Advantages of Involute Splines as Compared to Straight Sided Splines

by
Tifco Spline, Inc.
Wixom, MI

Since the design of involute splines and their manufacture requires considerable knowledge, not only of the basic properties of the involute profile, but also of various other elements which affect the spline fit, and the sometimes complex principles underlying manufacturing and checking equipment, the question is frequently raised as to why the involute profile is given preference in designing splines over the seemingly simpler straight sided tooth profile.

As a matter of fact, the first spline coupling was a straight sided spline with one tooth: a shaft keyed to a hole. The simple expedient of increasing the number of teeth, in order to increase the load carrying ability of this machine element, led to the development of straight sided spline fittings.

More exacting requirements on torque transmitting splines compelled designers to look for ways to satisfy the following conditions:

1) To increase the contact surface without decreasing the minor diameter of the shaft or increasing the major diameter of the splined hole.
2) To insure full surface contact on the tooth flanks, independent of the unavoidable clearance between the teeth. Although the necessity of a clearance between spline fittings is not disputed, it may be pointed out that such clearance will not be negligible if the parts are heat treated after machining. The distortions caused by the heat treating process must be compensated for by sufficient initial clearance to permit assembly of mating splines.
3) *To design a tooth profile which conforms* to the stress distribution along the depth of the tooth, i.e. which is heavier at the root than at the crest.
4) To provide a tooth profile which can be easily produced by means of fast cutting mass production machine tools (hobbing machines, shaper cutters), not a profile which only appears simple in a cross sectional view.

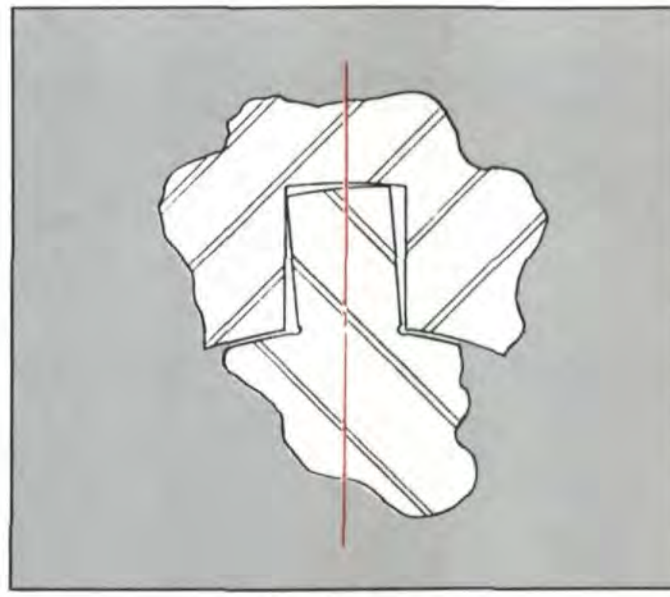

Fig. 1 – Line contact.

Conditions #1 and #2 are especially important when intermittent torque loads on the shaft cause intermittent length reductions and, as a consequence, longitudinal sliding movements in the spline fitting.

The following discussion of these four requirements demonstrates clearly why the involute profile has been selected, out of all other possibilities, as the best spline tooth form which meets practical requirements.

Condition #1

A profile which is not straight radial should be acceptable, insofar as Condition #1 is concerned, calling for increased contact surfaces without a change in *diameters*.

Condition #2

Fig. 1 shows that straight sided splines, with the sides of the shaft tooth parallel to the center line cannot have surface contact on the side of the tooth due to the clearance between the mating parts: the shaft rotates against the splined hole when under load and the points farthest from the center travel faster than points near the minor diameter. Therefore, the tip of the tooth on the shaft reaches the side of the hole splines before any other point of the tooth side can contact.

The problems can only be overcome by making the amount of clearance proportional to the distance from the center. In fig. 2-A, this condition is satisfied since the clearances C_1 and D_2 are in proportion to the diameters, D_1 and D_2. Such splines, however, with radial tooth sides are, by no means, the solution of the problem, due to the weak cross section of the shaft tooth at its root and the impractical shape of the splined hole.

Fig. 2-B shows how this condition could be satisfied with straight sided serrations. The clearance C_1 and C_2, *subtending the same angle are in proportion* to the diameters D_1 and D_2 at which they are measured. When the spline tooth rotates under load against the side of the female spline tooth, it matches this side along its whole active depth. Consequently, after it is rotated back into the position shown in fig. 2-B the angles 1 and 2, which represent the

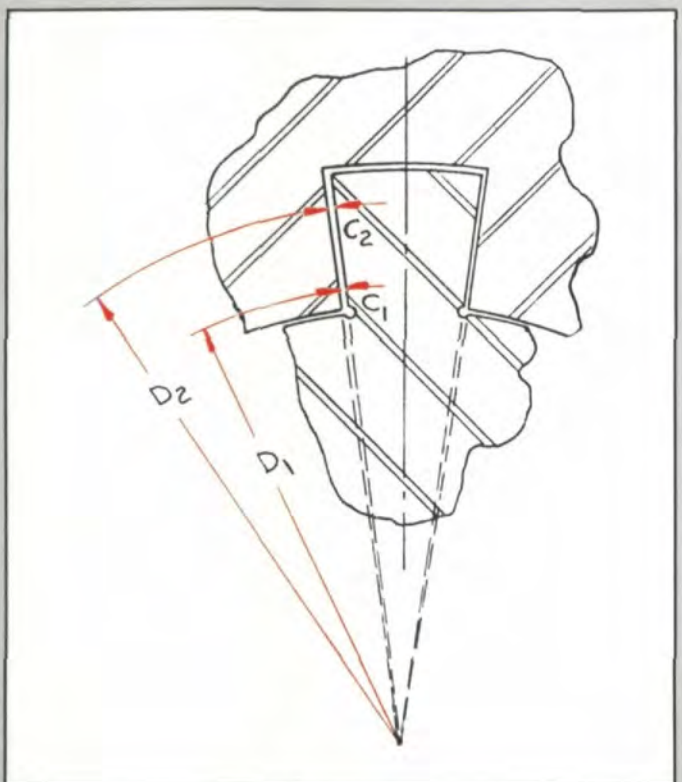

Fig. 2A

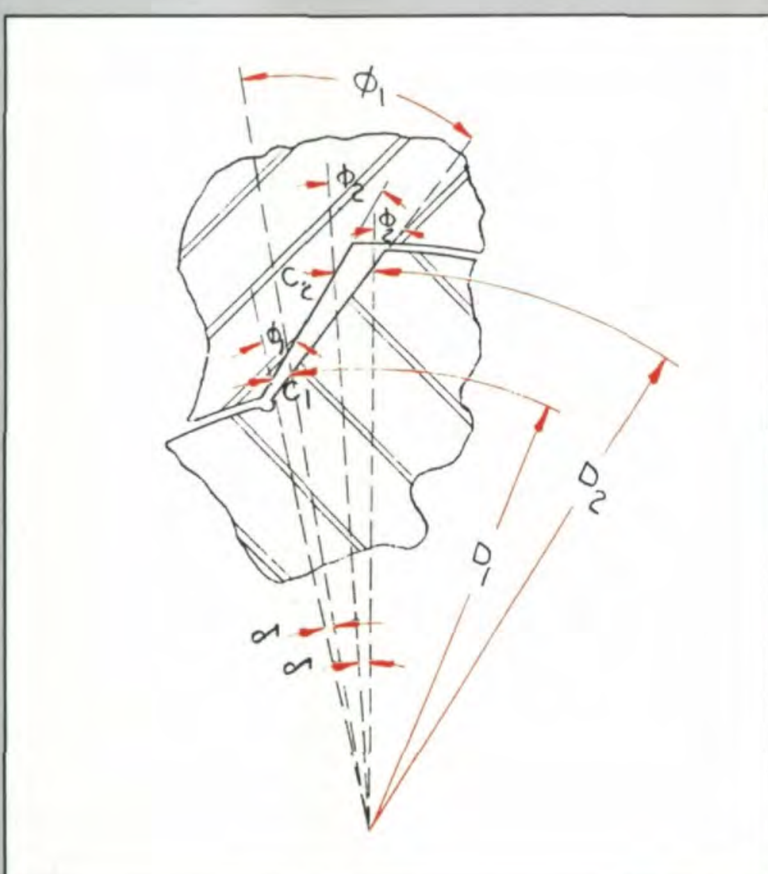

Fig. 2B

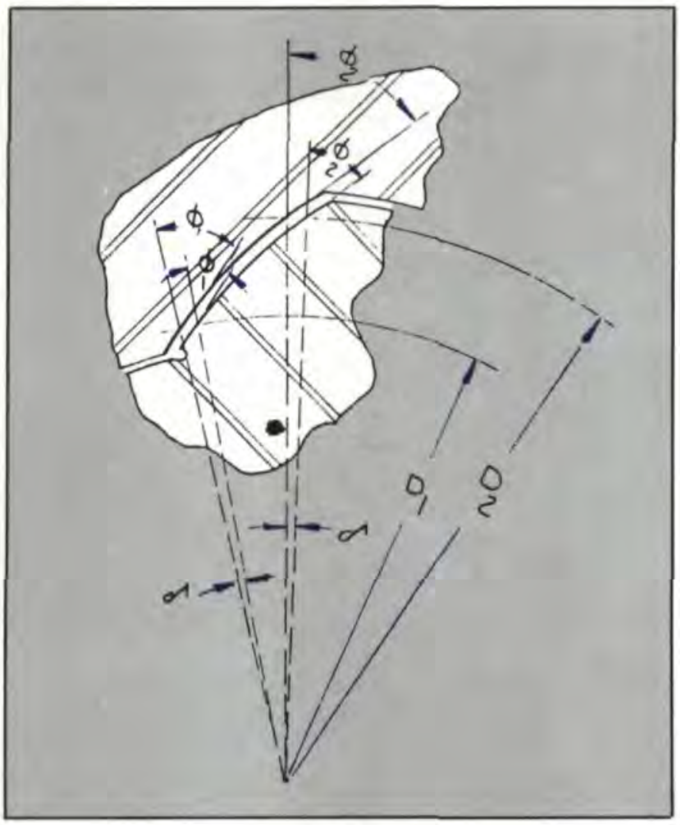

Fig. 2C

angles between the profile and a radial line through the intersection of the profile with reference diameter, are equal on the female and the male spline tooth. These angles are commonly called the pressure angle. *This discussion shows that the requirement of surface contact demands equal pressure angles at the same reference diameter for both splines.* The application of this principle, on the general case of splined teeth with curved sides, is shown in fig. 2-C. The pressure angles 1 and 2 are the same on both mating spline profiles. The advantages of curved tooth profiles will be discussed under Condition #4.

Condition #3

This condition will be satisfied by selecting a sufficiently large pressure angle, for instance 30°. An additional advantage of the large pressure angle appears in connection with case hardened splines and relatively fine pitches, where a small pressure angle is sometimes the cause of breakage, because no soft core is left at the root of the tooth. The larger pressure angle assures that such a core exists where it is needed.

Condition #4

If straight sided teeth could easily be produced on fast cutting machine tools, the development of the previous paragraphs would already present the solution of the problem. However, a straight sided spline can only be produced with straight sided cutters by milling, which requires time consuming indexing operations.

In view of the fact that the gear industry developed the machine element which conforms, not only to the first three conditions (presenting even a further improvement with regard to condition #1), but also to this last condition #4, the ideal of producing splines with the same shape as gear teeth appears as the next logical step. It is granted that splines of the serration type, as discussed above, could also be produced on fast cutting hobbing machines or on shaper cutters. The scales, however, are definitely turned in favor of involute splines, if the tool profiles are required for the two alternatives as compared.

It is possible to design a hob or shaper tool profile which will cut straight sided splines of any pressure angle. The development of this tooth profile requires either cumbersome calculations or time consuming layouts; but even after all of this work is completed, such tooth profiles present difficulties in manufacture and inspection. In addition to this, it would only be correct for cutting one gear of the pitch, pressure angle, *and the number of teeth for which it has been developed.* It could not be used interchangeably to cut any tooth form of the same pitch and pressure angle, regardless of the spline size. Besides these prohibitive disadvantages, the inherent inaccuracy of a tooth form on the cutter, which could not be generated by simple means, would cause corresponding inaccuracies of the tooth form on the part, which would defeat the purpose of the constant pressure angle, as outlined in condition #2. These difficulties restrict the general use of straight sided splines with constant pressure angle in the mass production of spline fittings for transmission of high loads. They are overcome by the application of involute profiles which can be easily generated by means of straight sided tools, by hobs with practically straight sided profiles, or by shaper cutters which themselves are produced by generation. It is true that this solution creates new difficulties in connection with producing small splined holes, since it is easier to produce a broach for straight sided splines than for involute splines. The involute spline broach, however, can, in many cases, be hobbed and, when grinding is necessary, is furnished with very satisfactory results by various tool manufacturers.

It should be borne in mind that the problem of providing a satisfactory involute profile, and at the same time the necessary back off (relief) angle, sometimes presents difficulties, but it is preferable to transfer manufacturing difficulties from the production line to the tool shop. Consequently, the involute splines have replaced straight sided splines in recent years to a very large extent, and they will continue to maintain a dominating position in the field of spline fittings.