line with research work already carried out in the past. By the described successful application of co-ordinate metrology for the solution of measurement problems of various kind also new challenges are put onto precision production measurement technology especially in the area of GPS.

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ANALITIČKI OPIS I KONSTRUKCIJA RADNOG KOMADA U MAŠINSTVU

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REZIME

Izbor i utrošak materijala i energije za izradu radnog komada u zahtevanoj tačnosti u serijskoj proizvodnji zavisi u velikoj meri od geometrijskih i drugih tolerancija radnog predmeta (hrapavost, oblik, pozicija, dimenzija) koje su propisane i koje treba da se realizuju u proizvodnji. Ove tolerancije garantuju propisanu funkciju radnog komada, njegovu prilagođenost upotrebi za koju je namenjen, ali se pri tome takođe mora voditi računa i o ekonomičnosti same proizvodnje. Ovaj ekonomski aspekt postaje sve važniji, imajući u vidu energetsku krizu i krizu sirovina.
Adekvatno znanje u ovoj oblasti je važan preduslov za postizanje proizvodnje bez (ili sa što manje) otpada uz niske troškove izrade i visoke tačnosti i kvaliteta radnog komada. Ovo je od izuzetnog značaja u sadašnje vreme kada je konkurencija na internacionalnom tržištu sve oštrija, a sirovine i energija sve skuplji.

Ključne reči: *Proizvodnja, Radni predmet, Tolerancije, Dizajn, Ekonomija, Metrologija.*