Research on precise measurement method of full parameters of spline interlocks

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Abstract. This paper mainly introduces the types, characteristics and applications of spline, studies the high-precision measurement technology of different types of spline. Based on gear measuring instrument, optical coordinate measuring machine and coordinate measuring machine, the high-precision full-parameter measurement methods of spline. Developed countries in Europe have spline standards in the 1950s. At present, China has formed a relatively complete system of key and spline linkage standards, but the overall level is still far from developed countries. With the revision of national standards, spline coupling has been applied in more and more fields with the development of industry. It also puts forward higher requirements for high-precision detection methods. Especially for rectangular splines, there is no national calibration specification for the traceability of rectangular splines. We determine the measurement methods and parameters according to the national standards, international standards and the actual production process of the factory. We hope that we can help the factory to improve the precision of splines and prolong their working life.

1. Introduction

The spline has the unique advantages of high bearing capacity, small stress concentration, high centering accuracy, good guidance and so on, becoming an important connection part for torque transfer[1]. It plays an irreplaceable role in aircraft transmission, and is also widely used in automobile steering gear, weapons, agricultural machinery and heavy machinery transmission equipment. The aviation industry in developed countries has always attached importance to the design, use, maintenance and testing of splines. So far, no coupling has been recognized as superior to the spline in terms of military industrial standards[2] [3].

In the manufacturing process, the size error and the form and position tolerance will increase the wear speed and shorten the service life of splines, and may lead to overload or fatigue fracture[4]. The precision detection of spline gauges can improve the bearing capacity, slow down the wear rate, increase the gauge life and reduce accidents[5].

2. Types and characteristics of splines

Splines can be divided into involute splines and rectangular splines according to the shape of the teeth. Involute spline is the most widely used. It is often used in static connection and dynamic connection which require high centering precision, but it is difficult to repair and has high friction force[6]; Followed by rectangular spline, suitable for light medium load transmission mechanism. Light series of
lower load-carrying. Medium series has high strength, large bearing capacity can still ensure centering accuracy[7]. Typical types are shown in Figure 1 and Figure 2.

![Figure 1. Involute spline](image1)

![Figure 2. Rectangular](image2)

3. **Measurement of cylindrical straight involute splines**

3.1. **Measuring parameters of cylindrical straight involute splines**

Individual tolerance grades are shown in Table 1. The tolerances are fit size and non-fit size[8] [9]: fit dimensions include Tooth thickness S, Tooth groove width E, Profile tolerance F_a, Lead tolerance F_b, Index variation F_p. Spline measurement usually adopts single inspection method, the advantage of single geometric deviation measurement is easy to analyze and diagnose the spline processing quality, and based on this to adjust the machine tool processing parameters. Some spline measurement parameters can be directly measured, and some need to be measured indirectly. The following describes the measurement process and method.

| reference circle D (mm) | profile tolerance F_a/um | Index variation F_p/um | Lead variation F_b/um |
|-------------------------|--------------------------|------------------------|-----------------------|
|                         | New spline | Wear limit | New spline | wear limit | New spline | wear limit | New spline | wear limit |
| 1≤D≤100                 | 5          | 7.5        | 5          | 7.5        | 3          | 4.5        | 5          | 7.5        |
| 100<D≤150               | 5          | 7.5        | 8          | 12         | 3          | 4.5        | 5          | 7.5        |
| 150<D≤180               | 5          | 7.5        | 10         | 15         | -          | -          | 5          | 7.5        |

3.2. **Measuring method for parameters of cylindrical straight involute spline**

Cylindrical straight involute spline tooth thickness S. For the involute spline plug gauge, the dimension over two balls can be calibrated with a horizontal length gauge, and then the tooth thickness can be calculated. As shown in Figure 3.
Figure 3. The dimension over two balls

The formula for calculating tooth thickness is as follows:

\[ S = D \left[ \frac{\pi}{Z} + \text{inv} \left( \cos^{-1} \left( \frac{D_b}{M_{Re} - D_{Re}} \right) \right) \right] \]

\[ = \left[ \frac{\pi}{Z} + \text{inv} \left( \frac{D_b}{M_{Re} - D_{Re}} \right) \right] \left( \frac{D_{Re}}{D_b} \right)^{\frac{1}{2}} \]

(1)

- \( Z \) — number of teeth;
- \( D \) — pitch diameter (mm);
- \( D_b \) — base diameter (mm);
- \( a_\phi \) — Pressure Angle (°);
- \( D_{Re} \) — dimension over two balls (mm);
- \( M_{Re} \) — dimension over two balls (mm);
- \( S \) — tooth thickness (mm);

3.3. Profile tolerance \( Fa \), Lead tolerance \( Fb \), Index variation \( Fp \) of the Cylindrical straight involute spline [10] [11]

When setting up the coordinate datum, the probe whose diameter is slightly larger than the spline Modulus is usually used to reduce the measurement deviation caused by the eccentricity between the instrument and the sample; During the measurement, the diameter of the measuring needle is slightly smaller than the spline module, so as to avoid the result deviation caused by the deformation of the small needle in the process of movement; Drum teeth are also used in gears, which can improve the contact condition of gears and minimize the maximum load on the unit tooth length. The wear value of tooth surface is evaluated by its drum value \( C_a \) and \( C_b \), profile tolerance \( F_a \), Lead tolerance \( F_b \), Index variation \( F_p \) are measured by Gear Measuring Center. They are shown in Figure 4 and Figure 5.
4. Reserching the measurement method of rectangular spline

4.1. Comprehensive test method
The comprehensive test method is widely used in the mass production of rectangle splines, which has high efficiency and saves the test cost. The through spline gauge shall pass unimpeded through the full length of the detected spline under its own weight or under a not too great external force. The test shall be carried out at least at three angular locations where the spline is uniformly distributed. The non-full Stop Gauge shall not pass the inspected spline under its own weight or under a not-too-large external force, and shall be inspected at all angular positions of the spline. If the internal and external splines can pass the comprehensive general test, and the single stop test does not pass, then the part is qualified; If the integrated general gauge does not pass or the single stop gauge passes.

4.2. Test Methods for single parameter[12][13]
There are many kinds of rectangle spline products, and it is difficult to manufacture the integrated
gauge to match them. In the absence of the integrated gauge, the rectangle spline product and the Integrated General End Gauge and stop gauge which are used to inspect the product need to measure the actual size, shape error and position error of each element respectively by the single item inspection method. The actual dimensions of each element measured are used to judge indirectly whether each individual element exceeds the minimum specified entity size.

4.2.1. The major diameter, minor diameter, and key width of a rectangular spline. Figure 6.

\[ D ------ \text{Major diameter; } d ------ \text{Minor diameter; } B ------ \text{Key width; } \]

4.2.2. The position tolerance can be replaced by the symmetry tolerance of the spline, and the equal division tolerance is equal to its symmetry tolerance. Table 2, Figure 7 and Figure 8.

4.2.3. Lead tolerance Fb: When the key of spline is long, the parallelism of the key side to the axis should be measured according to the performance of the product. Figure 9.

4.2.4. Profile tolerance Fa: The key of splines is deeper still need to measure the parallel degree of the key side to the axis according to the product performance. Figure 10.

4.2.5. Index variation Fp. Figure 11.

| Key width B | 3   | 3.5-6 | 7-10  | 12-18 |
|-------------|-----|-------|-------|-------|
| General application | 0.010 | 0.012 | 0.015 | 0.018 |
| Precision drive | 0.006 | 0.008 | 0.009 | 0.011 |

Figure 6. Major diameter, Minor diameter, Key width

Figure 7. Symmetry Tolerance Diagram

Figure 8. Measuring Diagram of rectangular spline Minor diameter
Figure 9. Experimental results of rectangle spline(Fb)

Figure 10. Experimental results of rectangle spline(Fa)

Figure 11. Experimental results of rectangle spline (Fp)
5. Conclusion

At present, The calibration specification of cylindrical straight Involute spline Gauge (JJF 1557-2016) has only been issued for five years in the domestic metrology field. There are few metering mechanisms which can measure the whole parameters completely. For two reasons: 1). There are some deficiencies in the methods of Metrologists, and the updating of knowledge is too slow; 2). More advanced precision equipment is needed for complete parameter measurement.

The full range of spline measurements is described above. There are few metering mechanisms which can measure the involute spline and rectangle spline with full parameters and high precision. We share the experience of our work through the above, and hope to have more excellent teachers to discuss together. At the same time, we hope that we can promote the systematization of spline measurement based on the research of spline measurement method. For the rectangle spline which is also widely used, it is also necessary for the production enterprise, the using unit and the powerful measuring organization to develop the specification.

The purpose of this paper is to explore a set of perfect value transfer traceability system for all kinds of spline gauges, To help production plants and users for quality control.

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