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Research Paper

Impact of Uneven Loading of Spline Teeth Pairs on Surface of Spline Tooth.

Engineering

KEYWORDS : Splines, spline tooth deflection, wear, surface fatigue.

Patil harsh — Department of Mechanical Engineering, Sinhgad Institute of Technology, Lonavala, Tal- Maval, Dist- Pune.

Prof. Gaikwad S. M. — Professor, Department of Mechanical Engineering, Sinhgad Institute of Technology, Lonavala, Tal- Maval, Dist- Pune

ABSTRACT

Spline couplings are used to transmit torque from a shaft to a gear hub or other rotating component. Because multiple teeth engage simultaneously, they can transmit much larger torques than a simple key and keyway assembly. However, manufacturing variations affect the clearance between each pair of mating teeth, resulting in partial engagement. The teeth needs to engage in a sequence, determined by the individual clearances. As the shaft load is applied, the tooth pair with the smallest clearance engages first and then deflects as the load increases, until the second pair engages and so on, until the full load is reached. Thus, only a subset of teeth carries the load. In addition. Due to uneven loading on spline tooth, different types of wear may be observed on tooth. So it is necessary to study tribological properties of spline teeth.

1. INTRODUCTION:

In spline coupling and shaft assembly, as shown inFigure 1, all teeth engage at the same time and the load is carried equally between all tooth pairs which increases the load capacity than ordinary keyway coupling. However, due to variations in teeth clearances, all teeth in spline couplings do not engage simultaneously causing some of the teeth to carry a disproportionately large portion of the total load. These variations in tooth-to-tooth clearances mean the first pair of teeth to engage will carry more load and fail sooner. This has led to an industry practice of designing splines around the criteria that 25-50% of the teeth on a spline coupling will engage and carry the load, and it is assumed to be uniformly distributed. This research on tooth engagement is part of an ongoing study sponsored by an industrial partner with the objective to accurately describe and improve tooth engagement in spline couplings in order to increase their load capacity and durability.

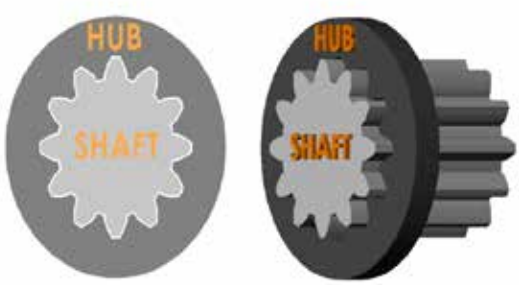


Fig. 1. Spline coupling and shaft assembly

With ideal tooth engagement there is a linear relationship between torque and angular deflection. As a torque is applied, all the teeth engage simultaneously and deflect proportional to the torque that is applied. The stiffness of four engaged teeth is four times the stiffness of a single tooth and each tooth carries 25% of the load, as shown in Figure 2.

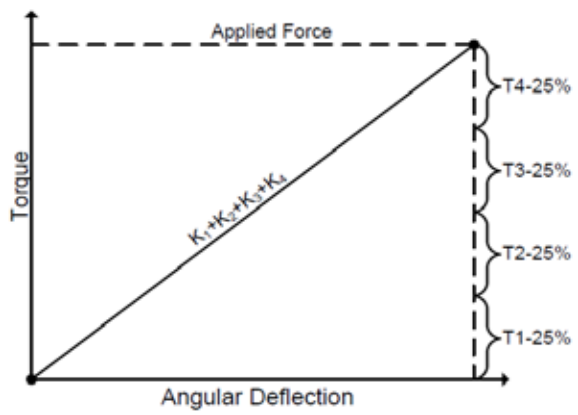


Fig. 2. Torque deflection relationship for ideal tooth engagement

The sequential tooth engagement curve, shown in Figure 3, is formed from the sum of the individual tooth engagement lines K1-K4.

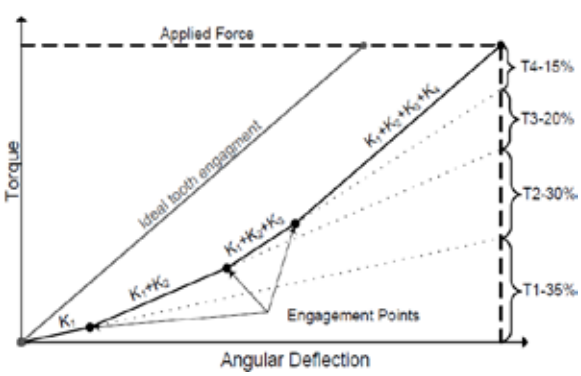


Fig. 3. Sequential tooth engagement profile

It shows sequential tooth engagement profile and the resulting load carried by each of the four teeth. Tooth 1 carries 35% of the total load while tooth 4 carries only 15%. Due to variation, the first tooth to engage will carry significantly more load than the last tooth. The amount of load carried by a given tooth pair can be found by extending the slope of each line segment, at the engagement points, then measuring the vertical distance between segments at the deflection value that results from the applied force.

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This uneven loading on spline teeth causes wear and surface rupture at initial phase of working. The tribological concerns like pitting and surface fatigue become the prime cause for the earlier destruction of spline teeth. Highly loaded spline teeth often rely on lubrication to prevent tooth failures. So two types of materials are considered to study about the impact of uneven loading and there comparison with surface fatigue and wear.

2. LITERATURE REVIEW:

1. J. Silvers, C.D. Sorensen, K.W. Chase, (2010, October) A New Statistical Model for Predicting Tooth Engagementand Load Sharing in Involute Splines, American Gear Manufacturers Association.

Spline designers typically assume only a fraction of the teeth are engaged and distribute the load uniformly over the assumed number of engaged teeth. A new statistical model for involute spline tooth engagement has been developed, which takes into account the random variation of gear manufacturing processes. It predicts the number of teeth engaged and percent of load carried by each tooth pair. Tooth-to-tooth variations cause the clearance between each pair of mating teeth to vary randomly, resulting in a sequential, rather than simultaneous tooth engagement.

2. Ellen Bergseth, Influence of surface topography and lubricant design in gear contacts, Royal Institute of Technology, Stockholm, March 2009.

The thesis gives the idea about the tribological concerns in gear manufacturing processes. Types of wears and surface failures of gears due to surface fatigue and view on lubrication systems are the content of this research.

3. OBJECTIVES:

Tribological failure of spline teeth causes due to uneven loading may be classified into two categories:

1. Surface fatigue (pitting),
2. Wear

Therefore study of these tribological concerns is required. So objectives of this study are:

1. Examining the wear of teeth.
2. Examining surface fatigue.

Spline materials taken under consideration:

1. Through-hardened splines
2. Surface hardened splines

4. OBSERVATIONS:

The appearance of the various distress and failure modes can differ between spline teeth that have through-hardened teeth and those that have surface hardened teeth. These differences result from the different physical characteristics and properties and from the residual stress characteristics associated with the surface hardened spline teeth.

4.1. Surface fatigue

Surface fatigue is the result of repeated surface or sub-surface stresses beyond the endurance limit of the material of the splines and cardan shaft. Surface fatigue is a process by which the surface of a material is weakened by cyclic loading, which is one type of general material fatigue. Fatigue wear is produced when the wear particles are detached by cyclic crack growth of micro cracks on the surface. These micro cracks are either superficial cracks or subsurface cracks.

4.1.1. Pitting

Pitting is a form of surface fatigue which may occur soon after operation begins and may be of three types:

1. Initial (corrective)
2. Destructive
3. normal

Initial pitting is caused by local areas nearly at pitch line, of high stress due to uneven surfaces on the spline tooth in relatively short time, reach a maximum and with continued service polish to a lesser severity. It is most prominent with through-hardened spline teeth and is sometimes seen with surface-hardened spline teeth.

Destructive or progressive pitting, on the other hand, usually starts below the pitch line, in the dedendum portion of the tooth and progressively increases at starting of contact in both the size and number of pits until the surface is destroyed. As time goes, the severity of destructive pitting sharply increases and far surpasses the severity of corrective pitting. Figure 4 illustrates this type pitting on a through-hardened spline teeth. Figure 5 shows destructive pitting of a surface hardened spline teeth.

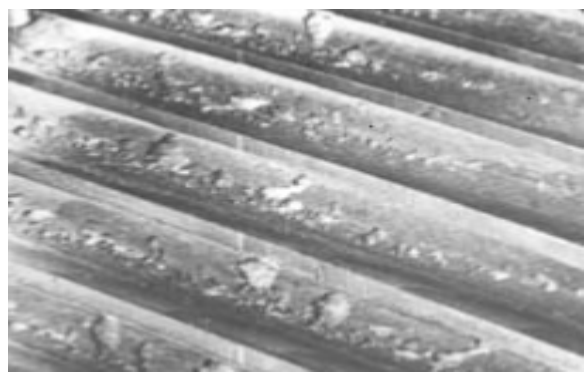


Fig. 4. Pitting of through-hardened spline teeth

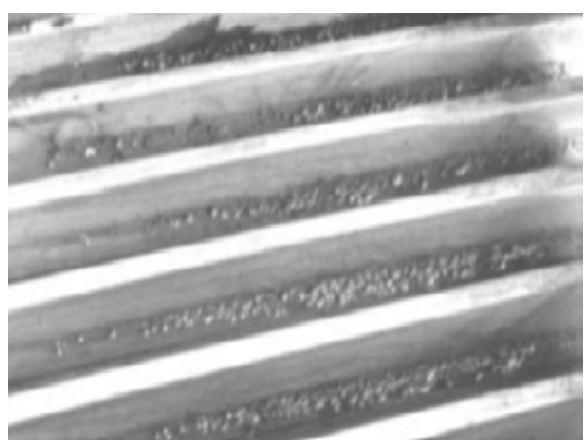


Fig. 5. Pitting of surface hardened spline teeth

Normal wear of fullyloaded through-hardened spline teeth manifests itself as small ormodest size pits, covering the entire dedendum portion of thetooth flanks. Continued operation results in pit rims beingworn away with virtually no further pitting occurring.

5. LUBRICATION:

Highly loaded spline teeth often rely on lubrication to prevent tooth failures. In a spline and cardan shaft assembly, lubrication is usually applied by so-called splash lubrication; the spline teeth dip into a reservoir of oil in the bottom of the spline and cardan shaft assembly and splash the oil around.

A lubricant consists of base oil and additives, and its properties depend upon various parameters such as rheological, chemical, thermodynamic, environmental, and additive response properties. These properties help to ensure that a mild wear condition is obtained.

Depending on the amount of direct contact between the surfaces, the lubrication regime is classified as boundary, mixed, or full-film. Stribeck studied the general dependence between the friction force and the lubricant viscosity, sliding speed, and load; this resulted in the creation of the Stribeck curve shown in Figure 6, the Stribeck curve is often used to show the different regimes of lubrication, ranging from boundary lubrication where metal contact or contact via boundary layers occurs, to full-film lubrication where the surfaces are totally separated by the lubricant and no metal contact occurs.

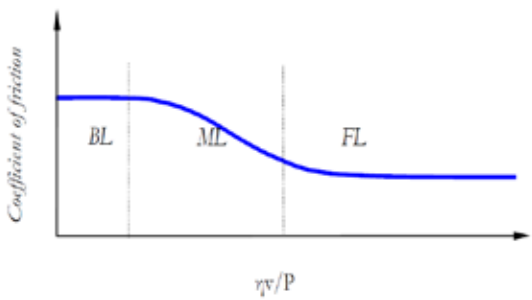


Figure 6. The coefficient of friction varies depending on lubricant viscosity (η), sliding speed (v), and load (P). BL – Boundary lubrication; ML – Mixed lubrication; FL – Full film lubrication.

Spline teeth predominantly operate in the so-called elastohydrodynamic lubrication regime, which ranges from mixed lubrication to full-film lubrication. Elastohydrodynamic behaviour occurs at high contact pressures which deforms bounding surfaces elastically. In the mixed lubrication regime the lubricant film separating the contacting teeth is nearly as thin as, the magnitude of roughness, which may cause lubricant film breakdown which leads to occur boundary conditions. At this point, reduction of friction and wear depends on the surface boundary layer formed on the surface asperities by the additives. These chemical changes occurring within a few nanometres are key to the performance of lubricants in the boundary lubrication regime.

Spline teeth are sometimes coated with a manganese-phosphate-treated layer for better surface hardness and greater advantage in terms of resistance to scuffing. However, this coating wears off at earlier stage.

The formation and composition of surface layers depends strongly on the chemical composition of the lubricant and also on the nature of the surface. The formation of oxide films is known to play an important role in the reduction of wear and friction in sliding metal surfaces. The thickness of the oxide layer was found to play an important role with respect to wear. The mechanism of formation and rupture of oxide layers and boundary layers is not completely known, and there is no reliable model for rough surfaces in boundary lubrication.

6. CONCLUSION:

Uneven loading of spline teeth does not only lead to deflection of teeth but also starts wearing and decaying its surface material. Different wear regimes are formed on surface of surface hardened and through hardened spline teeth. Lubrication of teeth doesn't predict exactly the prevention of wear and surface fatigue but mitigates its severity with help of additives, coating and formation of oxide layers. But coating wears off and formation of boundary layers due to elastohydrodynamic behaviour of lubricant causes wear. So there is no reliable model for rough surfaces in lubrication.

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