# A Comparison of ISO 4156/ANSI B92.2M-1980 With Older Imperial Standards

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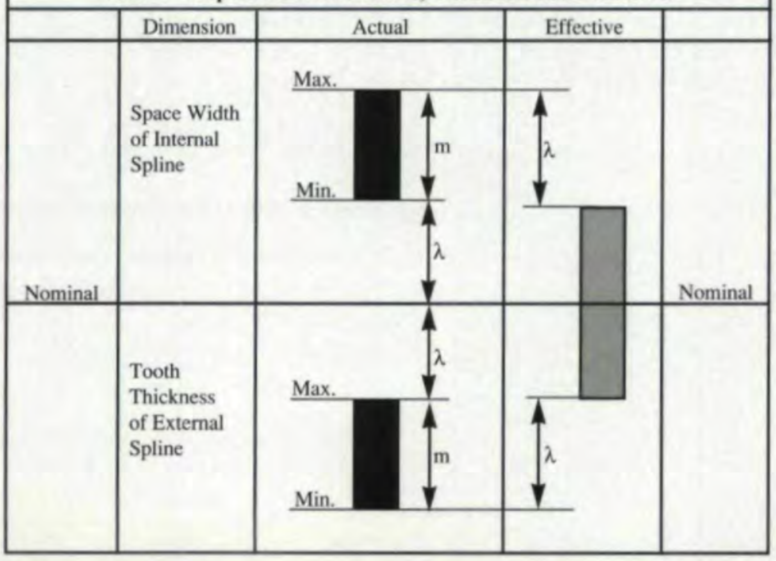
The purpose of this article is to discuss ISO 4156/ANSI B92.2M-1980 and to compare it with other, older standards still in use. In our experience designing and manufacturing spline gauges and other spline measuring or holding devices for splined component manufacturers throughout the world, we are constantly surprised that so many standards have been produced covering what is quite a small subject. Many of the standards are international standards; others are company standards, which are usually based on international standards. Almost all have similarities; that is, they all deal with splines that have involute flanks of 30°, 37.5° or 45° pressure angle and are for the most part flank-fitting or occasionally major-diameter-fitting.

**Table 1 - Disposition of Allowances, Clearances and Tolerances**




Although ISO 4156 was published in 1981 and is widely used in Europe, we find that it is not used as frequently as it should be in the United States and United Kingdom for a number of reasons. One is that many engineers do not seem to be aware of it; another is that because it is a metric module standard, the circular pitch is different from that of imperial-standard-based diametral pitch splines. This fact can necessitate buying new cutters; however, this should not present any problem where new projects are involved, as a module cutter is no more expensive than a DP (diametral pitch) cutter. Also, DP cutters have to be periodically replaced, so why not change to metric splines? Furthermore, spline gauges designed to a module standard are no more expensive than DP gauges. These arguments, of course, cannot apply to components that have been made for many years, and therefore have to be interchangeable.

In our opinion, the main reason that ISO 4156 is not used more in these countries is lack of awareness. We hope the following is informative to those who have not heard of it and encourages those who are aware of it to use it. We feel this is necessary because quality control these days is of the utmost importance. This standard (unlike the previous imperial standards) has many classes of fits that will guarantee sliding, clearance or interference. Also, in general, components manufactured to this standard are of a higher quality, as tighter

tolerances have to be maintained to achieve these better fits. Section 8.1 of the standard is of paramount importance to component manufacturers. This paragraph has wide-reaching implications, as it means that closer tolerances have to be maintained to obtain the desired fits, meaning that quality control during manufacture and gauging will have to be increased, but that is inevitable anyway in today's competitive global markets.

### ISO 4156/ANSI B92.2M-1980 — Its Origins

During the 1970s it was realized in the United Kingdom that with metrication in mind, a new standard for involute splines was required. Up to this time and indeed still today, the most widely used standards were BS 3550-1963 and ANSI B92.1-1970. Both of these standards are, of course, imperial standards based on DP. The DP is the number of teeth per inch of pitch-circle diameter and as such provides a standard series of tooth sizes on various pitch-circle diameters. The proposed standard, of course, would have to be, like European standards, metric-module-based. Similar to DP, the module is the ratio of the pitch circle in millimeters to the number of teeth and provides a standard series of tooth sizes. It was not satisfactory simply to convert DP to module because the pitch-circle diameters and tooth proportions would still be imperial-based and would therefore give no degree of interchangeability with metric components.

AFNOR (the French national standards authority) and DIN were consulted to see if there were any standards in existence on which the new standard could be based. The existing French standard E22-141 was considered to be out of date, as it made no reference to variation allowance (discussed later). The German standard DIN 5480 seemed to be the only other possibility, since it did take into account variation allowance. The result of this consultation was the realization that more than a new metric standard was required. What was needed was an international standard that could be used throughout the world.

To achieve this, working groups were established at the various standards organizations; the working groups consisted of representatives from the United Kingdom, France, Germany, Scandinavia, the United States and Japan, among others. At a meeting of all members in Paris, two draft proposals were put forward for consideration: One proposal was based on DIN 5480, and the other was a completely new draft proposal by AFNOR and British Standards. The basis of the tolerances for this draft was taken from ISO 286; i.e., tolerances for plain parts with an additional tolerance for variation allowance.

After discussion, the new draft was adopted and contributions from all member organizations were invited. The result of the collaboration is ISO 4156. This standard also has been published in the United Kingdom as BS 6186, in France as E22-144/E22-145, and in the United States as ANSI B92.1-1980. It is used extensively in Europe and is gradually becoming more and more popular throughout the United States, where transition from imperial to metric is taking place.

### Explanation of Variation Allowance & Effective Size

To enable ISO 4156 to be compared with the older standards, it is necessary to understand the concept of effective fit. The effective tooth thickness of the space width of a component is the most important element because it is this size that determines whether the fit is good or bad. It is not only the *actual* tooth thickness or space width that determines the resultant fit between an external and internal spline. This is because, unlike plain parts, splines have multiple engaging surfaces. Each of these surfaces is subject to an error of either profile, spacing/index or parallelism, which must be allowed for if the parts are to fit. This variation allowance is determined by allocating to each of the elements a permissible tolerance. The sum of these tolerances is then referred to as an error allowance $e$ or variation allowance $\lambda$.

It is generally accepted in most standards that because it is unlikely that these errors will occur simultaneously and in their maximum amounts on the same spline, a variation allowance consisting of a percentage of the sum of the positive profile error, the index error and the parallelism error for the length of engagement is allowed.

To achieve a suitable fit, the nominal tooth thickness of the external spline and the nominal space width of the internal spline usually are equal to one half of the circular pitch at the

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pitch-circle diameter. The internal spline is allocated a space width greater than nominal. A machining tolerance *m* is determined to arrive at a maximum and minimum actual space width, and the variation allowance $\lambda$ is then subtracted from each value to arrive at a maximum and minimum effective space width.

Similarly, the external spline is allocated a tooth thickness that is less than nominal. A machining tolerance is used to arrive at a maximum and minimum actual tooth thickness, and the variation allowance is added to each value to arrive at a maximum and minimum effective tooth thickness. Table 1 shows a typical fit condition between an external spline and an internal one.

**ANSI B92.1-1970**

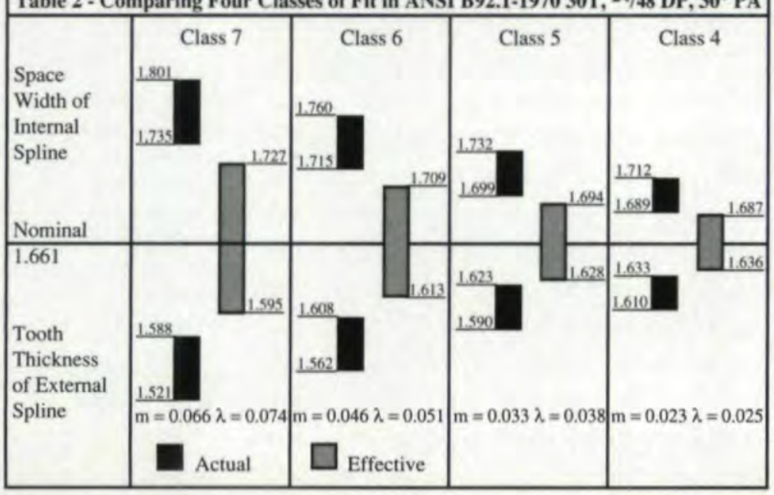
This standard is probably the most widely used standard today. As can be seen from Table 2, it shows four classes of fit. The maximum effective tooth thickness of the external spline and the minimum effective space width of the internal spline are equal to nominal. The machining tolerance and effective clearance are different for each class of fit, resulting in Class 4 being the closest fit and Class 7 being the loosest.

According to this standard, the allowable errors for a Class 5 spline (the most widely used) are

**For 30 teeth, 24/48 DP, 30° PA**
Total Index Variation = 0.038
Profile Variation = +0.005/-0.010
Lead Variation = 0.010 (for a spline length of 25)

As described previously, it is not accepted that all elements will occur in the same position. In this standard, 60% of the accumulated

**Table 2 - Comparing Four Classes of Fit in ANSI B92.1-1970 30T, 24/48 DP, 30° PA**




values of total index, twice the positive profile and lead variation are used to calculate the variation allowance; i.e., 0.6 (0.038 + 0.010 + 0.010) = 0.035 (Due to rounding of various elemental errors the value is stated as 0.038 in the ANSI standard.)

For Classes 4, 6 and 7, the machining tolerances and allowable errors for a Class 5 spline are multiplied by the following factors:

Class 4 = x 0.71
Class 6 = x 1.4
Class 7 = x 2.00

Because the minimum effective space width of the internal and the maximum effective tooth thickness of the external spline are equal, a fit is always guaranteed. To ensure this, the GO plug gauges and the GO ring gauge have a tooth thickness/space width equal to nominal (with a tolerance and wear allowed), which means that one single GO plug gauge and one GO ring gauge can be used for checking all four classes of fit. The NOGO gauges have to be unique to each class of fit.

The only disadvantage of this system is that, while a fit is guaranteed (provided the spline is accepted by the gauges), the type of fit is not. For example, if you were designing components requiring an extremely loose fit, Class 7 tolerances would be used. However, in the case of a poorly made component with splines on maximum metal condition and with excessive profile, index and lead error, it is possible for the gauges to accept the spline, providing, of course, nominal size is not exceeded. The fit obtained from this condition would be a tight fit rather than the desired loose fit.

**BS 3550-1960**

In this standard, the tooth proportions are similar to those in ANSI B92.1-1970. The allowable elemental errors (profile, spacing and lead errors) are identical to those of a Class 5 spline in ANSI. The only pressure angle referred to is 30°. There are just two classes of fit. The internal splines have only one tolerance band (identical to a Class 5 ANSI spline). For Class 2, both external and internal splines have the same tooth thickness and space width dimensions as an ANSI Class 5 spline. For Class 1 splines, the machining tolerance and variation allowance are identical to Class 2. However, a clearance or deviation allowance *Cv* is introduced, thus ensuring a

degree of looseness between the male and female splines. The clearance is shown in Table 3. As shown, the tooth thickness dimensions of the external splines are displaced or adjusted by the clearance *Cv*. It also can be concluded that while BS 3550 has fewer fits, a Class 1 spline does ensure clearance.

**DIN 5480**

DIN 5480 has been in existence for many years and is predominantly used in Germany, but also is used in many other countries. It is a metric module standard and was therefore considered a basis for ISO 4156. Its popularity is due to its 1) being a metric standard, and 2) offering a vast diversity of fits that ANSI B92.1-1970 and BS 3550 do not. In the past, if you wanted to produce a metric spline, and it was necessary to achieve a certain fit, DIN 5480 was the only metric standard available to enable you to achieve this (the only other metric standards that were available were older standards that did not take into account variation allowance and therefore were unsuitable).

In this standard, the outside diameter is considered as a basis rather than the pitch-circle diameter; i.e., DIN considers that the outside diameter of a spline should conform to a preferential series of whole numbers. To ensure this and to enable common cutting tools to be used in manufacture, it is necessary to correct the tooth profile; i.e., it is not possible for the nominal tooth thickness (0.5 x circular pitch) to occur always on the pitch-circle diameter, but sometimes on a corrected pitch circle, either larger or smaller. This correction does not cause any problem to the spline designer, as all corrected sizes are specified in the standard.

To calculate the variation allowance, 60% of the tooth thickness machining tolerance is used. This means that profile, spacing and lead errors are not specified. This can be a disadvantage if a splined component manufacturer wishes to check these errors on conventional or computerized universal gear checking machines. In the writer's opinion, DIN 5480 is an excellent standard, but the vast choice of fits must cause confusion to the inexperienced. In addition, the machining tolerances for some of the closer fits are extremely tight and the variation allowances consequently minuscule, which must make manufacturing on a production basis difficult. Having said this, these days with modern computerized machinery and measuring machines, which have eliminated a great deal of human error, it is now possible to manufacture components that are accurate and consistent, so perhaps there is nothing wrong in setting limits that were at one time considered impossible. Table 4 shows a small selection of fits from this standard.

**Table 3 - Comparing Two Classes of Fit in BS.3550.1963 30T, 24/48 DP, 30° PA**

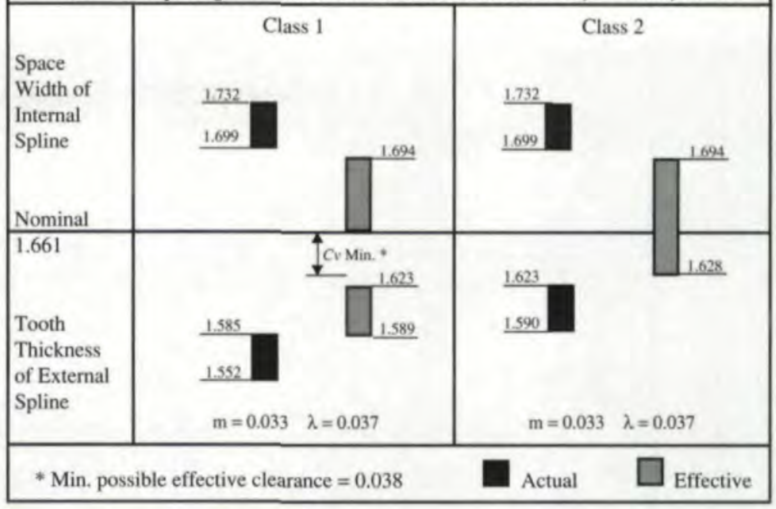
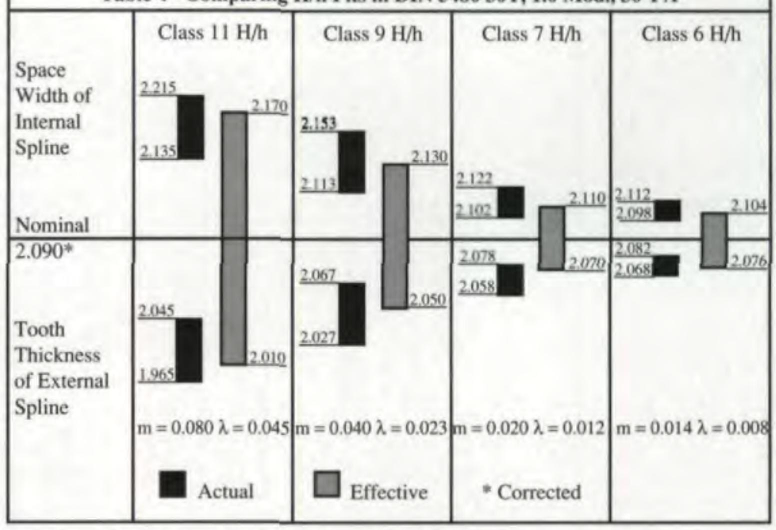



**Table 4 - Comparing H/h Fits in DIN 5480 30T, 1.0 Mod., 30°PA**




**ISO 4156/ANSI B92.2M-1980**

This new standard also allows engineers to select various types of fits; i.e., sliding, close sliding, clearance and interference. Because the splines are not outside-diameter-based, the tooth profiles are not corrected, and the resultant outside diameters are not whole numbers and, consequently, do not conform to a preferred series. This, however, does not present any problem, because a suitable tooth number can be selected for a particular application.

The nominal tooth thickness/space width is calculated in the same way as ANSI B92.1-1970

Table 5 - Comparing Four Classes of Fit H/h in ISO 4156/ANSI B92.2M - 1980 30T, 1.0 Mod., 30° PA

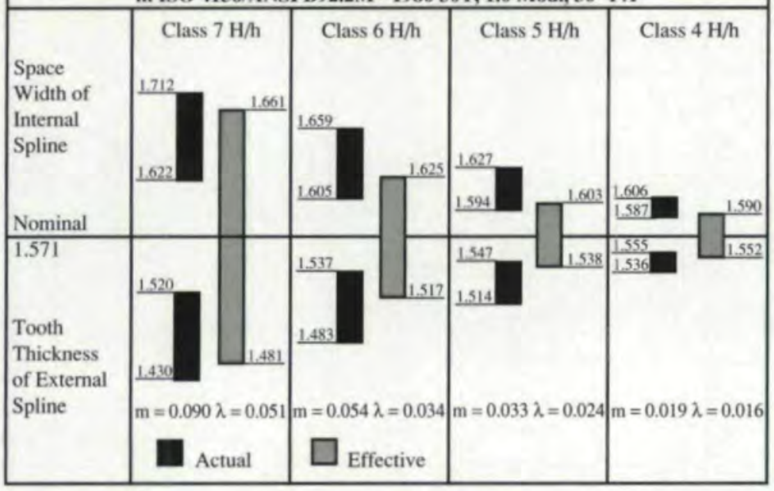
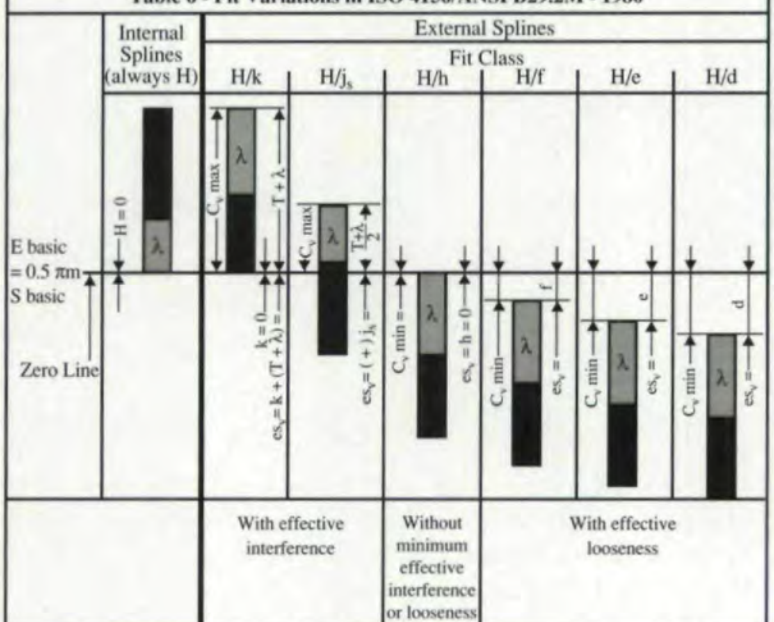



Table 6 - Fit Variations in ISO 4156/ANSI B29.2M - 1980




Graphical representation of deviation allowances for the spline fit classes

and BS 3550; i.e., 0.5 x circular pitch. There are four basic classes of fit, referred to as 4H/h, 5H/h, 6H/h and 7H/h. The suffix H refers to the internal spline and h to the external (as described in ISO 286 limits and fits for plain parts).

Table 5 shows the four H/h fits and can be compared with the four ANSI fits in Table 2. As can be seen, the fits obtained for Classes 4, 5 and 6 in ISO 4156 are significantly closer than those from the older ANSI standard (particularly Classes 4 and 5). The machining tolerances for both standards are approximately equal; consequently, the closer fits obtained in ISO 4156 are due to a reduction in the variation allowance λ.

As stated earlier, Section 8.1 of the standard has wide-ranging implications for the spline manufacturer. It states that the variation allowance λ should be calculated using the following expression:

$$\lambda = 0.6\sqrt{\text{Index Variation}^2 + \text{Profile}^2 + \text{Lead Variation}^2}$$

The expression is different from that used in ANSI B92.1-1970 and BS 3550-1960, which states that variation allowance is calculated as follows:

$$\lambda = 0.6\,[\text{Index Variation} + 2\,(\text{Positive Profile Variation}) + \text{Lead Variation}]$$

The result of the expression specified in the newer standard is a value that is less than that of the old standard, as can be seen from the following example. A 30-tooth, 1.0 module, 30° PA Class 5 spline is used.

Total Index Variation = $Fp$
$Fp$ in micrometers = $3.55\sqrt{L} + 9$
$Fp$ in micrometers = $3.55\sqrt{47.124} + 9$
$Fp$ in micrometers = 33.370
$Fp$ in millimeters = 0.033

where the length of arc $L$ = 0.5 x Pitch Circle Circumference.

Total Profile Variation = $Ff$
$Ff$ in micrometers = $2.5\,\phi f + 16$
$Ff$ in micrometers = $2.5(1.375) + 16$
$Ff$ in micrometers = 19.4375
$Ff$ in millimeters = 0.019

where Tolerance Factor $\phi f = m + 0.0125\,m.Z.$

Total Lead Variation = $F$
$F$ in Micrometers = $1\sqrt{g} + 5$
$F$ in Micrometers = $1\sqrt{25} + 5$
$F$ in Micrometers = 10
$F$ in Millimeters = 0.010

where $g$ is the spline length in millimeters.

Substituting the above values into the new expression in ISO 4156:

$$\lambda = 0.6\sqrt{(0.033)^2 + (0.019)^2 + (0.010)^2} = 0.024.$$

Referring to Table 2, we see that the allowable errors of index, profile and lead for an ANSI B92.1-1970 spline are reasonably comparable to the above (it must, of course, be appreciated that the above value for $Ff$ is total and should there-

fore be interpreted as ± 0.0095).

The variation allowance, however, for an ISO 4156 spline is less than that for an ANSI B92.1-1970 spline; consequently, when machining splines to the later standard, greater care and more rigorous quality control have to be applied.

The above demonstrates that by using ISO 4156, it is possible to maintain closer fits than those obtained from the older imperial standards.

**Further Fit Variations**

By using ISO 4156, it is possible to achieve fits other than those shown in Table 5; i.e., the H/h fits. This is made possible by introducing further fit classes to the external spline while maintaining the H fits on the internal spline (it is beneficial to adjust external splines, as these are usually machined, while many internal splines are produced by broaching).

These additional fits are designated *f*, *e*, *d*, $j_s$ and *k*, and are obtained by applying a deviation allowance ($Cv$) to the shaft-tooth thickness. The deviation allowances to guarantee clearance for a 30-tooth, 1.0 module spline are as below:

$$f = -0.020$$
$$e = -0.040$$
$$d = -0.065$$

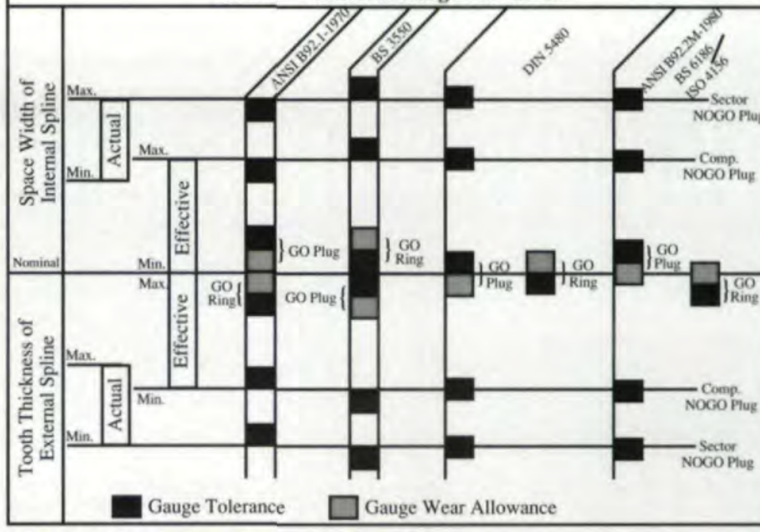
The clearance becomes progressively larger from *f* to *d* and ensures looseness. If interference is required, it is possible to employ fits *k* or $j_s$. Fit *k* guarantees interference, and with $j_s$ it is most probable that interference will exist. Spline tooth thickness values for the two fits can be determined by referring to Table 6, which also shows the clearance fits.

It should be remembered that when using fits *f*, *e* or *d*, the shaft major diameter and minor diameter also should be adjusted by a value equal to the deviation allowance divided by the tangent of the pressure angle.

ISO 4156 specifies only side-fitting splines. The older imperial standards also contained major-diameter-fitting splines, which could be an advantage in maintaining concentricity; in this instance, the spline flanks were used as drivers only.

The fact that ISO 4156 does not contain major-fitting splines should be offset by the greater accuracies achievable by using the close tooth thickness tolerances recommended in this standard. This, however, may be debatable by spline manufacturers, who find the major diameter easier to control than the tooth thickness.

**Table 7 - Position of Gauge Tolerances**




**Comparison of Gauging Procedure**

All the standards that have been used for comparison have a section that clearly defines the method of tolerancing for gauging. Note the following points upon which all standards are in agreement:

An internal spline should at the very least be checked with

1. a full-form GO plug gauge designed to check "min. effective" space width,

2. a sector-type NOGO plug gauge designed to check "max. actual" space width,

3. an additional composite NOGO plug gauge to check "max. effective" space width (this is very occasionally required if it is necessary to restrict the effective size).

An external spline should at the very least be checked with

1. a full-form GO ring gauge designed to check "max. effective" tooth thickness,

2. a sector-type NOGO ring gauge designed to check "min. actual" tooth thickness,

3. an additional composite NOGO ring gauge designed to check "min. effective" tooth thickness where it is necessary to restrict the effective size.

The position of the gauge tolerance and wear allowances is the place where the various standards do not agree. As can be seen from Table 7, ANSI B92.1-1970 places the gauge tolerance within the part tolerance, BS 3550 puts the gauge tolerance outside the part tolerance, and in DIN 5480 and ISO 4156, the gauge tolerances are bilateral. ■