A BRIEF OVERVIEW OF SPLINES

Splines must be properly sized and designed in order to ensure the proper torque capacity and operation.

SPLINES PROVIDE A CONNECTION BETWEEN TWO SHAFTS OR other components that transmit torque and rotation. Splines may be straight sided, tapered, or have an involute form. We will only be considering involute splines here because they are much more common. Involute splines have teeth similar to gear teeth except spline teeth are much shorter, and they do not roll. They have the same number of teeth and fit together as one. Typical involute SAE/ANSI spline teeth are specified as two numbers: a numerator that specifies the tooth thickness in diametral pitch (DP) and the second number that specified the tooth height in diametral pitch (DP). Thus an 8/16 spline has the tooth thickness of 8 DP and a tooth height (whole depth) of 16 DP.

Involute splines are available in several different pressure angles: 30 degrees, 37.5 degrees, and 45 degrees. The 30-degree splines are by far the most common, so that is what will be considered here. Splines are made with either a fillet root or a flat root at the interface of the tooth flank and the root diameter. The root diameter of a flat root external spline is typically larger than a fillet root spline, but the stresses are close to being the same because the fillet root with the smaller root diameter offsets the sharper corner but larger root diameter of the flat-root spline. Standard cutting tools are available for both types in a range of standard DPs.

Splines are specified as either side fit or major-diameter fit. A side-fit spline has clearance between the root diameter of the external part and the inside diameter of the internal part. Also, there is clearance between the outside diameter of the external part and the major diameter of the internal part. The fit for a side-fit spline is the difference between the circular-tooth thickness of the external splined part and the circular-space width of the internal part. This difference is called the backlash or clearance.

In a major-diameter fit spline, the major diameter of the internal part and the outside diameter of the external part act like pilots to each other, and there is only a small amount of difference between these two values, which is the radial clearance. Sometimes this value is negative, causing an interference fit. With a major-diameter fit, the concentricity of the major diameter of the internal-part/outside-diameter of the external part to the pitch diameter of the external and internal spline teeth being a positive value, causes the circumferential fit of the spline teeth to be able to effectively contact and transmit torque on only some of the spline teeth but not all of them. This reduces the capacity and strength of the spline connection. Side-fit splines do not have this problem.

Major-diameter fits tend to center the spline connection between the external and internal parts by the major diameter and the outside diameter. The spline teeth have little-to-no centering effect. On side-fit splines, it is the opposite. The major-diameter/outside-diameters have no centering effects, but the spline teeth do have a centering effect under load because of the pressure angle of the teeth.

Splines are further specified by tolerance classes. In the SAE B92.1 standard, there are 4 tolerance classes: 4, 5, 6, and 7, which represent increasing levels of accuracy. A spline made to any of these tolerance classes will mate with a spline made to any of the other tolerance classes.

The tooth thicknesses and space widths of spline teeth are specified as both actual and effective. Actual tooth thicknesses and space widths are those for an individual spline tooth and are typically measured by over- or between-pin measurements. Effective sizes for these parameters are for the spline teeth taking into account the variations such as involute, lead, spacing, etc., and these variations add to the circular tooth thickness of an external part and are subtracted from the space width of an internal part. These variations take into account all of the spline teeth and are essentially equivalent to the max material condition for the external part and the min material condition for the internal part. It represents the worst-case scenario as if the parts take up all of the available tolerances for variation.

This is usually measured by go/no-go spline gages.

All of the above describes the spline teeth for a part that has already been sized properly and where the number of spline teeth, diametral pitch, type of fit, pressure angle, etc., has been selected. This information is readily available in ANSI/SAE B92.1 and other places.

Perhaps more important, however, is sizing the splines and calculating the spline stresses for the different failure modes. This information is not as readily available, and I know of no standards that cover this topic. Spline teeth are usually sized and fail in the following ways: spline tooth shear stress, compressive stress on the flanks of the teeth, bursting stresses, and torsional-shear stresses of the shaft or supporting structure.

External spline teeth can be manufactured by hobbing, shaper cutting, or rack rolling. Internal spline teeth can be manufactured by shaping or broaching.

Adequate lubrication is important for proper spline operation. Inadequate lubrication can lead to wear and fretting corrosion. Ideally, a flow of oil should go through the splines, removing particles generated by this wear or fretting corrosion and lubricating the splines.

This is a brief overview of sizing, specifying, and designing splines. For more information, consult ANSI/SAE B92.1, B92.1M, and the SAE paper: Design Guide for Involute Splines by Robert W. Cedoz and Michael R. Chaplin.

Involute splines are a simple but effective means of coupling two components and transmitting torque between the two.

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