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# Clarifications of a Datum Axis or Centerplane Specifying in Maximum Material Condition of Geometric Dimensioning and Tolerancing

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# Geometric Dimensioning and Tolerancing: Clarifications on Specifying a Maximum Material Condition Datum Axis or Center Plane


## Abstract

Engineering and Engineering Technology students and professionals learning the processes and standards in computer-aided design (CAD) and computer-aided manufacturing (CAM) should learn and understand the methodology of geometric dimensioning and tolerancing (GD&T) to describe the intent and requirements for part and assembly geometries. Correct application of GD&T ensures that the part and assembly geometry defined on the drawing will have the desired form and fit (within limits) and function as intended. One learning difficulty in understanding GD&T is the concept of defining a datum axis or center plane using Maximum Material Condition (MMC). To overcome this difficulty, a new approach is presented that uses a modifier "Ⓥ" (Virtual Condition) instead of "Ⓜ" (MMC). A thorough rationalization of using "Ⓥ" in datum axis specification is discussed. The paper also provides a convenient table on how to use this modifier.


## 1. Introduction

Geometric dimensioning and tolerancing (GD&T) is a quality control method using a symbolic language that allows design engineers, manufacturing personnel, and quality inspectors to describe geometry and allowable variation of parts and assemblies in an efficient and effective manner[1]. GD&T is used to define the theoretically perfect geometry of parts and assemblies, to define the allowable variation of individual features (e.g., surfaces, holes), and to define the allowable variation between features. When compared to coordinate dimensioning, GD&T has the benefits of reducing the manufacturing cost and number of drawing revisions, describing an important functional relationship on a part, saving inspection time by using functional gages, and improving measurement repeatability[2,3].

GD&T has been widely accepted in manufacturing, both in the United States and internationally, and as such has been included in curricula focused on developing engineering and manufacturing drawings. However, GD&T has a fairly complex rule-based system, and as a result can be difficult to teach and learn. Several papers have been published to explain various aspects of the GD&T methodology and to improve the student's learning performance[4,5,6,7,8]. Unlike existing papers that have published to bring clarity to the difficult subject of GD&T, this paper examines the challenges in defining a datum axis or center plane using Maximum Material Condition (MMC) and provides a clarification approach using Virtual Condition (VC).

## 2. Datum References

Datum references, such as a datum axis or center plane, play a key role in achieving the advantages of the GD&T methodology. A datum reference is defined as a theoretically exact plane, edge, point, or axis from which a dimensional measurement is made (Krulikowski, 1998, 2012). Figure 1 shows a GD&T drawing using three planar features as datum references: A, B, and C. Here Datums A, B, and C are known as the primary datum, secondary datum, and tertiary datum respectively.

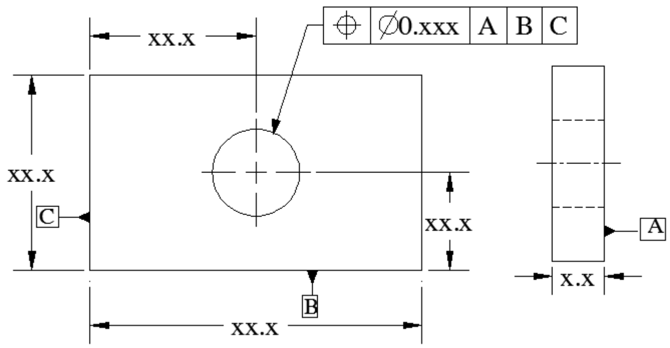


**Figure 1**: Three Planar Datums

Figure 2 shows another drawing using a feature of size (FOS) as a datum reference. A FOS is defined as a cylindrical surface, spherical surface, or two opposed parallel elements or surfaces that can be associated with a size dimension. When a FOS is specified as a datum feature, it results in an axis or a center plane as a datum. In Figure 2 the datum feature is defined as the center axis of the drilled hole.

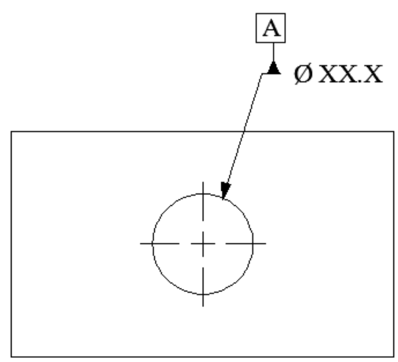


**Figure 2**: A Feature-of-Size (FOS) Datum

While many datum references can be been clearly defined, students and professionals have experienced learning difficulties in correctly defining an MMC datum axis. MMC, VC, and an approach to resolve difficulties with MMC datum axis are discussed below.

## 3. Maximum Material Condition (MMC)

Maximum Material Condition (MMC) refers to the condition when a FOS contains the maximum amount of material, yet remains within its stated limits of size[2,3]. The MMC for an external FOS (e.g., shaft diameter or outer sizes of an object) is the largest value of the basic dimension and tolerance. The MMC for an internal FOS (e.g., hole diameter) is the smallest value of the basic dimension and tolerance. Figure 3 shows an example of MMC for both internal and external FOS.

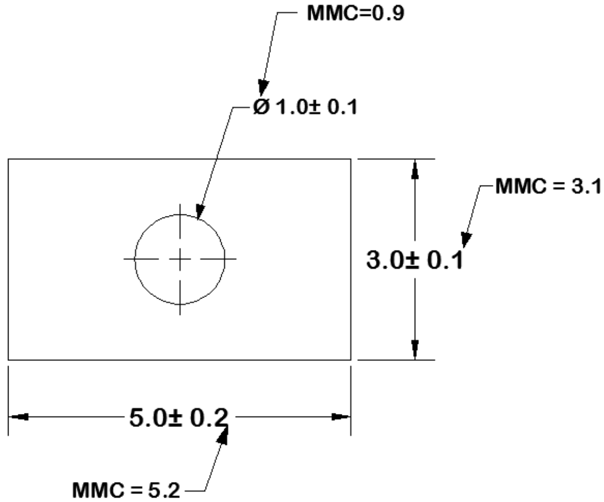


**Figure 3:** Specifying MMC for External and Internal Features

## 4. Virtual Condition (VC)

Virtual Condition is the theoretical extreme boundary condition of a FOS generated by the collective effects of MMC and any other applicable geometric tolerances[2,3]. Virtual condition is used by designers to analyze mating parts, by gauge manufactures to find the gauge dimensions and by inspectors to check extreme conditions. Figures 4 and 5 give examples of VC calculations for both external and internal FOS.

In Figure 4, when a GD&T tolerance is not applied to an external feature, VC is equal to the MMC (largest size) of the material. However, when a GD&T tolerance is applied to the FOS, *VC = MMC + GD&T Tolerance*.

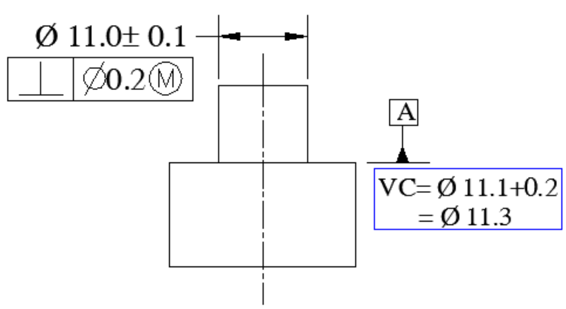


**Figure 4:** VC for an External Feature

In Figure 5, when a GD&T tolerance is applied to an internal feature, VC is equal to the MMC (smallest size) of the material. However, when a GD&T tolerance is applied to the FOS, *VC = MMC - GD&T Tolerance*.

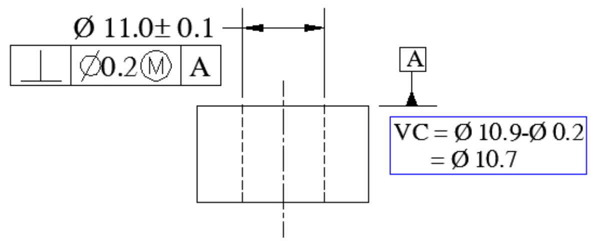


**Figure 5:** VC for an Internal Feature

**5. MMC Datum Axis**

When a FOS is used as a datum reference, an adjustable gage element is needed to simulate the geometric counterpart of the datum feature. The gage element is also used to orient and secure the part. When the FOS datum is referenced at MMC, the gaging equipment that serves as the datum feature simulator is a fixed size[2]. The datum axis or centerplane is the axis or centerplane of the gauge element. Figure 6 shows a datum axis specified as "AⓂ" (MMC). Since the MMC of the FOS is ∅2.0050", the fixed gage size which defines the datum axis is easily understood to be ∅2.0050" (showing on the very right side of Figure 6).

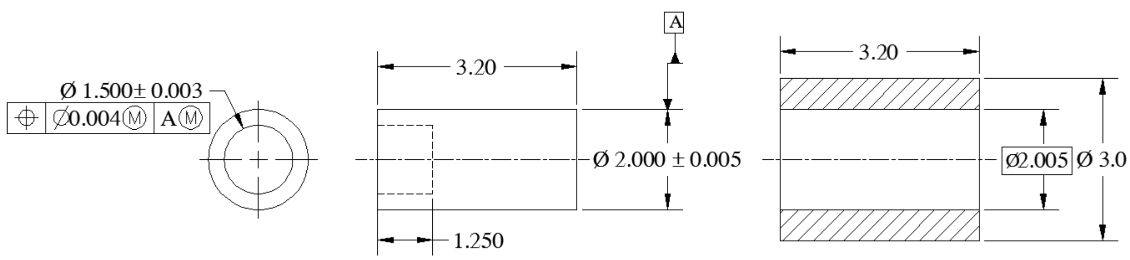


**Figure 6**: Datum Axis Using AⓂ to Define the Datum Axis

However, the datum axis "AⓂ" specified in Figure 7 causes a problem to students. The gage size for this datum axis is equal to ∅2.0070", the VC of the external feature. While the Ⓜ symbol can be interpreted as VC for MMC in the ASME Y14.5M – 1994[2] or as Maximum Material Boundary (MMB) in the ASME Y14.5M – 2009[3], the Ⓜ symbol is commonly recognized as MMC for the FOS. This ambiguity introduces uncertainty and frustration to students that are learning to master the rules and methodology of GD&T.

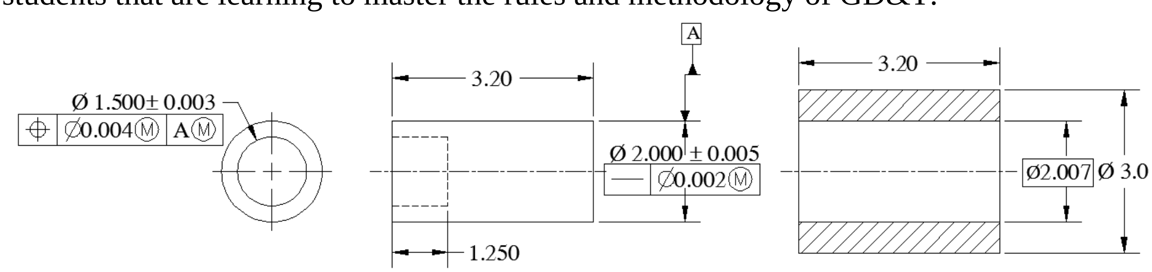


**Figure 7:** Datum Axis Associated with a GD&T Tolerance to Define the Datum Axis

To avoid this confusion, and to clarify an important aspect in the learning process for GD&T curricula, the authors propose that a new modifier symbol, Ⓥ , referring to the Virual Condition (VC) be used. This new modifier symbol Ⓥ is used to replace Ⓜ, when both the MMC and geometric tolerance are necessary to fully describe the part feature, as shown in Figure 8. Note, the use of the new modifier Ⓥ can only be applied to define a center axis or center plane when an Ⓜ is used in the geometric tolerance associated with the datum.

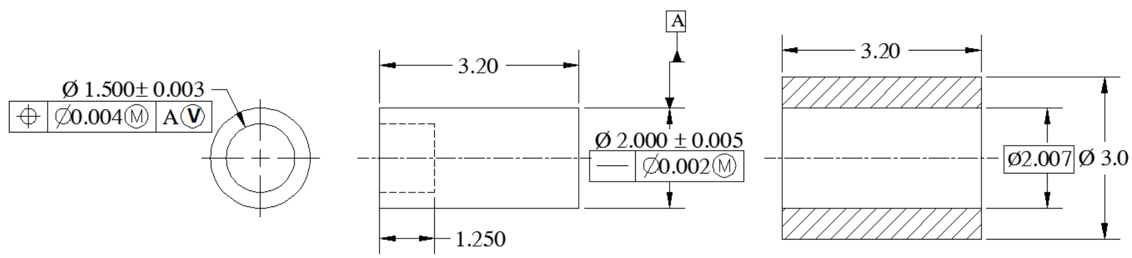


**Figure 8:** Approach using New Modifier Ⓥ to Replace the Part Showing in Figure 7

Table 1 provides convenient guidance regarding how the new modifier Ⓥ in specifying a datum axis and center plane for MMC is intended to clarify this procedure in GD&T.

**Table 1**: Proposed Definitions for Datum Axis

| Modifier Used in Defining the Datum Axis | No Modifier<br>⌖ .XXX A | Modifier Ⓜ<br>⌖ .XXX AⓂ | Modifier Ⓥ<br>⌖ .XXX AⓋ |
|---|---|---|---|
| Definition of the Datum Axis | Regardless of Feature of Size[1] (RFS) or Regardless of Material Boundary[2] (RMB) | No GD&T Tolerance Specified in Defining Datum A | Ⓜ Used in the GD&T Tolerance In Defining Datum A |

The authors have recently introduced this new approach to the classroom. Students were surveyed on their understanding of specifying a datum axis or center plane. Students agreed that this will certainly clarify the issues in specifying a datum axis or center plane. A group of fifty one students (including 31 undergraduate seniors and 20 industrial engineers) have been asked the same question using original definition and new approach; the later improved the test performance from 65% to 91%. As this was a small class size, the authors plan to integrate this approach into the classroom for several semesters and evaluate the impact it has in the learning process.

**6. Summary**

The use of a modifier Ⓥ in defining a datum axis is proposed to clarify a datum axis when an Ⓜ is used in the geometric tolerance associated with the datum. As VC has been clearly defined, students will have no difficulty calculating the fixed gage size for the datum axis. Students can be guided to use Table 1 in defining the datum axis. However, as Ⓥ is not adopted in the current standards, instructors can emphasize the meaning of what Ⓜ really represents in the current standards when an MMC GD&T tolerance is specified with the datum.

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