Specific Requirements for Technical Documentation in the Automotive Industry

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Abstract. This paper focuses on solving some of the problems arising in the design process groups in the automotive industry. The geometrical specification of machine parts in the automotive industry creates a number of problems, the solutions of which is not entirely trivial and even the current standards do not offer a satisfactory solution or do not solve the issue at all. For this reason, a number of non-standardized, fragmented and mutually inadequate methodologies are created, which do not address this issue comprehensively and sufficiently satisfactorily to allow these individual adjustments and proposals to be applied on a larger scale.

Keywords: Reference Points System · Drawing Datum · Degrees of System Freedom

1 Introduction

In the automotive industry, designers are confronted with a significant discrepancy between GPS what useful resources to solve emerging problems offers relevant technical standards. It turns out that in order to meet the needs of the automotive industry, the resources offered are insufficient and do not bring the required flexibility of the tools offered. The aim of this study is trying to provide more powerful and more flexible tools to designers. The problem of reference structural elements is solved. Obviously, the reference structural element must be redesigned to determine its type and to show the directions and rotations in which the degrees of freedom are removed by the reference element. The state of the reference element must be clearly defined. Unambiguous resolution of degrees of freedom is very important for determining the movement/fixation of floating tolerance fields, which is related to the respective reference point. The paper also focuses on the definition and solution of the issue of functional structural elements and related functional schemes, the design of which is a complete novelty in the design process.

J. Homišin et al. (Eds.): ICMD 2020, AHE 17, pp. 293–308, 2023.
https://doi.org/10.2991/978-94-6463-182-1_31

2 Materials and Methods

2.1 Reference or Functional Structural Elements

In [1] was designed a system allows not only to specify RPS points more precisely but also to created reference or measured structural elements. These elements can be not only basic lines, segments, curves, planes but also directional vectors and planes and structural planes. Another option is the ability of the system to create structural elements by defining boundary elements on specific surfaces of 3D machine parts. The structural elements created must be assigned a unique ID [1, 2] and the purpose of their use must be clearly defined.

Reference Structural Elements

The reference structural element can be considered datum which are specified by the standard and currently used in geometric product specifications. To define datum for designing new technical products (TP) in a changing environment of modern technology enterprises (increasing TP entitlements, new options and methods entering the design, measurement, control and use of new technologies and materials), the reference elements known to date are insufficient and a design datum has to be re-designed to specify its type (in relation to the structural element used) and to display directions and rotations in LCS/TCS/GCS [2], in which the degrees of freedom are withdrawal by the datum. It should also be noted that the state of the datum must be clearly defined (pressing, tightening, fixing, friction …, PC = indicator of pre-tensioned contact (e.g. with a pre-tensioned screw connection), FC = indicator flexible contact free (combining the indicators it is possible to define a flexible contact FC/PC)), to see under what conditions was investigated the withdrawal of degrees of freedom by the datum. The unambiguous resolution of the degrees of freedom is very important for determining the motion/fixation of floating tolerance fields that are related to the respective datum. New demands on geometric product specifications have led to the uncertainty and attempts at solving problems related to the degrees of freedom taken off by datum in the industrial environment. Some solutions can be seen in the following figures.

If we take a closer look at the Fig. 1 and Table 1, we find that datums are not assigned a unique identifier and the directions in which degrees of freedom are with-drawn are not clearly identified.

Table 2 shows a table where, in addition to Table 1, directions in which the degrees of freedom are withdrawn are determined, which was not solved in the previous case and became a major handicap. However, it was already possible to detect an error in the geometric specification of the location of the groove from the table shown in Table 2.

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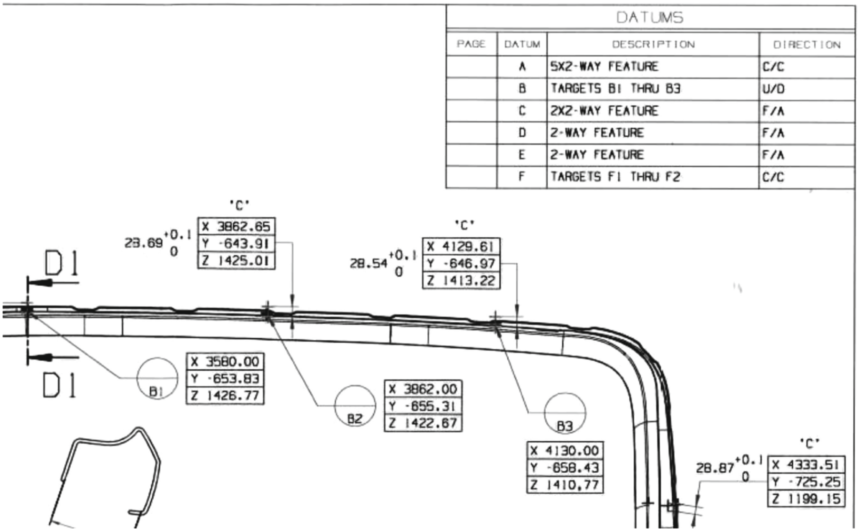

Fig. 1. Technical drawing (table of degrees of freedom)

Table 1. Table of degrees of freedom

Datum	Datum Target	Displacements			Rotations		
		u_x	u_y	u_z	rx	ry	rz
A	***A1***	---	x	---	x	---	x
	A2	---	x	---	x	---	x
	A3	---	x	---	x	---	x
B	---	x	---	---	---	x	---
C	---	---	---	x	---	---	---

of the car that no reference structural element corresponding to the frontal face of House Ending 2 (see Fig. 2). is defined in the drawing. The element should take away the degree of freedom in the direction –*uy*. Thus, in the current drawing, the definition of groove position is not fully specified and hence it is not possible to accurately determine its position during the control process. However, the described methodology has allowed us to identify the indicated problem and consequently a complete specification of the geometric tolerance of the position of said groove must be performed.

An important handicap of the system is that it does not allow the definition of TCS [2]. Since designers did not have a more comprehensive methodology when specifying GPS (Fig. 2), they decided to solve this problem by rotating the House Ending 2 axis in such a direction that it corresponds to the direction *uy*. After this transformation, the removal of degrees of freedom in individual directions of displacement and rotation around the respective axes of LCS was subsequently solved. Another problem is that the methodology does not allow specifying the state in which the base is located [TC/PC/FC/FIX] [2] so that the detachment of the degrees of freedom is dealt with correctly with respect to this state, which corresponds to the method of mounting and fastening the proposed machine part in the associated assembly. An illustrative example here may be the application of pressure to the surfaces forming the contact. If we consider the friction between the contact surfaces, the degrees of freedom will also be removed in directions in which friction is preventing the surfaces from moving together.

A new design specification and determination of DOF for reference structural elements, as shown in Table 3, 4, seeks to eliminate all of the above-mentioned shortcomings in the automotive industry solutions used.

Obviously, using the proposed TCS [2], the above problem with the House Ending 2 freedom of removal is simply solvable. Now it is enough to define a new TCS so that its 'X' coordinate vector is collinear with the centerline of the hose end being examined.

As mentioned above, a construction datum (Fig. 3) had to be redesigned, which is a complementary element to the table shows in Table 3, 4 and allows the graph of deprecated degrees of freedom to be displayed in a graphical manner. Furthermore, specify the reference element type, contact indicator and preloading force more precisely.

The construction datums are used mainly on so-called 'functional schemes', which are processed before the creation of the drawing documentation and primarily used to analyze of functional conditions 'FPod' (e.g. dimensional FPods are clearances, overlaps,

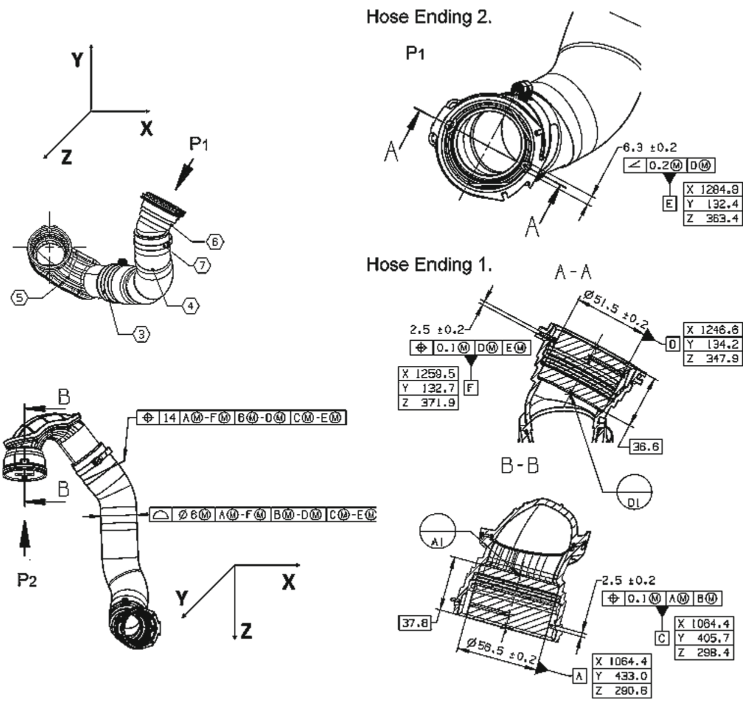

Fig. 2. Hose drawing (automotive industry)

Table 2. Table of DOF - extended with directional resolution

Hose Ending	Datum	Datum Target	Displacements			Rotations		
			u_x	u_y	u_z	rx	ry	rz
1.	**A**	---	±	±	---	±	±	---
	B	---	±	---	-	---	---	±
	C	---	---	---	±	±	±	---
2.	**D**	---	±	---	±	±	---	±
	E	---	---	+	±	---	±	---
	F	---	---	±	---	±	---	±

Table 3. Table of DOF - new proposal (first part)

Drawing Sector	Identification code	Datum	Datum Target	Partitions Specifications of the-Machine Part (identifier) [especially in non-rigid parts]	Displacements			…
DSec	ID	A, B, …	A1, A2, … B1, B2, … …	*Partition ID1, Partition ID1,* …	$u_x^{TCS,LCS,GCS}$	$u_y^{TCS,LCS,GCS}$	$u_z^{TCS,LCS,GCS}$	…
								…
								…

Table 4. Table of DOF - new proposal (second part)

…	Rotations			TCS, LCS or GCS identifier Target/Local/Global Coordinate System	Contact Indicator	Preloading Force	Friction
…	$u_x^{TCS,LCS,GCS}$	$u_y^{TCS,LCS,GCS}$	$u_z^{TCS,LCS,GCS}$	e.g. TCSPn(X[A], Y[A], Z[A], rx^{LCS}, [rx^{LCS}], [rx^{LCS}])	[*TC /PC /FC /FIX*]	PF [N] e.g. *PF x/da* [%][2]	[between prestressed surfaces]
…				…			
…				…			

etc.) specified for specific machine parts in relation to their closest neighborhood, but also a more complex group / whole of the technical system. Based on this analysis, it is then possible to more accurately and more specifically implement the geometric and structural product specification. A triangle indicated by a dashed line is added when it is necessary to define Movable Datum Target and indicates that the target date is not fixed at its basic location and is free to translate and rotate during product alignment. Once fixed, the DOF is also removed in the respective directions.

Functional Structural Elements

Functional surfaces

For functional surfaces it is first necessary to specify their properties, especially the functional properties.

For the specification of the functional properties of the surface elements whose boundaries could be more precisely defined by the so-called GPS Bindings, which are formed by the Feature Types listed in [1], it is possible to use the analysis of the functional properties of the surfaces shown in Fig. 4.

Figure 4 on the right shows the contact bond of two surfaces (KP). This contact can be described by the following features:

TF – Forming Function of the contact area (introduces each area for better orientation in the scheme).

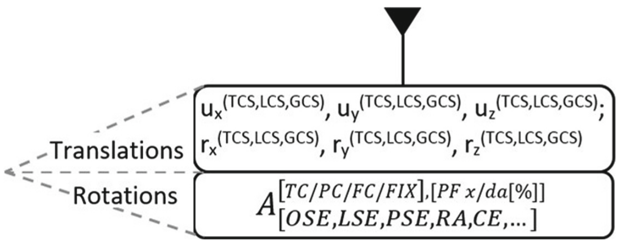

Fig. 3. Construction Datum - new proposal

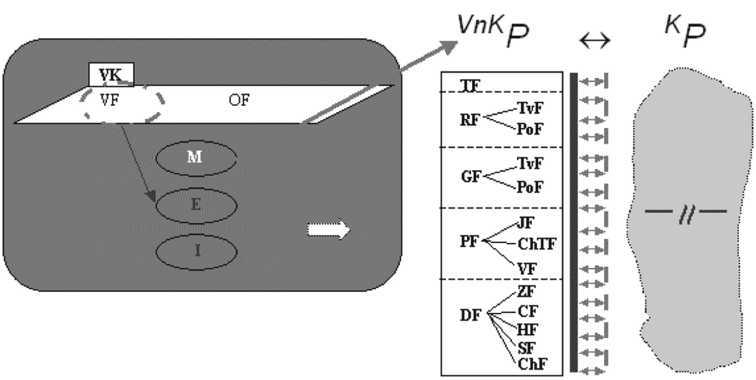

Fig. 4. Functional structure with representation of contact binding functions

RF - Dimensional Functions.

TvF - Dimensional Functions of Shape PoF - Dimensional Functions of Position GF - Geometric Functions.

Note:

GFs are of great importance for describing complex shapes in the automotive industry.

TvF - Geometric Function of Shape.

PoF - Geometric Positioning Functions PF - Surface Functions.

JF - Surface Quality.

ChTF - Chemical Thermal/TF - Thermal Surface Treatment VF - Layers Applied to the Base Surface.

(OF) - Further Surface Treatment (e.g. rolling, peening, knurling, etc.)

DF - Complementary Functions - these functions can be derived from human senses ZF - Functions Derived from Visual Perception. This includes both TS design perception and safety issues (e.g. dark car on the road, all-year lighting, yellow-green back-lighting, etc.)

CF - the Function of Olfactory Perception (e.g. the issue of exhalation, defensive function) based on odour, etc.)

HF - Functions Derived from Touch Sensation (including direct contact with TS, does not cause an allergic reaction - e.g. cases of various toys and soothers for children).

SF - Functions Derived from Hearing Perception (known problems with TS noise, safety functions, etc.)

ChF - Functions Derived from Taste Perception (including the fact that a user may not, for example, poison if a given TS (such as a pencil), or chew in the mouth (again known problem with toys), etc.

So far, we have only described the functions of the surface element of a machine part that is in direct contact with the other parts. However, it is clear that there are surfaces/surfaces that do not form contact bond.

The functional surfaces need to be divided into measurement and control according to the required specifications.

Types of specifications:

Specification in general, as specified in document (ISO 9000: 2015), where “document” can be e.g. drawing or digitized information.

Function specification (FUN-SPEC designation) as a function request document.

The designer is responsible.

Production specification (MAN-SPEC designation) as a production process requirement document. One or more MAN-SPEC can be derived from FUN-SPEC, taking into account, for example, knowledge of production processes. MAN-SPEC must always be in accordance with FUN-SPEC. MAN-SPEC can never replace or change FUN-SPEC (that is the control), so FUN-SPEC must never be removed for some reason.

Verification Specification (VERI-SPEC), as a requirement for the related manufacturing process.

There are two types of VERI-SPEC:

- VERI-SPEC (F) in conjunction with FUN-SPEC
- VERI-SPEC (M) in connection with MAN-SPEC

Specification of the agreement (contract, marking CON-SPEC) between the manufacturer and the customer.

Manufacturing companies set the functional and verification characteristics in internal guidelines.

Technical and functional characteristics - CTF.

(based on FUN - SPEC/MAN - SPEC).

- Dimensional property, which can be measured (length, weight, time, frequency…)
- Evaluable target parameter (e.g. material composition, color assessed by main sampler, OK/NOK criterion…)

These are the characteristics of the final product whose compliance with the requirements ensures that the product meets all the requirements of the technical specification (specification of requirements for TP properties).

Validation Plan (VP).

Describes the tasks that must be performed to ensure that product/process solutions meet all technical requirements.

This plan is fulfilled by the supplier in those parts for which he is responsible.

VP describes:

- Access to justification, calculations, tests …
- Check the results if they are within tolerance limits.

Supplier.

- Designs a product manufacturing solution and an associate flow chart of production process.
- Specifies and favours CTF for each request (nominal + tolerance) by modelling the case to provide the necessary functionality.
- It creates the first part of the validation plan: it performs calculations, evaluations or tests to justify the relevance of the proposed solution with regard to critical requirements, operational safety and reliability.
- Assessing the industrial feasibility of the proposed solutions.
- It completes the validation plan by verifying the results of whether it lies within the tolerance limits for each CTF.
- It modifies proposed solutions to be relevant and feasible if evaluation results are negative.

The main expectations and results of this activity are.

- Validated product definition.
- For each requirement: a list of related CTFs defined for the product (for measurable physical quantities, tolerances applied to CTF).
- Explanatory notes on calculations, testing and product design.
- Production process diagram.

- Feasibility reports of proposed solutions in practice.
- Definitive version of the validation plan.

At the same time, the subscriber evaluates the integration into the system for supplier solutions in parts where they contribute to the entire system. It sends the results and the necessary information to the supplier.

Product eligibility elements are obtained throughout the development phase.

During these activities, the suitability and feasibility of the product-process solution is estimated when compared to the requirements.

This estimate is created and verified sequentially by the customer following the re-view of the justification and CTF list submitted by the supplier during the project evaluation.

The activity is completed when the solutions are modified and feasible and the related CTFs have been sufficiently identified and defined.

Definition of a Monitored Essential Characteristic - CSE.

Characteristics to be monitored:

- Conformity necessary for the flow of production flow, in the downstream stages of the production flow, can be produced in concert to ensure that the finished component or the entire vehicle is in accordance with its definition.
- Disconformity that may have a negative impact on the end customer.

For a given part, CSE should preferably correspond to CTF (Fig. 5), but may also be a characteristic if intermediate product or, exceptionally, a process parameter. Based on the CTF list, related customer risks, provisional or known process complexity and variability, the supplier proposes a CSE list.

The customer and the supplier agree on the CSE and these CSEs are formalized in the Component Control Plan.

Product Control Plan (PCP).

A Product Control Plan is a supplier-defined document and officially certified by a customer that lists the features of a component whose compliance must be proven by the supplier during development and during full production. The content of this list changes from the CTF list established at the design stage to the CSE list established on the basis of the real production and production analysis. In the case of CTF and CSE, PCP further includes a more detailed specification that determines whether it is a Significant Characteristic (SC) or a Critical Characteristic (CC).

The PCP summarizes the following:

- Criterion for checking compliance of characteristics.
- The methods and/or means of control used to check the criteria to be respected.
- Inspection conditions (sampling, selection type, frequency…).

The main outputs are:

- Production process monitoring system.
- Product/Part Control Plan (PCP).

The activity is completed when the customer believes that the planned system is capable of ensuring product compliance.

Significant and Critical Characteristics.

Identifying the drawing specifications by dividing the drawing into sectors using a grid has proven to be inadequate, and for this reason, every geometric product specification - dimension, length tolerance, shape and position tolerance, surface quality, processing, note… - needs to be assigned unique code (mostly serial number), which is stated in so-called “tears” (Fig. 6) or in circles. Additional information can then be added to each specification through the technical documentation management software products (PDM (Product Data Management)).

Within PDM are listed all the necessary product information and, of course, the information contained in ‘VP’ and ‘PCP’. This information can also be presented in the drawing in a simplified graphic form.

The meaning of the CTF, CSE, SC, CC symbols (see Fig. 7) is shown.

The significance of the symbol <DA>.

In accordance with VDA Vol. 1 (1998) may be required by law or contract to classify documentation and records as DmbA (Safety-Document Parts).

Note:

DmbA is a replacement for the older ‘D-Part’.

So if it is in Fig. 10. Listed <DA> symbol (documents with special archiving requirements) is required to substantiate the actions performed under ‘VC’ and ‘TCP’ in an agreed and determined manner (the legislation may apply to the eradication and data protection).

DmbA documents should be labelled and kept in archives for at least a legally specified or agreed time.

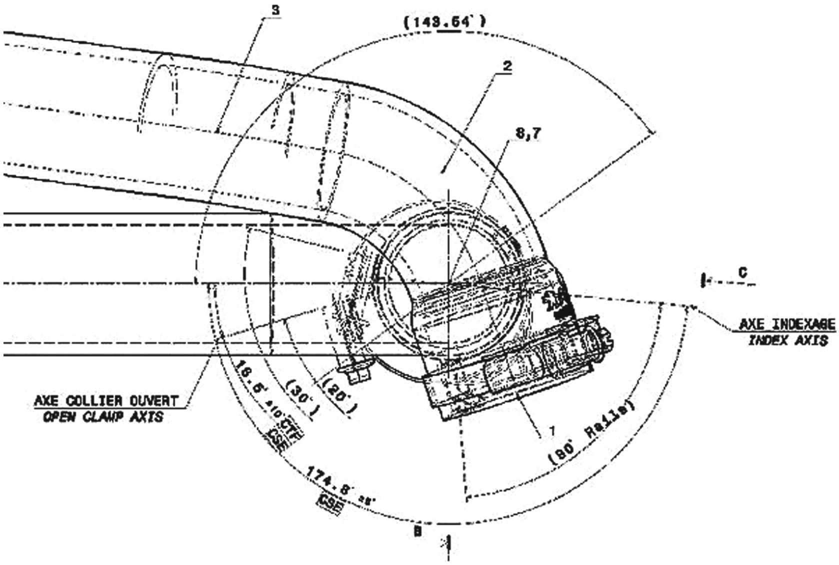

Fig. 5. Definition of CTF/CSE on hose drawing

The DmbA specification only specifies the requirements for maintaining and archiving documentation and records. DmbA does not contain any specifications and requirements needed to control, measure and ensure product functionality.

The significance of the symbol <S>.

This symbol refers to critical elements that have a significant impact on the safety of the entire technical system throughout its life cycle.

The meaning of the filled triangle.

The meaning of this graphic symbol is governed by the corporate regulation in which they are for individual filled quadrants and all completed rhombus stated particular specifications for conducting experiments (DOE), conducting tests, heat treatment, product modifications and coatings as specified in 'VP', performing measurements and methods of measurement (simplified measurement methods must satisfy the condition that they may indicate non-compliance with the property specification. However, it should

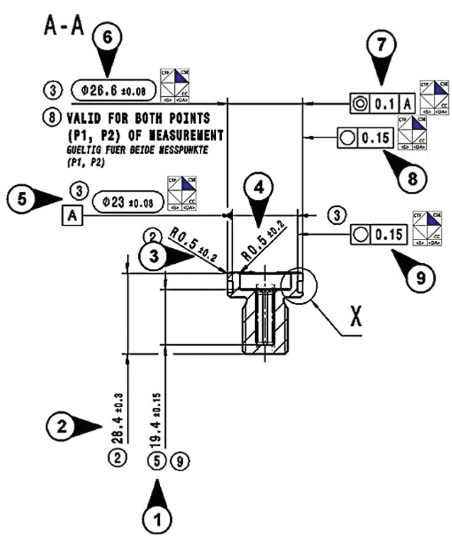

Fig. 6. Introducing the Functional Structural Elements Specification on the Drawing

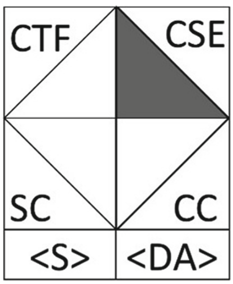

Fig. 7. Functional Structural Elements specification symbol design

not indicate conformity if a standard mismatch is indicated with its specification in the 'PCP' and so on.

In total, there are five options available (Q1, Q1, Q1, Q1, Set all Q). If more variants are required, they can be added to the basic rectangular shape other rhombus and a combination of filled triangles to obtain other necessary variations of additional specifications.

However, it should be noted here that the purpose of the graphic symbols is to achieve transnational clarity (global company), simplicity and ease of remembering graphic symbols. It follows from the logic of this case that the graphic symbol should not represent too many variants.

Figure 9 shows a plastic blind screw whose main function is to seal. The seal is provided with an O-ring that is mounted in the groove shown in detail 'X'. Since the screw is made of plastic, the geometric tolerances of the groove are relatively high and therefore the parameters listed under ID 5, 6, 7, 8, 9 are critical, needing to be secured and adhered to concentrate extraordinary attention and these are parameters to be archived during 10 years.

In the company regulation, the specified triangle symbol is specified for the given graphic symbol helium test.

The helium test responds to the tightening of the criteria according to the Euro 6/Euro VI emission standard for car hydrocarbon leakage. The test is carried out on a test bench. It is a two-chamber leak testing system. The test vacuum chamber is divided by the central part with the sealing screw into two parts. When the chamber lid is closed, it will be exhausting air from the upper chamber. Thereafter, helium is pressurized under the flange to the desired test pressure level. The pressurization is usually carried out in successive steps of increasing the pressure of the helium because of the smallest possible contamination of the system and the detector in case of greater leakage. Air is also removed from the bottom and helium leakage is measured. The leak size of the product is then proportional to the size of the helium leakage [Pa.m^3/s].

2.2 Floating Tolerance Field and Fixation of Their Movement in Defined Direction

To define/detect the fixation of the floating GPS tolerance fields, use the DOF removal table shown in Table 3, 4. The motion of the floating tolerance fields is fixed in those directions in which the related reference element takes-of the degree of freedom from the technical system.

The customer requests the proper shape of the seal profile specified in the technical drawing shown in Fig. 8.

In the first step, it is necessary to define a Root Parenting Layout of GPS (RPL) that can pass as an ancestor hereditary the properties of their descendants (heirs).

Homogeneous RPL (HRPL) it can be composed of one or several individual reference elements (Theoretically exact feature - TEF) or continuous reference elements that are controlled by one basic geometric specification. If the HRPL consists of multiple TEFs, it must be supplemented with the Common Zone Modifier (CZ) in the tolerance section. The reference profile line thus represents the so-called TEF, which is part of the RPL.

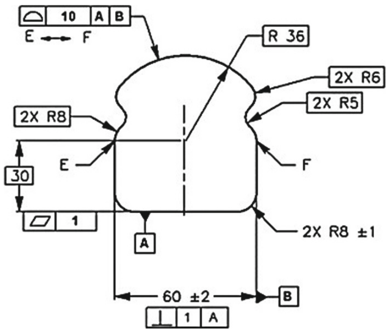

Fig. 8. Geometric specification of the seal profile

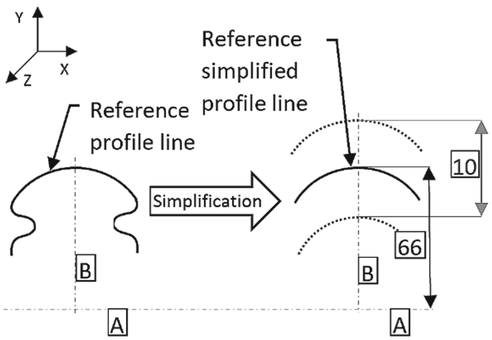

Fig. 9. Root Parenting Layout of GPS (RPL)

Inhomogeneous RPL (IRPL) can be composed of several individual reference elements (TEFs) or continuous reference elements that are controlled by more than one basic geometric specification. The IRPL must be complemented by the Simultaneous (SIM) modifier.

The sealing function and Fig. 8 show that the geometric position tolerance reference profile line is bound to two datum (A, B). Since the seal is housed in a groove - installation space, the axial base removes the degrees of freedom in both directions of the X-coordinate. The degrees of freedom are again taken in both directions of the Y-coordinate. The position of the tolerance field is fixed in the plane $\overline{XY}$ (fixed position with respect to datum A and B). The position relative to datum A is expressed explicitly (theoretically exact dimensions: 30 and R36). The position relative to datum B is expressed implicitly (displaying axial symmetry). Since the geometrical tolerance of the surface shape is too great in this case, the correct shape of the sealing surface of the seal (e.g. flattening) and the correct orientation of the partial surface areas in the longitudinal direction of the seal (depression, bulge, local descent and climb, etc.).

If we imagined this simple seal as an automobile door seal, it would be necessary to squeeze the seal too much (> 10) since with less compression tightness of compression would not be guaranteed. If we add to this the inaccuracies of the installation space and sealing surfaces, this is the case that compression is too big. It would appear to

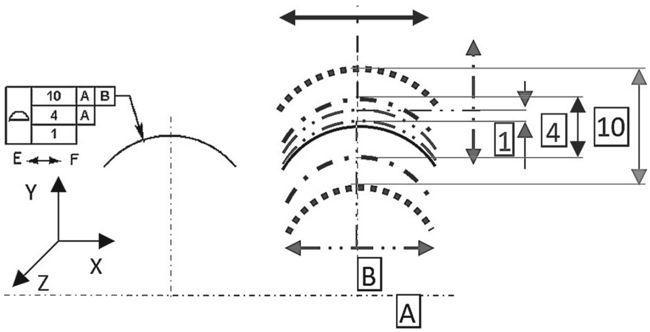

Fig. 10. Restricting the movement of floating tolerance fields based on DOF removal

be particularly difficult to close the car door (excessive force is required for sufficient deformation of the seal).

The tolerance field shown in Fig. 10 is fixed in Y directions to datum A, and in X directions it can be within the boundaries defined by the blue tolerance field. The green tolerance field is not fixed to the datum and can move in all directions of the $\overline{XY}$ plane.

The movement is limited by the red field boundaries. As a result, the shape of the profile is determined by the green tolerance field, the orientation of the sub-parts is determined by the red field.

This specification indicates that the seal tightness must be slightly greater than 4 [mm] and the door closure will be easier than in the previous case. The seal can be moved perpendicular to the longitudinal direction of the installation slot within the blue tolerance of 10 [mm].

This allows a sufficient width of the sealing surface of the door frame and therefore this inaccuracy no longer affects the function of the seal, but it has the effect of reducing the overall cost of providing zero leakage of the doors seal.

3 Results and Discussion

The presented result of creative activity is the design of methodology and complementary functional tools, which allows a new approach to solving problems arising from the transfer of knowledge, ideas and information from the design process into practice through design documentation. This paper presents a proposal for solving specific problems that current methodologies and design tools can solve only partially or not at all. If we summarize the individual benefits, it is mainly about:

– The introduction of the new TCS coordinate system made it possible to unambiguously determine the directions in which degrees of freedom are taken from the system.
– Determining the state of the reference functional element in which it is currently located has made it possible to correctly determine the removal of degrees of freedom by the reference elements so as to take into account this state, which corresponds to the method of assembly and fastening of the proposed machine part in the relevant assembly.

- The new design specification and DOF determination for reference components made it possible to eliminate the shortcomings of current systems used in the auto-motive industry.
- The new design of the design reference element allows a graphical representation of the removed degrees of freedom. Furthermore, specify the type of reference element, contact indicator and bias strength more precisely, which the current methodology does not allow at all. The newly designed reference elements are mainly used on the so-called “Functional Schemes”.
- A new proposal of the methodology for the creation and processing of functional schemes, which are processed before the creation of the drawing documentation of the system and their goal is primarily the analysis and determination of functional conditions and determination of parameters of properties of structural functional elements.
- New design Functional Structural Elements specification symbol design that allows particular specifications for conducting experiments (DOE), conducting tests, heat treatment, product modifications and coatings as specified in ‘VP’, performing measurements and methods of measurement.
- Definition of floating tolerance fields and a new proposal of the method of determining their movement relative to reference structural elements. This allows you to define/detect the fixation of the floating GPS tolerance fields, use the DOF removal table. The motion of the floating tolerance fields is fixed in those directions in which the related reference element takes of the degree of freedom from the technical system.

4 Conclusion

The proposed system allows specify and created reference or measured structural elements. These elements can be not only basic lines, segments, curves, planes but also directional vectors and planes and structural planes. Another option is to create boundaries of existing surfaces. Structural elements were divided into Reference Structural Elements and Functional Structural Elements. The paper presents suggestions for solving the problems presented by designers working in serial and mass production of technical products in their daily practice. Problematics of Control and Measurement Structural Elements already exceeds the scope of this contribution and is therefore no longer mentioned here.

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