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AN EVALUATION OF THE EFFECT OF A DATUM SYSTEM ON THE DETERMINATION OF THE ACCURACY OF BEVEL GEAR TEETH

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Abstract

The purpose of this article is to demonstrate the influence of factors related to selected datums or datum systems on deviation values of gear tooth geometry, and, consequently, on the accuracy class of the aircraft bevel gear design. The item subjected to measurements was a bevel gear pinion machined by grinding on a brand new Klingelnberg G27 CNC machine tool. In the measurements, a P40 coordinate machine with a rotary table was used. The first step in the analysis was a multiple check of the accuracy of datum surfaces (the plane and cylindrical surfaces) and establishing the deviation of their dimensions and geometrical conditions (roundness, radial run-out, axial run-out). Next, tooth measurements were taken using the same setup with 13 different datum systems. The results were subjected to analysis, which yielded conclusions concerning the significance of the selection of datum systems for the correct evaluation of bevel gear accuracy. Findings indicated which datum systems are optimal and which prove insufficient to obtain reliable results. This can be used as a practical recommendation for gear tooth designers in establishing control datums for designed bevel gear members.

Keywords: *gear, measurement*

1. Introduction

In the manufacturing process, the teeth of a pinion and a bevel gear with circular pitch line are cut relative to two reference components: a cylinder/hole (or cylinders), i.e. relative to the actual axis of rotation of the machined part and the datum surface determining the mounting distance (MD). Therefore, the coordinate system used in the gear measurement process should be based on the same reference components to ensure metrological correctness [1, 7].

When describing measurements of tooth flank geometry, which is not related to datum systems by means of direct dimensions, one must differentiate between the terms 'datum' and 'datum feature'. According to ISO 5459, a datum is a theoretically accurate geometrical reference (such as an axis, plane, straight line etc.) to which tolerance components are related. Datums may be determined by one or more datum features of a part. A datum feature is a real feature of a part (such as an edge, surface, hole etc.) which is used to determine the location of the datum [6].

Defining a coordinate system for the measured gear on a type P40 coordinate-measuring machine involves entering comparative data from design drawings of gears, special bevel gear tooth software or data obtained by measuring a reference gear and fixing the object [2, 4].

Due to the possibility of a measurement error resulting from object fixation (determining the axis of the object) a compensatory measurement is performed (fixation error compensation). The measurement is taken by selecting a measurement option on unique geometrical features (datum features) of the gear:

- 2 radial run-out measurements,
- 1 radial run-out and 1 axial run-out measurement,
- 1 radial run-out measurement,
- 1 axial run-out and 2 radial run-out measurements.

To this end, reference surfaces (datums) are verified, the selection of which is made according to the geometry of the machined object (cylinder-, bushing- or ring-shaped) [3]. The software operating the machine allows the operator to select the plane and cylindrical surfaces, which are treated as datum features and used for establishing the location of datums or datum systems as well as identifying the location of teeth. Automatic measurement of the axial run-out of the plane or the radial run-out and roundness of cylindrical surfaces makes it possible to establish the location of datums and to compensate for object fixation relative to the machine's coordinate system.

Fig. 1. A bevel pinion in the P40 machine's measurement space

Teeth measurements include active and passive tooth flank topography, addendum and dedendum cone angles, tooth depth and pitch error on active and passive sides. Referencing the obtained geometry to the master must be based on a grid of points on the tooth flank, defined identically to the master, together with reference point M [5].

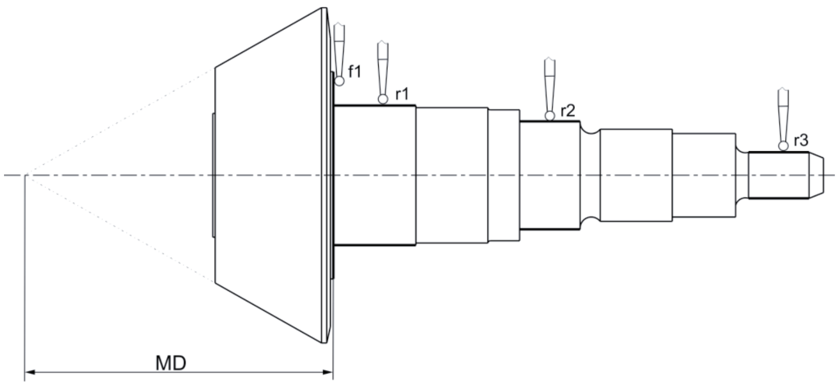

Fig. 2. Reference surfaces considered in the selection of object fixation compensation for the measurement

The following bevel pinion measurement conditions were established:
- one pinion fixation to determine deviation of datums and perform teeth measurements using various datum systems,
- one measuring station,
- stable humidity and temperature,
- the same operator,
- the same measurement procedure (same teeth measured by the same measuring tip after calibration on the same day).

Measured quantities:

- axial run-out,
- radial run-out (axial run-out deviation *Fr*),
- pitch measurement (maximum pitch deviation fp_{max}, maximum difference between adjacent pitches fu_{max}, total pitch deviation *Fp*),
- topography measurement (sum of squares, normal chordal tooth thickness).

Table 1 contains measurement results in reference to datum systems (first column). The letter “f” stands for the front plane (with a circle as the datum feature and its centre as the datum). Letters “r” signify cylindrical surfaces (like for the front plane, the circle is the datum feature and the centre of the circle is the datum). Numbers 1 and 2 preceding letters specify the number of datum features of a given type constituting the datum system. Numbers 1, 2, 3 following letters specify numbers of datum features constituting the datum system (cf. Fig. 1). For example, 1f2ro12 means that the datum system comprises one front plane and two cylindrical surfaces, in this particular case cylinder r1 and cylinder r2. Selected tooth parameter measurement values (directly or as deviations) together with corresponding accuracy classes are shown in Tab. 1 and Fig. 3-6.

Tab. 1. Bevel pinion tooth measurement results

Case marking	sum of squares	Norm. chord thickness	Fpmax (WK)	fpmax class (WK)	Fumax (WK)	fumax class (WK)	Fp (WK)	Fp class (WK)	run out calc. (WK)	cro class (WK)	Fpmax (WP)	fpmax class (WP)	Fumax (WP)	fumax class (WP)	Fp (WP)	Fp class (WP)	run out calc. (WP)	cro class (WP)	pitch line run out (WP)	plro class (WP)
1f2ro12	102	5.855	1.9	1	2.1	1	4.5	1	3.5	1	2.1	2	1.3	1	7.3	1	7.4	2	4.4	1
2ro12	159.1	5.854	2.1	2	2.1	1	4.9	1	4.5	1	2.2	2	1.2	1	9.2	2	9.3	3	5.3	1
1f1ro1	124.6	5.855	1.8	1	2	1	5.1	1	4	1	1.9	1	0.9	1	7.8	2	7.9	2	4.4	1
1f1ro2	122.8	5.854	2	1	2	1	6.3	1	5.3	1	2.1	2	1.1	1	7.9	2	8.1	3	3.1	1
1f2ro23	103.4	5.855	1.6	1	2.1	1	5.4	1	4.2	1	2	2	1.1	1	8.5	2	8.6	3	6.7	2
2ro23	100.3	5.855	1.6	1	2	1	5.3	1	4.2	1	2	2	1.1	1	8.5	2	8.7	3	6.8	2
2ro13	103.4	5.855	1.6	1	1.9	1	5	1	3.6	1	1.9	1	1.1	1	9.7	2	9.3	3	7	2
1f2ro13	103.4	5.854	1.6	1	1.7	1	4.8	1	3.4	1	1.9	1	1.1	1	9.4	2	9.2	3	7	2
1fro3	120.7	5.855	3	3	2.3	1	11.1	3	10.9	3	3.3	3	1.5	1	16.5	4	16.7	5	9.1	3
1f	93.2	5.855	2.4	2	1.9	1	6.8	1	6	2	3.3	3	1.3	1	14.7	3	14.7	4	9.3	3
1ro1	83.9	5.854	1.7	1	2	1	3.9	1	2.8	1	1.9	1	0.9	1	7.1	1	6.9	2	4.6	1
1ro2	81.1	5.855	1.6	1	1.6	1	5	1	3.8	1	1.7	1	0.8	1	5.8	1	6	2	3.2	1
1ro3	84.9	5.854	2.5	2	2.3	1	8	2	8	3	2.8	2	1.4	1	12.5	3	12.7	4	6.4	2

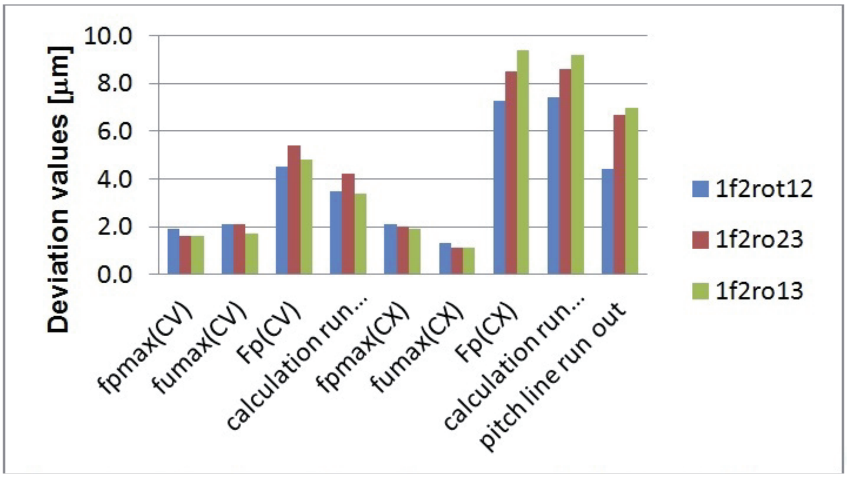

Fig. 3. *Performance deviation values (fpmax, fumax, Fp, run out calculation, pitch line run-out) obtained from the measurement of a bevel gear with circular pitch line, whose fixation error compensation is based on 1 axial run-out measurement and 2 radial run-out measurements of the reference surface*

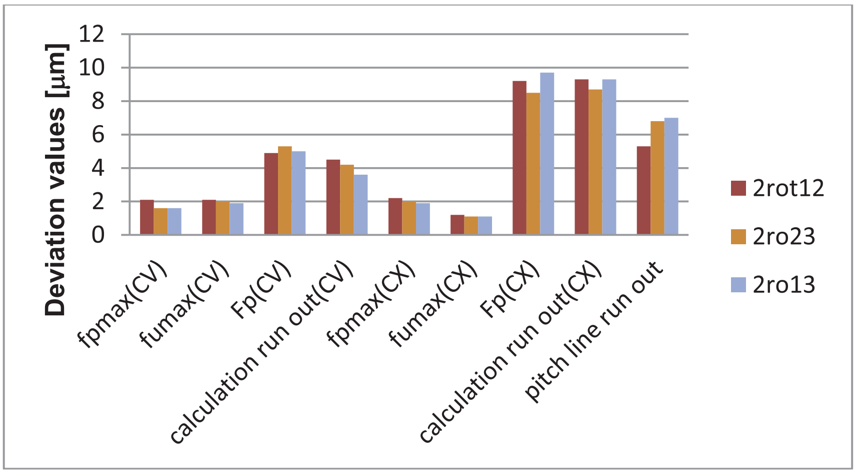

Fig. 4. *Performance deviation values (fpmax, fumax, Fp, run out calculation, pitch line run-out) obtained from the measurement of a bevel gear with circular pitch line whose fixation error compensation is based on 2 radial run-out measurements of the reference surface*

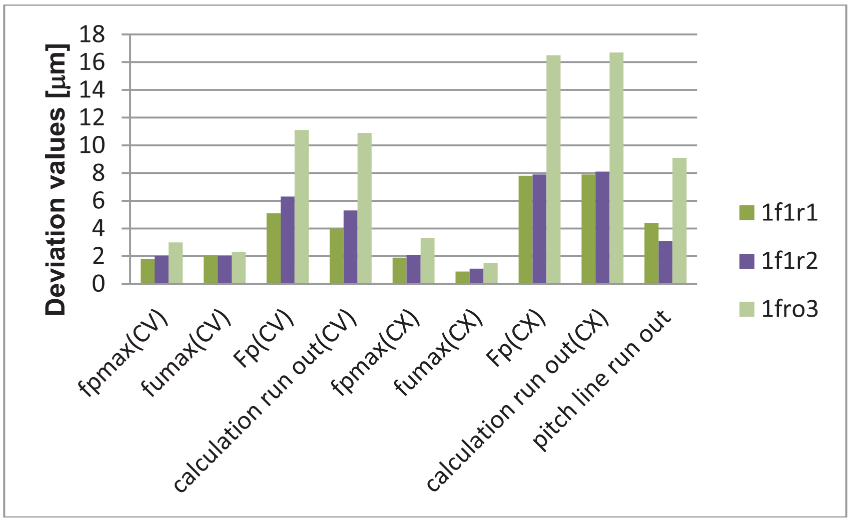

Fig. 5. *Performance deviation values (fpmax, fumax, Fp, run out calculation, pitch line run-out) obtained from the measurement of a bevel gear with circular pitch line, whose fixation error compensation is based on 1 axial run-out measurement and 1 radial run-out measurements of the reference surface*

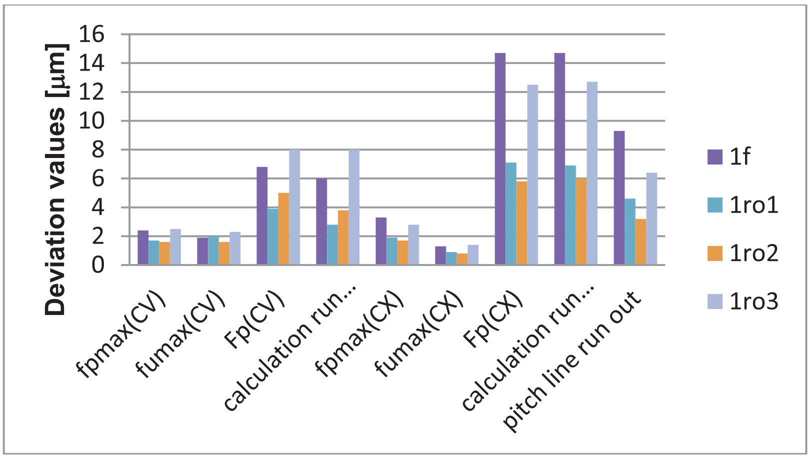

Fig. 6. Performance deviation values (fpmax, fumax, Fp, run out calculation, pitch line run-out) obtained from the measurement of a bevel gear with circular pitch line, whose fixation error compensation is based on 1 radial run-out measurement or 1 axial run-out measurement of the reference surface

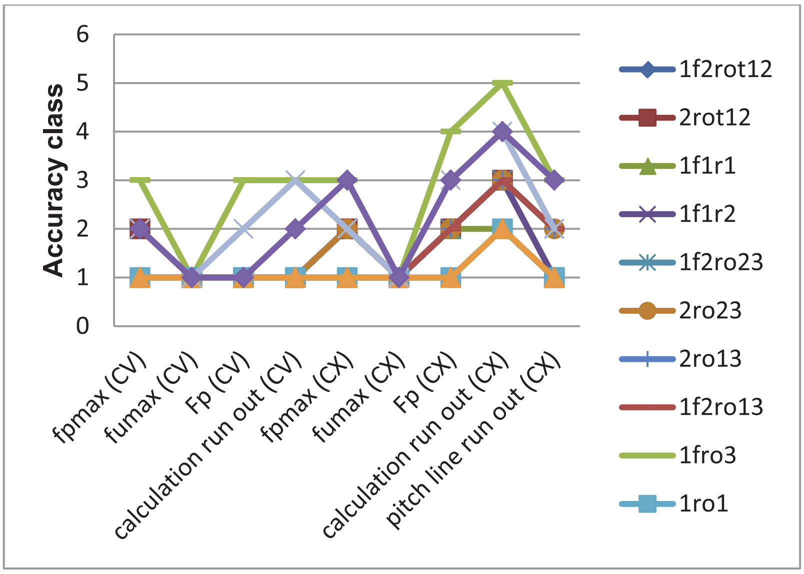

Fig. 7. Summary list of accuracy classes for individual parameters obtained from the measurement of a bevel pinion with circular pitch line for individual cases of fixation error compensation

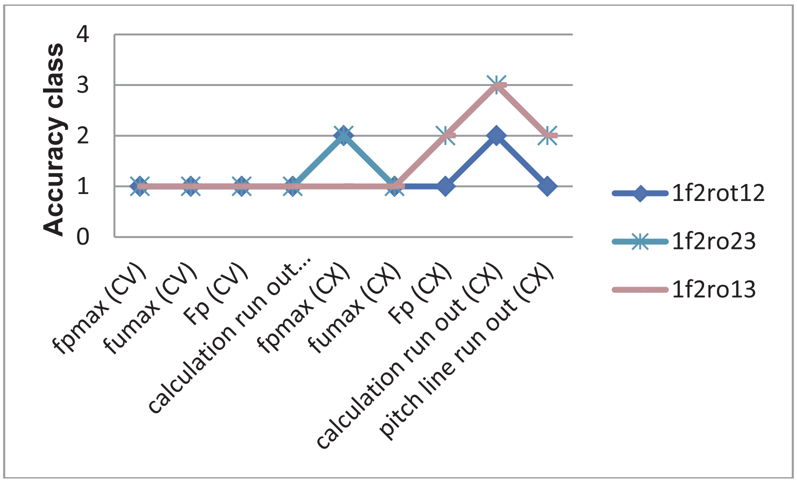

Fig. 8. Accuracy classes for individual parameters obtained from the measurement of a bevel pinion with circular pitch line for a fixation error compensation case based on 1 axial run-out measurement and 2 radial run-out measurements of the reference surface

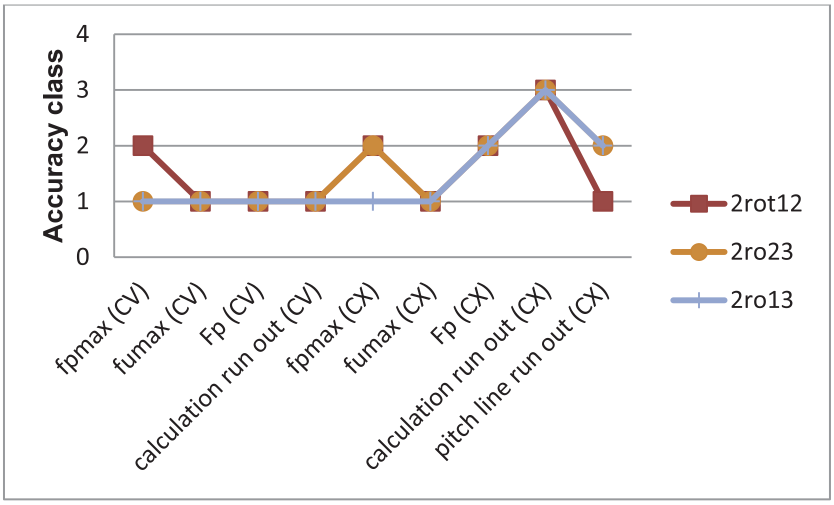

Fig. 9. Accuracy classes for individual parameters obtained from the measurement of a bevel pinion with circular pitch line for a fixation error compensation case based on 2 radial run-out measurements of the reference surface

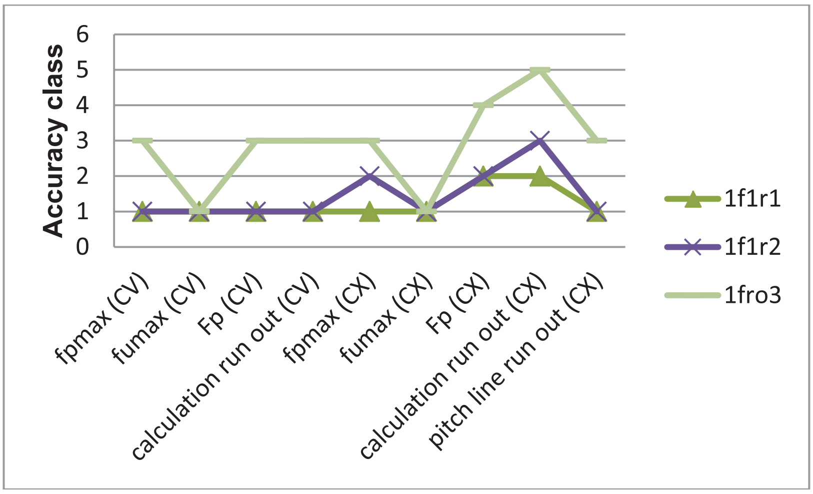

Fig. 10. Accuracy classes for individual parameters obtained from the measurement of a bevel pinion with circular pitch line for a fixation error compensation case based on 1 axial run-out measurement and 1 radial run-out measurement of the reference surface

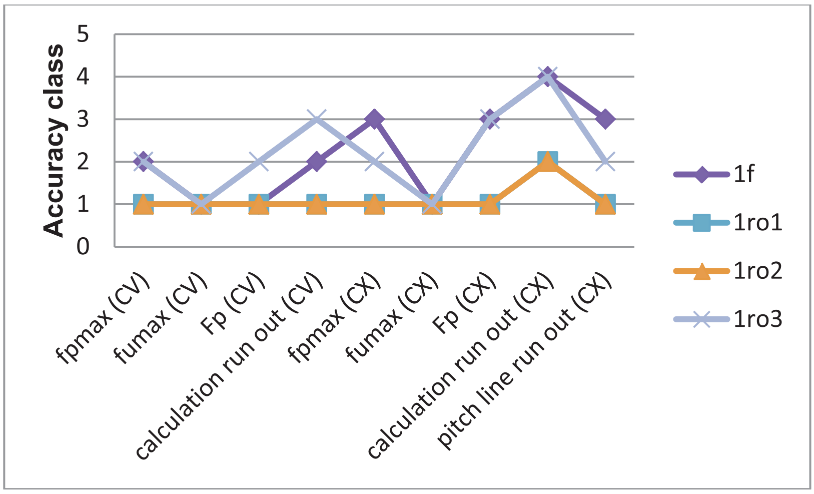

Fig. 11. Accuracy classes for individual parameters obtained from the measurement of a bevel pinion with circular pitch line for a fixation error compensation case based on 1 axial run-out measurement or 1 radial run-out measurement of the reference surface

Conclusions

Maximum tooth measurement accuracy was achieved when applying two datum systems: one is containing datum features in the form of plane f1 and cylindrical surfaces r1 & r2 and another one, datum features of which included cylindrical surfaces r1 & r2 only. Fixation error compensation for the measured object was carried out by determining the axial run-out of plane f1 as well as the radial run-out of cylindrical surfaces r1 and r2. It must be emphasized that tooth measurement result depended on the quality of performance of datum surfaces (run-out deviations measured for datum location compensation). The performance of r1 and r2 surfaces is the most accurate (with radial run-out deviations respectively 1.7 and 1.9 µm). The least preferable result of measurement is obtained when cylindrical surface r3 is one of datum features. Owing to its measured radial run-out (13.1 µm deviation) and considerable distance to the measured tooth, the applied datum (in the form of the axis) is determined with insufficient precision and, therefore, should not constitute a reference for gear tooth measurement. A key question is the performance of datum features according to suitable dimension tolerance, shape tolerance and location tolerance.

The measurements taken in this study revealed that the pinion may be assigned an accuracy class of 1-5 depending on the applied datum (or datum system), whereas the radial run-out of teeth is the most sensitive to the choice of the datum system. If the centre of the circle defined by the datum feature in the form of the front plane is selected as the datum, the pinion's accuracy is rated according to the radial run-out of the pinion as class 4. The result of measurement with compensation in the form of the front surface and cylindrical surface 3 (with the axis as the datum) indicates that the radial run-out of the surface causes significant error in defining the centre of the circle, which consequently negatively affects the determination of the axis being the datum. As a result, such errors yield a 'distorted' frame of reference for gear tooth measurement, augmented run-out and pitch deviations. The prerequisite for establishing the geometrical accuracy of datum features used when creating the datum system before taking gear tooth measurements is therefore substantiated. In the analysed case, all datum systems featuring automatic radial run-out measurement on surface 3 are unacceptable.

A reliable assessment of gear tooth accuracy class may be provided by datum systems defined on the basis of datum features whose geometry deviations are contained within accuracy class 1. Such systems are represented in Fig. 7-11 by graphs 1f2ro12, 2ro12 and 1f1r1. Datums, which utilize object fixation compensation by means of a single point only (single datums 1ro1, 1ro2, 1f), also reveal high quality of measured gear teeth. However, such compensation should be considered insufficient due to the potential for incidentally erroneous results, depending on the machine's read-out of the position of the measuring tip in a single point without any measurement of the geometrical deviation of the datum feature.

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