

Actual vs. Effective Involute Tooth Size

Understanding the difference between actual and effective tooth thickness/circular space width of involute splines is a well-known quandary. Here's a clear and basic explanation.

by Brian Stone

While splines have been manufactured for decades, they still seem to perplex the manufacturing engineer who is trying to insure the proper assembly of two mating components. The case frequently arises in which “the dimension over pins is within limits, but the parts won’t assemble.” Understanding why this happens—and learning how to avoid the associated confusion and resulting downtime—is the focus of this article. Specifically, we’ll take a look at the differences between “actual” and “effective” tooth/space thickness, and examine the elemental errors that can keep two components from assembling after manufacture.

First, the Basics

Spline (noun): an equally spaced, multi-toothed connector used to transmit positive rotary motion. The primary function of a spline is to transfer torque from one shaft to another shaft, or to other rotary components such as gears, pulleys, or hubs. The spline connection can have a loose, sliding, or pressed-fit condition.

This article will address splines with an involute tooth form, since they are so widely used in the industry. An “involute spline” is one that has a tooth profile form defined by an involute curve, often referred to as the “involute profile.”

Splines are designed and made with an involute form, due to the ease of manufacture and its self-centering attribute.

The “Effective Fit” Concept

The effective fit concept is based on the fact that a manufacturer simply can’t produce a perfect spline. There will always be some variation in the “index” (the spacing of the teeth around the spline), the “lead” (the straightness of the teeth), and the “profile” (the form of the involute profile) attributes of a spline. No matter how accurately you control the actual tooth size, you must account for the variation caused by index, lead, and profile deviations when considering the assembly of two parts.

The effective fit concept can be confusing to someone who has just been introduced to the world of splines. The terminology alone can be a challenge, but adding the fact that there are two different tooth-thickness values called for in the same part tends to magnify the confusion.

This issue—the difference between “actual” and “effective” tooth size—seems to be the most commonly misunderstood concept that engineers have to face on the shop floor when manufacturing splines. Other challenges are mostly related to the terminology used. The fundamental question that needs to be answered in the shop, however, is “will my two mating components have a proper fit at assembly?”

To answer this question, we must first understand what prevents two parts from being assembled. Every tooth on an external spline must fit into every corresponding space of the mating internal spline. For this to happen, the following conditions must be met:

- Each tooth size on the external part must be less than that of the corresponding space size of the internal mating part. The possible interference issues are tooth thickness and circular space width.
- Each tooth must not have a form error that would cause any portion of the tooth surface to be increased over the space size. The possible interference issues are: lead/helix and involute profile error.
- Each tooth/space must be in the correct angular position. The possible interference issue involves the index.
- The two splines must be coaxial. The possible interference issues are concentricity and runout.

We need to understand these potential interference issues by first looking at the proper terminology for describing them, and then look at how these errors are applied to the fit condition between two parts.

Understanding the Terminology

According to the ANSI B92.1 standard:

Actual Tooth Thickness is the circular thickness on the pitch circle of any single tooth, considering an infinitely thin increment of axial spline length.

Effective Tooth Thickness of an external spline is equal to the circular space width on the pitch circle of an imaginary perfect internal spline, which would fit the external spline without looseness or interference, considering engagement of the entire axial length of the spline (i.e. the smallest space width that would contain the entire full length of the given tooth).

Actual Circular Space Width is the circular thickness on the pitch circle of any single space, considering an infinitely thin increment of axial spline length.

Figure 1



Figure 2

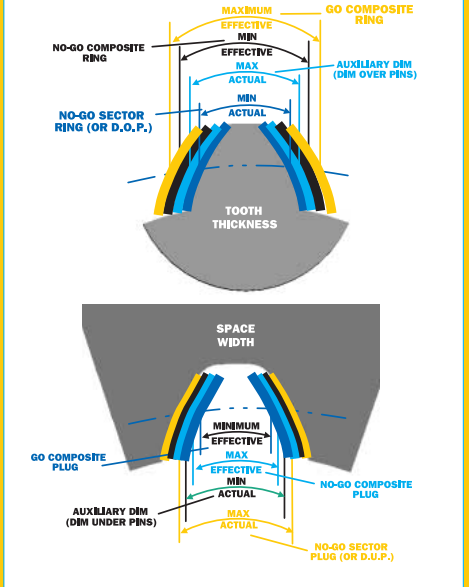
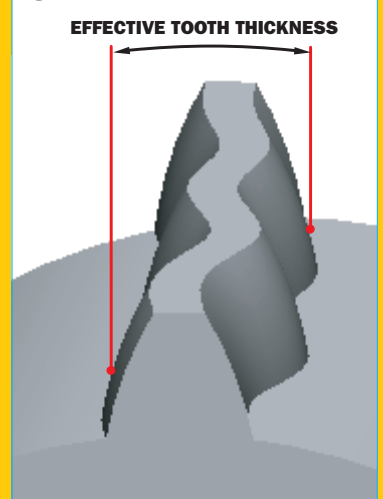


Figure 3



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Figure 4

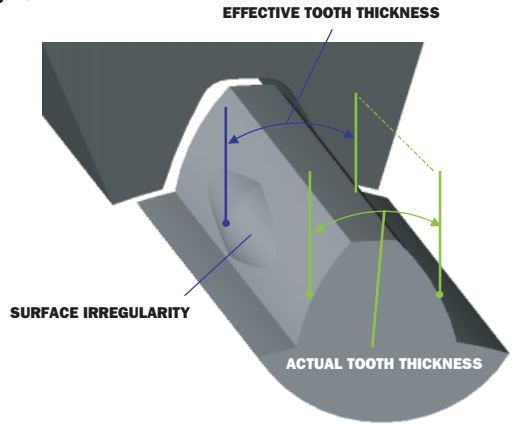


Figure 5

DIMENSION	ACTUAL, m	EFFECTIVE, λ	
SPACE WIDTH OF INTERNAL SPLINE			NO-GO SECTOR PLUG
TWOOTH THICKNESS OF EXTERNAL SPLINE			GO PLUG (COMPOSITE) (NOMINAL) GO RING (COMPOSITE) NO-GO SECTOR RING

Figure 6

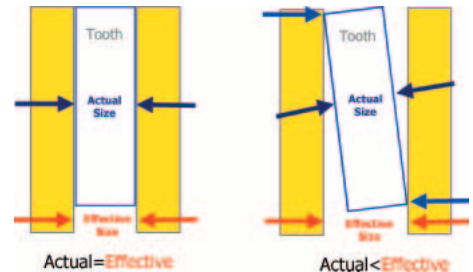


Figure 8



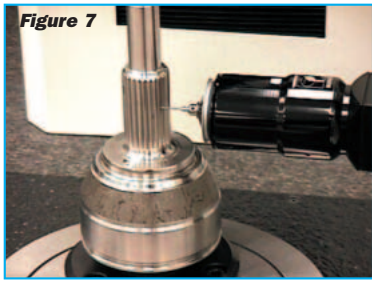


Figure 7

Effective Circular Space Width of an internal spline is equal to the circular tooth thickness on the pitch circle of an imaginary perfect external spline which would fit the internal spline without looseness or interference, considering engagement of the entire axial length of the spline (i.e. the largest tooth thickness that would fit into the entire full length of the given space).

Total Index Variation is the greatest difference in any two teeth, adjacent or otherwise, between the actual and the perfect spacing of the tooth profiles.

Profile Variation is any variation from the specified tooth profile normal to the flank.

Lead Variation is the variation of the direction of the spline tooth from its intended direction parallel to the reference axis, also including parallelism and alignment variations.

Determining Fit

The key values that determine whether two parts are going to fit together at assembly are the “minimum effective circular space width” on the internal spline and the “maximum effective circular tooth thickness” on the external spline.

The effective size can be considered the size seen by the mating component and is used to determine if the parts will fit together at assembly (not the actual size or dimension between pins value).

The effective size includes the actual size plus any errors due to index, lead, or involute profile variations (see Figures 4 & 8).

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When using the “effective fit concept,” for machining tolerances (“m”), a manufacturer is provided with a plus and minus actual tooth thickness limit for an external part, or an actual space width limit for an internal part. Adjusting the “depth of cut” in the manufacturing process controls these actual size limits.

Added to the machining tolerance is an allowance for “processing” errors such as total index, lead, and involute profile. This allowance is called the variation allowance (“l”). These variation errors, when added to the actual tooth or space size, will make the tooth size “effectively” larger than the “actual” tooth size, or in the case of an internal component, an “effectively” smaller space width. This “effective” size is what determines whether or not parts will assemble.

Thus, if your actual tooth size is within limits, but you have excessive error in your index, lead, or profile, you may not be able to assemble the part to its mate.

Positive errors—i.e. excess material on the flanks of teeth and flanks of the spaces—will cause parts not to assemble due to the reduced clearances. Negative errors, or material removed from the flanks, do not affect the ability to assemble parts, but they do reduce surface contact, thus raising localized surface stresses. If the actual tooth thickness is undersized, or actual space width is oversized, then excessive looseness may occur. This should be detected with a dimension between pins measurement, or with no/go sector gages.

Illustration of Actual & Effective Size

The diagram (Figure 6) on page 36 shows the difference between “actual” and “effective” size.

Analyzing Errors

When evaluating the size and accuracy of a spline, the actual size can be determined by measuring over or between pins and calculating an actual tooth thickness or actual space width. The actual size can also be directly measured on some analytical gear measurement systems, such as the ND430 Next Dimension™ Gear Measurement System.

To implement the effective fit concept, however, analytical gear measurement equipment must be used to determine total index error, lead error, and involute profile error. Once these variations are determined, they can be compared back to the allowances given in a standard such as the ANSI B92.1. These variations, if large, can prevent the successful assembly of components. If any one of these identified elemental allowances is exceeded, then the manufacturing engineer can begin to focus on determining the cause of the excessive variation that’s causing interference.

Still, the bottom line is, “will my two components fit at assembly?”

The best method for insuring assembly is to use an analytical measuring system to quantify the effective variation, and

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What many manufacturing engineers may have already experienced is that, just because the dimension over/under pins measurement on a component is within limits, it doesn't mean that it will fit at assembly. The reason? The effective errors of total index, lead, and profile are usually over their allowance. Without quantifying the magnitude of these errors, it is very difficult to know where to make the process adjustments in order to minimize the effective variation. With a proper understanding of spline terminology, and the right tools for determining variation, spline issues can be systematically addressed in a short amount of time. 

About the author:

Brian Slone is the owner of Slone Gear International, Inc. Troy, OH a developer and distributor of "Gear Production & Measurement Solutions". Brian has 25 years of experience in gear production and gaging solutions, supplying Spline Gages & Master Gears, and developing CNC Analytical Gear Measurement Systems. He can be reached at www.slonegear.com.

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