GEOMETRIC SPECIFICATION OF COMPLEX SPATIALLY-ORIENTED AND COMPLIANT COMPONENTS I.

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Abstract
The article is focused on geometric specification of complex spatially-oriented and compliant components. Manufacturers of complicated and flexible machine parts, particularly in the automotive industry, are finding themselves in almost insoluble problems when designing TS and preparing their technical documentation. These problems arise mainly in describing the geometrical properties of technical products in order to ensure their errorless production and control in subsuppliers. Unfortunately, GPS standards are not flexible enough to meet these specific requirements, and from this reason manufacturers or their consortiums respond to this situation by defining their own procedures and regulations that allow them to solve these problems. However, the negative consequence of this state is that there is no general agreement and consistency in the description between the individual internal rules of the firms and this creates considerable problems for the subcontractors, who cannot properly read the technical documentation and correctly set up production and control procedures, which in some cases can lead to a fatal consequences. The aim of this paper is to identify these inconsistencies and propose ways to solve the above-mentioned problems.

Key words: *reference points system; RPS; local coordinate system, global coordinate, CMM.*

INTRODUCTION

Correct localization and orientation of machine parts and their design parameters on the drawing, confusion in defining coordinate systems and their description, removal of degrees of system freedom and related fixation of movement of tolerance fields of geometric tolerances, determination of exact position of datums and directions of measurement for complex parts, definition of pressure and free states of flexible parts, uncertainty of parameter specification in dimensioning and resulting uncertainty for control and measurement, and a number of other uncertainties are the impetus for introducing a certain system and establishing clarity in the specifications of individual GPS parameters.

MATERIALS AND METHODS

If we take into account the needs of the automotive industry, which is very widespread in the Czech Republic, we have to introduce two coordinate systems. Global Coordinate System, which is a system of the whole car and is used for determining the localization of concrete machine part of in the whole system and a local coordinate system, which is used for specification of the geometric parameters of a particular part, for their control and measurement. The relationship between these coordinate systems is defined by reference points (RPS) of technical system (TS). Figure 1 illustrates the use of three methods of designating coordinate system axes. In the table showing the removal of the degrees of freedom, the directions of the axes according to the orientation of the car body (Fore/Aft; Up/Down; Cross/Cross) are given. There is also a similar system where O.L. (object location) is followed by the identification of the direction. The last direction is marked ℄, which is mistakenly taken over with the ISO drawing of piping systems, where it indicates the axis direction, the definition of which is completely absent and would be needed it for hose drawings in the automotive industry. Other directions can be indicated by a coordinate grid where the individual lines represent Water Line (WL), Buttock Line (BL), and Traverse Line (TL). In Figure 1, the coordinates of the reference points of the technical system (RPS) are designated X, Y, Z. In the drawing of Figure 1, it is very difficult to compare individual coordinate systems according to axes directions, which are however differently labeled. The solution is to introduce the unambiguous and usual designation of the coordinate axes and rotations [x, y, z, r_x, r_y, r_z]. The designer will determine the location and orientation of the global GCS coordinate system on the model of a complex technical system GCS [0,0,0,0,0,0]. In the production drawings, local coordinate systems (LCS) are localized. The position of origin and rotation of the LCS is given to the GCS in the so-called absolute coordinates and is given in the table for RPS points LCS [ACx, ACy, ACz, r_x^{GCS}, r_y^{GCS}, r_z^{GCS}] in the production drawing. The relevant specifications given in the drawing are then given in relative coordinates related to LCS. It is then possible to specify other target coordinate systems (TCS) in the drawing. In this system, it is necessary to define the origin with the RPS point and its rotation to the LCS, either by angles of coordinate rotation or more simply by coupling properties such as axial $TCS_{P1(XA,Y,Z,\ rx^{LCS})}$. The designation indicates that x is in the direction of the axis of the element passing through the RPS by the point P1 and the TCS_{P1} is rotated about the X LCS by r_x^{LCS}. The origin of TCS_{P1} lies in the RPS point marked P1. TCS are suitable, for example, for determining the degrees of freedom of the end sections of flexible systems.

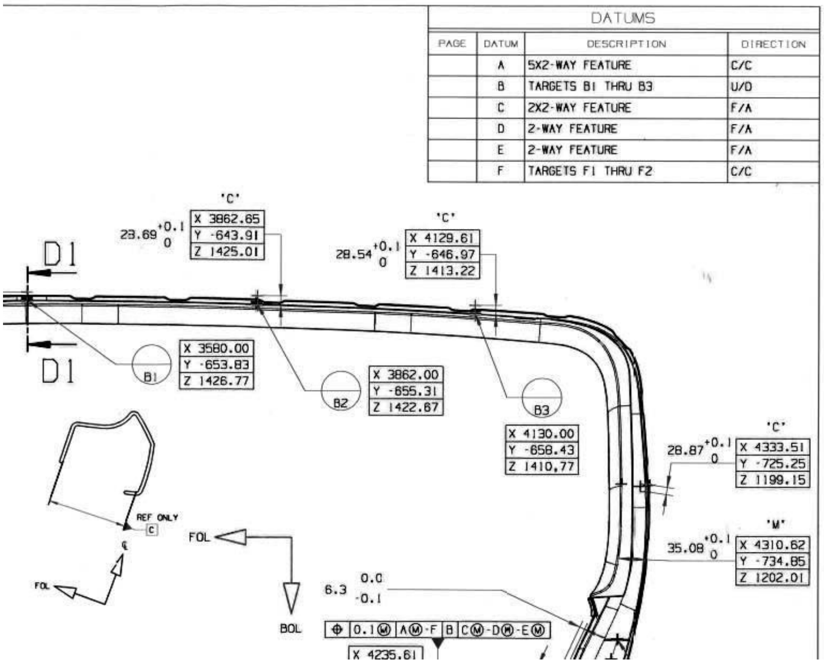


Fig. 1 Technical drawing (coordinate systems, table of degrees of freedom, RPS references)

RESULTS AND DISCUSSION

Similarly to reference datums elements, reference points can be used to set, ensure the correct position and orientation of a component. The establishment of the RPS should be based on a functional approach again, depending primarily on the purpose of the RPS:

1) RPS used for linking 3D models in CAD systems.
These RPS used to provide a link between the models defined in the GCS and the machine parts defined in the LCS. This makes it easy to fit individual parts into the overall TS (TS) model and to easily assess the smooth surface continuity, collision solutions, and so on. These points must be marked as follows in the drawing: ${}_{D}P_n\ [x_{GCS}, y_{GCS}, z_{GCS}, x_{LCS}, y_{LCS}, z_{LCS}]$ or to specify the RPS drawing in the table. Coordinates of RPS are considered theoretically accurate. Note: The CATIA module supports the creation of RPS points according to the corporate standard VW 01055.

2) RPS used for the positioning of coordinate systems and references defined in the drawings.
The meaning of this RPS results from the context of the drawing, and therefore it is not necessary to specify it in the lower left index of the point designation. At the base line, two RPS points are needed to specify the exact specification. In some special cases (a line parallel to the reference element and tangent to the structural element), it is sufficient to specify only one RPS. Similarly, this applies to moving targeted datum only by the fact that it is necessary to define the origin of the RPS vector in the so-called reference position and the direction of the vector (lines) is given by the start and the next RPS. For

targeted bases with a defined contact surface, the RPS point lies within the geometric center of the specified area. Point coordinates are again considered theoretically accurate.

3) RPS for specifying directional vectors.
The significance of this RPS point again arises from the context of the drawing. In Fig. 1 we can observe the confusing definition of the directional vector. The beginning of the vector is given by, for example, a targeted base B_2, Whose position is given by unlabeled RPS, and the direction is again given by an unlabeled RPS point [3862.65, -643.91, 1425.01]. In the direction of the vector, the size measurement is performed and is specified by the dimension $28.69^{+0.1}_{0}$. For a clear definition in the drawing, we suggest that the specification be done according to Fig. 2, where coordinates of labeled RPS points are listed in the RPS drawing table. Coordinates can of course be placed directly in the RPS point information field. The direction vector is then marked as follows: $\overrightarrow{DV}[P_{na}, P_{nb}]$. Coordinates of points are again considered theoretically accurate.

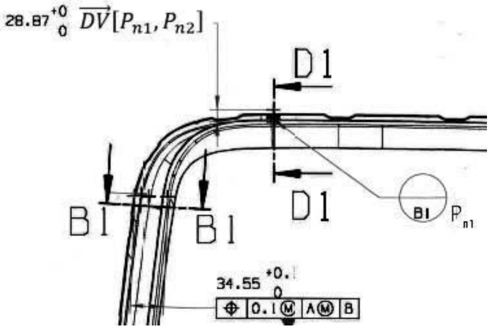


Fig. 2 Coordinates of points are again considered theoretically accurate.

4) RPS for control on metering machines (CMM).
We suggest the following way to mark such a point
${}^{Y(St)}_{CMM}P_n u_x, u_y, u_z/C(NC)^{SR\,x\,(F\,\phi D\,(a\,x\,b))}_{PF\,x/da[\%]}[x_{LCS}, y_{LCS}, z_{LCS}][ST_x, ST_y, ST_z]$, where
P = point mark, n = serial number, Y = yielding and St = stiff part, u_x , … = determines the directions in which CMM approaching the measurement, C/NC = contact / non-contact method of measurement, SR x = ball measuring contact with radius x, Fϕ D (a x b) = Measuring contact with a circular surface ϕ D or with an area of dimensions a x b, PF x = pressure force of the x-size [N], where $da[\%]$ allowable deviation from the nominal force, $[x_{LCS}, y_{LCS}, z_{LCS}]$ = measured LCS-related coordinates (if not specified, not measured), $[ST_x, ST_y, ST_z]$ = coordinate tolerance specification can be given by ES/ EI deviations, zero if it is theoretically accurate dimensions (used for reference elements), or not specified and then general tolerances. Fig. 3 shows the RPS points on the drawing in practice. The marking of point P_5u_x means that measuring contact track in direction of coordinate of LCS. Other required point parameters are specified in the RPS table.

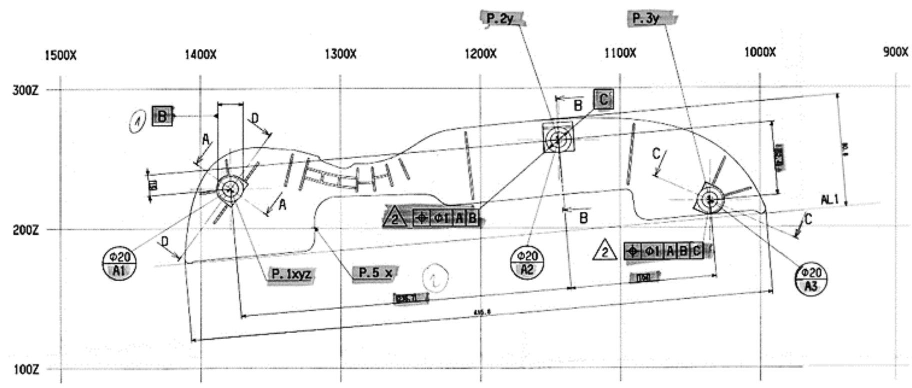
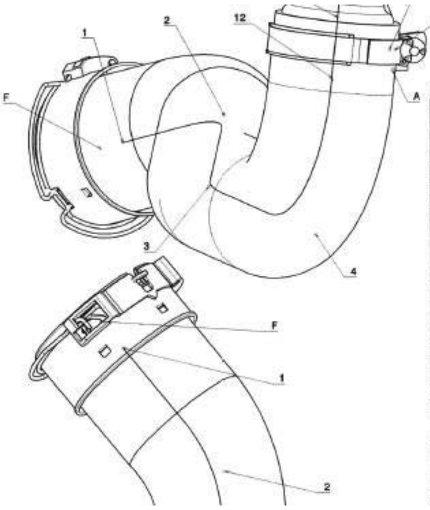


Fig. 3 RPS points on a technical drawing

5) RPS for specifying reference curves for tool making and control of machine parts shapes.
In Fig. 4 we can see the definition of the hose centerline in the automotive production drawing using RPS points. The centerline is seen here as the reference base of the curve type and therefore the coordinates of the individual RPS are theoretically exact dimensions. At the points of the transverse arcs, points are defined at the intersection of the tangent lines, which must be supplemented by the radius of the transition arc in the RPS point table. In Fig. 1, the coordinates of the RPS points in both GCS and LCS are given in the tables. We propose the following point designation:

$_{RefC}P_n\ [x_{GCS}, y_{GCS}, z_{GCS}, x_{LCS}, y_{LCS}, z_{LCS}][R_T^{P_i,P_s}]$ kde

P = point mark, n = serial number, RefC = reference curve, $[x_{GCS}, y_{GCS}, z_{GCS}, x_{LCS}, y_{LCS}, z_{LCS}]$ = theoretically accurate coordinates (unnecessary coordinates are not required), $[R_T^{P_i,P_s}]$ = The radius of the tangent arc to the point connecting line $\overline{P_i\ P_n} and\ \overline{P_n\ P_s}$.



PART COORDINATE AXIS

REF.	X	Y	Z	Radius
1	-454,06	356,31	-170,79	
2	-403,51	295,22	-167,71	R75
3	-411,52	127,26	-192,62	R80
4	-358,37	-26,97	-216,56	R70
5	-347,26	-34,93	-109,78	
6	-8,74	-7,3	11,73	
7	-34,24	-28,61	45,92	R50
8	-86,81	-40,62	48,83	R50
9	-112,2	-39,92	36,45	R45
10	-118,57	-38,78	31,31	R45
11	-153,99	-38,78	17,14	
12	-350,36	-32,71	-139,53	
13	-341,87	-38,78	-57,99	
14	-124,28	-38,78	29,03	
A	-320,12	43,5	-135,79	
B	-321,57	43,5	-125,49	
C	-318,67	43,5	-125,49	
D	-156,92	21,33	-29,12	
E	-149,71	17,87	-29,12	
F	-464,95	369,48	-173,61	
G	0	0	0	

VEHICLE COORDINATE AXIS

REF.	U	V	W	Radius
1	-363,14	102,31	258,65	
2	-312,6	41,22	271,73	R75
3	-320,61	-126,74	236,82	R80

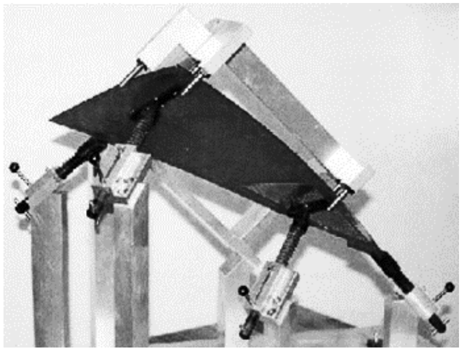


Fig. 4 RPS for specifying reference curves

Fig. 5 RPS for clamping in measuring devices

The definition of reference centerlines finds application, for example, in the design of hose shaping pins. The production of the hoses takes place by means of a non-vulcanized straight rubber hose, followed by vulcanization. After shaping it is necessary to remove the hose from the mandrel, which can cause problems. It is advisable for the reference center line of the hose to be composed of a line and tangent arcs whose spatial position and orientation is given by RPS points. It is not recommended to create a centerline in the CAD system using a spline curve => Problematic hose production. It is also not recommended to connect two tangent arcs. It's not a bug, but it's difficult for programmers to bend the thorns. Table for entering RPS points is good to supplement by the total length of the hose centerline. This information serves as a check number in case any error occurs when entering the 3D coordinate of the hose. Tolerances of the shape of the outer surface of the shaping hub of the hose are specified in the drawing by means of the geometric tolerance of the shape relative to the reference axis of the mandrel. The reference center can also serve to specify the geometrical tolerances of the surface of the hose and to design special control means to control the shape of the hose.

6) RPS for clamping in measuring devices and their designing (Fig. 5.)
For defining these RPS points, RPSs are used to locate the references defined in the drawings according to 2). Most often, they are targeted datums and hence the coordinates of the point are understood to be theoretically accurate.

$_{MI}P_n\ [x_{GCS}, y_{GCS}, z_{GCS}, x_{LCS}, y_{LCS}, z_{LCS}]$

Targeted bases may have prescribed force-specified depressions. In this case, it is within the competence If it is necessary to define precise positioning pressures with RPS points, then the following point is necessary:

${}^{Y(St)}_{MI}P_n u_x, u_y, u_z{}^{SR\,x\,(F\,\phi D\,(a\,x\,b))}_{PF\,x/da[\%]}\,[x_{LCS}, y_{LCS}, z_{LCS}]$, where
Individual indicators are already explained in 4) with the difference that u_x, u_y, u_z Indicates the direction take the contact to job and the load on the contact. Unless specified, the load direction in the normal direction to the tangent face is the area of the measured surface at the RPS site. The contact may be again at a point or in the area.$[x_{LCS}, y_{LCS}, z_{LCS}]$ = coordinates of the RPS point of reference in which pressure is to occur, and therefore these coordinates can be considered theoretically accurate. Deviations from the exact position of the pushing point are compensated by the pre-tensioning springs.

7) RPS for the construction of the contact measuring templates – 'LER' (Fig. 6)
In practice, LER is used very often, mainly because of its ease of use and providing a quick and inexpensive measurement of the measured parameters. It is mostly about checking the accuracy of achieving the shape parameters of the surfaces. The CMM performs a part-time measurement that is determined by an internal company policy. This procedure are investigated, using the SPC, trends in the magnitude of deviations from the reference shape of the component, which leads to the timely adjustment of the LER and thus to the reduction of the risk of a defective part => achieve low PPM (parts per million).
For defining these RPS points, RPS are used again to locate the references defined in the drawings according to 2).
${}_{LER}P_n\ [x_{GCS}, y_{GCS}, z_{GCS}, x_{LCS}, y_{LCS}, z_{LCS}]$
If it is meaningful, it is possible to define additional points and mark them as follows>
${}^{Y(St)}_{MI}P_n{}^{SR\,x\,(F\,\phi D\,(a\,x\,b))}_{PF\,x/da[\%]}\,[x_{LCS}, y_{LCS}, z_{LCS}]$,
If necessary, it is possible to define the pressure at the point of the measuring contact $F\,x/da[\%]$. In most cases, however, in technical practice this force is not defined, which leads to the simplification and acceleration of the measurement process. Whether this is a flat or spot control element is differentiated by using $SR\,x\,(F\,\phi D\,(a\,x\,b)$. Since it is again a point of reference between the part structure and the LER construction, the coordinates $[x_{LCS}, y_{LCS}, z_{LCS}]$ theoretically accurate. Permissible deviations of contact faces/points of clamping contacts from reference position and shape are specified using geometric tolerances on the LER technical drawings.

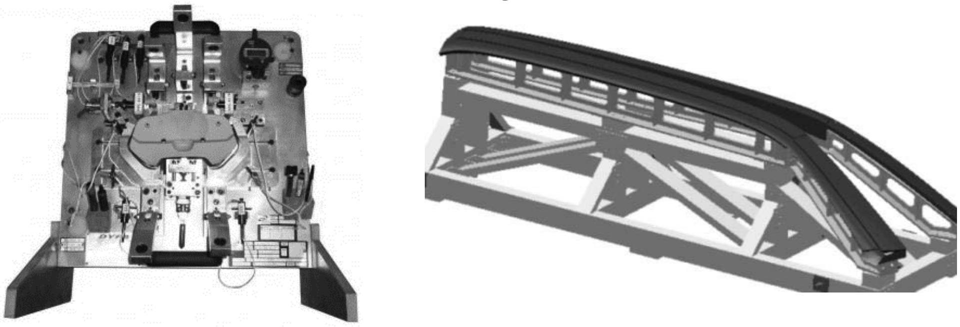


Fig. 6 'LER' for measure shape and dimensions [3]

8) RPS for the designing of cubings – CBG (obr. 7)
For the construction of complex cubing, the RPS is most often used to locate the references defined in the drawings according to 2). Most often, these are targeted reference datums, through which the parts are connected to the surroundings (generally the frame) and to one another. Therefore, when defining target bases, the designer must respect the interdependence of parts and the overall structure of the proposed TS.
${}_{CBG}P_n\ [x_{GCS}, y_{GCS}, z_{GCS}, x_{LCS}, y_{LCS}, z_{LCS}]$
When designing partial cubings, the situation is somewhat more complicated, since some bonds may be removed and thus the self-sustainability of the part under consideration may be impaired. In this case, another RPS needs to be defined. Points so that all the necessary design freedom points are taken and an adequate substitution for the omitted part of the total TS is ensured.
${}^{Y(St)}_{MI}P_n{}^{SR\,x\,(F\,\phi D\,(a\,x\,b))}_{PF\,x/da[\%]}\,[x_{LCS}, y_{LCS}, z_{LCS}][TC/PC/FC/FIX]$

Since it is again a point of reference, the coordinates are considered theoretically accurate. TC = indicator of two surfaces in contact with each other (since the contact is solid, it is possible to loosen the surfaces due to inaccuracies, deformations and vibrations during operation), PC = indicator of pre-tensioned contact (eg with a pre-tensioned screw connection), FC = indicator flexible contact free (combining the indicators it is possible to define a flexible contact pre-fed FC / PC). It is used, for example, to dampen the mutual transfer of vibrations between the parts. FIX = fixed contact secured eg with snap pins or teeth.

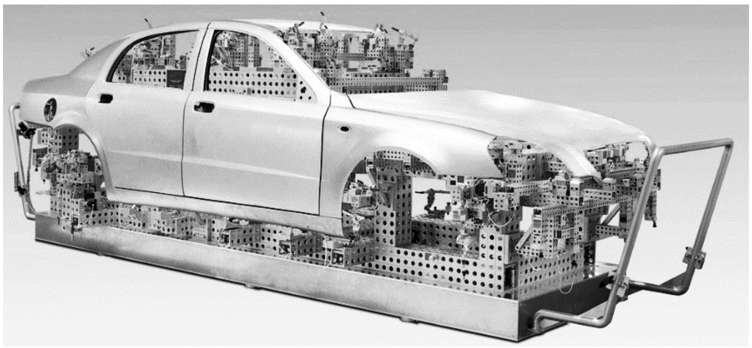


Fig. 7 Complex car cubing

CONCLUSIONS

The paper deals with the issue of the full specification of RPS points. Since there is no standard for RPS points, individual firms are creating their own internal regulations that are not in line with the regulations of other companies. This confusion leads to problems with the correct reading of the technical documentation, which is reflected in the serious problems arising from reading drawings and understanding the individual specifications. The above presents considerable problems for the production, measurement and control of machine parts. The authors' suggestion is to establish order in the RPS specification and to perform their breakdown by function and purpose of use. Since RPS points are particularly widespread in the automotive industry and essential for specifying geometric parameters of technical systems, it is necessary to create an impetus for RPS points to become part of official normative documents, thus achieving the unification of RPS point definitions and hence higher clarity and understanding of this problem by people in technical practice.

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