New concepts for the calculation of datums and datum-systems based on cylindrical features

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Abstract. In ISO 5459: 1981 the problem of datums and datum-systems established by cylindrical features is described graphically. The figures in the standard, however, show solutions that sometimes are not unique irrespective of the realization with hard gauging or by using algorithms. In order to develop algorithms to solve the above mentioned problems, well known ideas of hard gauging have consequently been applied. For the example of cylindrical features unsolved problems will be discussed. Proposals for the cases of maximum inscribed and minimum circumscribed geometrical elements will be presented. In addition the problem of common axes of two or more cylinders with any diameters is covered. The new concept is generic to solve all possible cases including the ones, which can not be solved by applying algorithms used today. The results obtained by the new concept are consistent with the solutions found by hard gauging.

1. Introduction

The manufacturing of workpieces causes deviations of size, form, orientation, location and run-out. Therefore the features of the workpiece differ from the ideal features given in the technical drawing. To ensure the function of the workpiece these deviations have to be limited by tolerances in the technical drawing. Datums and datum-systems have to be specified to tolerate the deviations of orientation, location and run-out. The orientation and/or the location of the toleranced geometrical feature are determined based on these datums.

Rules for the indication of datums and datum-systems in a technical drawing are standardised in ISO 1101: 2004 [1] and ISO 5459: 1981 [2] respectively. For establishing datums rules are also given
in ISO 5459: 1981 [2]. The conditions described in this standard are not unambiguously transferable to hard gauging or the use of mathematic algorithms. The paper will discuss the unsolved problems and introduce a new concept for cylindrical features.

2. Rules and deficiencies for establishing datums based on ISO 5459: 1981 [2]

A datum is defined in ISO 5459:1981 [2] as:

“A theoretically exact geometric reference (such as axes, planes, straight lines, etc.) to which tolerated features are related. Datums may by based on one or more datum features of a part.”

“Datums and datum-systems are used as the base for establishing the geometric relationship of related features. The quality of relevant datum features and simulated datum features must be adequate for functional requirements.”

Datum features are geometrical features as part of a workpiece with deviations. The datum features provide a basis for establishing datums and to specify the location and orientation of datums as well. The establishment of datums is not unambiguously defined by the specification of datums in the technical drawing. ISO 5459: 1981 [2] describes the establishment of datums by a few graphic examples.

In ISO 5459: 1981 [2] datums are ideal geometrical features. They are established by simulated datum features which contact the surface. These simulated features are described in ISO 5459: 1981 [2] as:

“A real surface of adequately precise form (such as a surface plate, a bearing, or a mandrel, etc.) contacting the datum feature(s) and used to establish the datum(s).

NOTE: Simulated datum features are used as the practical embodiment of the datums during manufacture and inspection.”

For practical implementation in metrology the application of simulated datum features for establishing datums is close to the functional requirements. In case of computerized metrology ideal simulated features are nominal geometrical features of perfect shape.

For a datum being the axis of a cylinder (see figure 1) it is defined in ISO 5459:1981 [2]:

“The datum is the axis of the largest inscribed cylinder of a hole or the smallest circumscribed cylinder of a shaft, so located that any possible movement of the cylinder in any direction is equalised.”
Figure 1: Datum being the axis of a cylinder [2] page 2

The figure 1 shows largest inscribed cylinder and its axis for a hole. The orientation of the cylinder depends on the surface and might therefore not produce an unambiguous orientation. For that case the standard requires an equalization of the angles $\alpha$ in all directions of space. The same will be for the smallest circumscribed cylinder respectively and consequently its axis for a shaft. A deficiency of the standard is that the required equalization of angles $\alpha$ in all directions of space is not defined for hard gauging or mathematic algorithms.

In addition to the single axes it is necessary to define common axes as well. For establishing a datum being the common axis of two cylinders (see figure 2) the following definition is stated in ISO 5459:1981 [2]:

“In the example (…), the datum is the common axis formed by the two smallest circumscribed coaxial cylinders.”

Figure 2: Datum being the common axis [2] page 3

The minimization of the diameters of the contacting cylinders is not solved. Furthermore the graphic example as well as the description of establishing common axes is restricted to two datum features of different diameter. The solution of establishing common axes based on datum features of equal
diameter is not shown. In addition to that a method to establish common axes based on more than two datum features is not given.

The deficiencies for the establishment of axes and common axes according to ISO 5459: 1981 [2] are summarized to:

- The requirements of the standard are incomplete and not unambiguously transferable to hard gauging or the use of mathematic algorithms.
- When the associated datum feature and consequently its axis does not produce an unambiguous orientation the required equalization of angles $\alpha$ in all directions of space can not be realised by hard gauging or by mathematic algorithms.
- For common axes there are no rules how to minimise and maximise the diameter(s) of the simulated datum feature(s) of the coaxial cylinders for establishing datums.
- The establishment of common axes is restricted to two datum features of different diameter. A method to establish common axes based on more than two datum features is not given.
- A solution for the calculation of common axes based on datum features of equal diameter is not shown.

Based on the identified problems a concept for establishing the axis of a cylinder or a common axis as a datum has been developed.

3. A proposed solution for establishing single datums

This concept for establishing the axis of a cylinder as a datum is functional oriented and follows the basic tenets of ISO 5459: 1981 [2]. Using the terms and definitions of ISO 14660-1/-2: 1999 [3] and ISO 2692: 1988 [4] the association criterion for the extracted feature data points is contacting. This results in the calculation of the largest inscribed and the smallest circumscribed cylinder as associated simulated datum feature. The diameter of the contacting cylinder is equal to the mating size defined in ISO 2692: 1988 [4]:

"Mating size for an external feature: The dimension of the smallest perfect feature which can be circumscribed about the feature so that it just contacts the surface at the highest points." [4] page 2

"Mating size for an internal feature: The dimension of the largest perfect feature which can be inscribed within the feature so that it just contacts the surface at the highest points." [4]

A perfect feature in the context of ISO 2692: 1988 [4] is identical to an ideal-geometrical feature or a form ideal feature.

A new additional criterion for the orientation of the associated feature will be introduced since the associated datum feature and consequently its axis does not always produce an unambiguous orientation. The new criterion requires that

the maximum distance between the extracted and the associated datum-system is a minimum.

This is consistent with the method given in ISO 5459: 1981 [2] for the establishing of datums being planes. Figure 3 shows the example of a maximum inscribed cylinder.
Mathematically the calculation of the maximum distance being a minimum is identical with the condition of minimum zone under the constraint that the location of the minimum zone cylinder is fixed and the minimum zone condition can only lead to the variation of orientation.

4. A proposed solution for establishing common datums

For common datums the same condition for circumscribed or inscribed cylinders respectively as for single datums exists. The two or more associated cylinders will generally not be coaxial. The additional constraint of the minimum zone as for single datums however will not lead to the solution of a common axis as required by the standard as well as for functional reasons (see figure 4).

The active mating size as a new definition for the association of a common axis has to be introduced. It is the mating size in compliance with constraints. The mating size and the active mating size can
differ. For datums established by a single feature no constraints exist. In this case the mating size is equal to the active mating size. In case of common datums (see figure 4 and 5) the constraint for the active mating size is a common axis. For external features the active mating sizes is larger than the mating sizes due to the constraint.

![Diagram of active mating size and common axis](image.png)

**Figure 5: Active mating size and common axis**

To establish the common axis the new concept calculates a minimum between the active mating size and the mating size. This new concept for establishing common datums is expandable to any amount of datum features and is not longer restricted to two datum features.

The new concept enables a simulation of mating as the best approximation or even superior to a physical gauge because the orientations of the physical gauges as well as the associated datum features depend on the real surface. The new concept thereby implements all requirements for establishing datums described above.

To obtain a unique result for the datum feature for single datums as well as for common datums, the extraction of the permissible data points is very important. In the future the selection of data points will be investigated considering the constraint of contacting elements. Reasonable is the selection of peaks without valleys.

### 6. Summary

The current standard for establishing datums – ISO 5459: 1981 [2] – is incomplete and shows obscurities concerning the practicability of the demanded rules. Therefore new requirements for establishing datums have been introduced. The new concept is generally applicable to all possible geometric features used as datum established by a single features as well as to all possible combinations of geometric features used for establishing common datums or datum-systems. The result is a new concept that delivers an unambiguous, appropriate solution that is close to the requirements of the standard and also to the functional requirements in all cases of establishing datums, common datums and datum-systems.
The provision of the extraction of the permissible points as well as the verification of the concept by means of real workpieces is content of future investigations.

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Figures 1 and 2 reproduced from ISO Standard ISO 5459-1981 by permission of Deutsches Institut für Normung e. V.

7. References

[1] ISO 1101: 2004, Geometrical Product Specifications (GPS) – Geometrical tolerancing – Tolerances of form, orientation, location and run-out, ISO 2004, Switzerland

[2] ISO 5459: 1981, Technical drawings – Geometrical tolerancing – Datums and datum-systems for geometrical tolerances, ISO 1981, Switzerland

[3] ISO 14660: 1999 Part 1/2, Geometrical Product Specification (GPS) – Geometrical features –, ISO 1999, Switzerland

[4] ISO 2692: 1988, Technical drawings – Geometrical tolerancing – Maximum material principle, ISO 1981, Switzerland