A Comprehensive Report on the Thermal, Static and Dynamic Behaviour of Spline Shaft

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Abstract— In the area of machining technology, lathe operation are is considered as one of the most significant conventional machining process where by means of spline shaft effective machining power can be achieved to transmit power from one source to another source to machine any component in order remove material. Spline shaft are widely been used in the field of industrial and automotive applications for power transmission. Now a day, due to advancement in designs of spline shaft critical failure in spline shaft can be overcome. For this, various materials, alloyed material, as well as composite material are used. This In this paper a comprehensive review has been presented which shows the noteworthy contribution of various researchers in improving the technology of Spline shaft.

Keywords: Spindle, Design, Failure

I. INTRODUCTION

A spline coupling is an effective mode of torque transfer between two rotating parts. It transmits torque, but permits axial sliding. The spline coupling is used in high torque transmission engines like vehicles, turbines, and jet engines. The literature that deals with spline coupling has been investigated experimentally and theoretically in several studies which considered the spline tooth profile like ; Yeung 1999, Baker 1999, and Yang et al 2007, failure analysis of the spline coupling like: Ding et al 2007, Ding et al 2008, and Lin et al2008, and the stress distribution along the axial direction of a spline coupling under static load like; Barrot et al 2009, and Grath 2009. In the present work the stress distribution, velocity of crack propagation, and cyclic crack growth rate in a spline coupling subjected to cyclic torsional impact load have been investigated analytically and experimentally for two different boundary conditions.

Fathi and Hawaa 2014 the effect of engagement length, number of teeth, amount of applied load, wave propagation time, number of cycles, and initial crack length on the principal stress distribution, velocity of crack propagation, and cyclic crack growth rate in a spline coupling subjected to cyclic torsional impact have been investigated analytically and experimentally. It was found that the stresses induced due to cyclic impact loading are higher than the stresses induced due to impact loading with high percentage depends on the number of cycles and total loading time. Also increasing the engagement length and the number of teeth reduces the principal stresses (40%) and (25%) respectively for increasing the engagement length from (0.15 to 0.23) and the number of teeth from (8 to 10). while increasing the other parameters (amount of applied load, wave propagation time, number of cycles, and initial crack length) increase the principal stresses at the root of the tooth (37% when the applied load rises from (8 KN to 11KN) and (62% when the wave propagation time rises from (0.5 to 1).

Andrea et al. 2018 The simulations have been performed considering a standard transmission scheme composed of two shafts connected by a spline coupling and supported by four roller bearings (two for each shaft), mounted in isostatic configuration. The effect of spline coupling teeth microgeometry has been taken into account along with the misalignment angle magnitude and the torque level in particular the influence of these parameters on teeth contact pressure has been evaluated, as tilting moment is mainly driven by the contact pressure distribution among engaging teeth and by the position of maximum pressure distribution along teeth in axial direction. Results obtained in this work may be useful to designers, suggesting some basic criteria to reduce the bearings overload, allowing designing more reliable and efficient machines

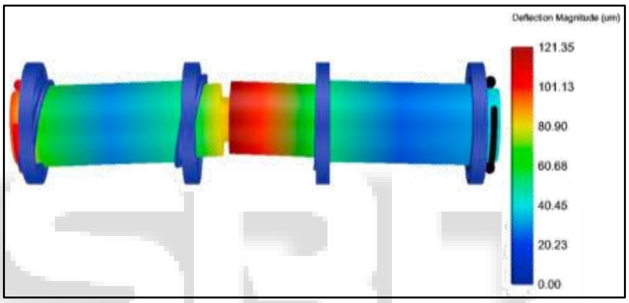

Fig. 1: Deformation of misaligned shaft at 400Nm torque. Andrea et al. 2018

Barsoum et al. 2014 presents a finite element modeling framework to determine the torsion strength of hardened splined shafts by taking into account the detailed geometry of the involute spline and the material gradation due to the hardness profile. The aim is to select a spline geometry and hardness depth that optimizes the static torsion strength. Six different spline geometries and seven different hardness profiles including non-hardened and through-hardened shafts have been considered. The results reveal that the torque causing yielding of induction hardened splined shafts is strongly dependent on the hardness depth and the geometry of the spline teeth. The results from the model agree well with experimental results found in the literature and reveal that an optimum hardness depth maximizing the torsional strength can be achieved if shafts are hardened to half their radius.

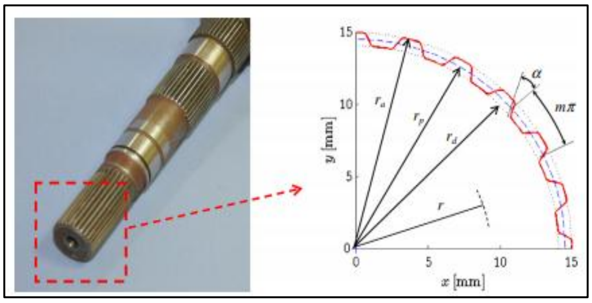

Fig. 2: Parameters defining the spline geometry Barsoum et al. 2014

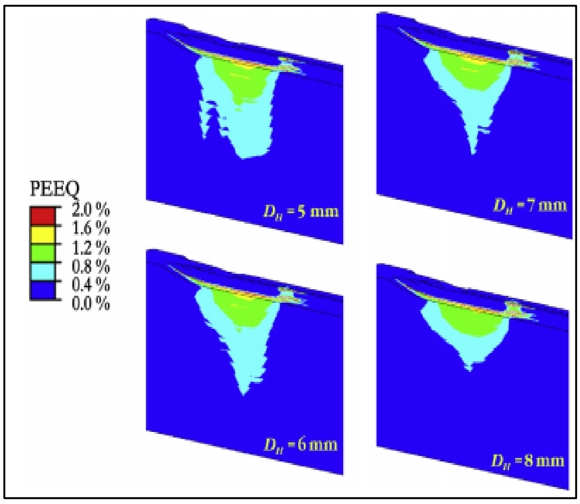

Fig. 3: Contour plot of PEEQ for hardness depth DH = 5, 6, 7 and 8 mm. Barsoum et al. 2014

Yu et al. 2012 The splined-shafts used in truck diesel engine fractured after service of merely 7–8 h. The transverse fracture occurred at the root fillet between the tooth portion and the cylinder portion. The fracture surfaces, corresponding to the carburized layer, of the failed splined-shaft and manufactured artificially show intergranular fracture features. Intergranular facets within a depth of about 20 μm from the surface were found to be associated with the oxide compounds of Cr, Mn, Si and dimples. The fracture mechanism of the splined-shaft was ductile intergranular cracking. Microstructure observation indicates intergranular internal oxidation occurred in the carburized layer to a depth of about 20 μm, in which oxide compounds of Cr, Mn, Si are along the grain boundaries. The association of intergranular oxidation pre-cracks with microstructural embrittlement promoted the premature failure of the splined-shaft. Over-short axial free length between the tooth portion and the cylinder portion enhances the degree of stress concentration, which contributes to the failure of the splined-shaft.

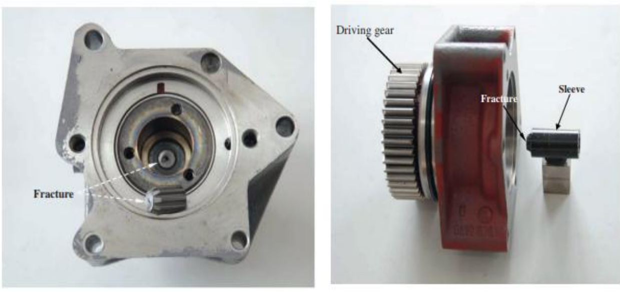

Fig. 4: Failed auxiliary driving assemble. Yu et al. 2012

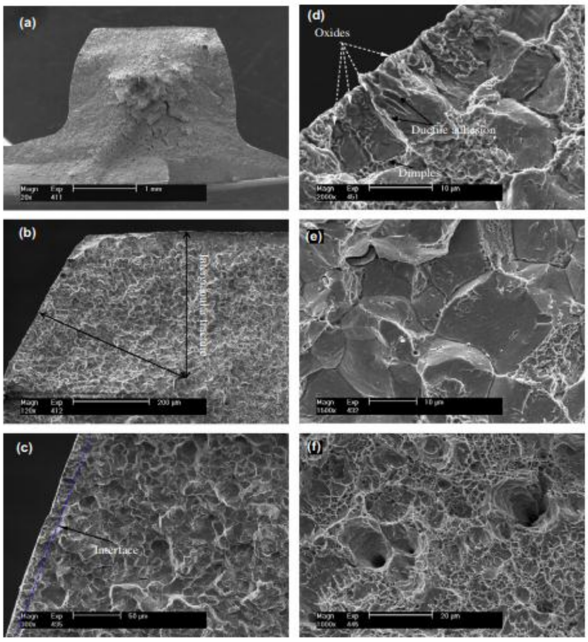

Fig. 5: SEM observation on the fracture surface prepared artificially: (a) general view, (b) showing intergranular fracture zone, (c) showing the interface corresponding to internal oxidation zone, (d) showing intergranular facets associated with the oxides and dimples, (e) showing intergranular fracture in subsurface, and (f) showing dimple morphology in the middle region Yu et al. 2012

Suresh and Mruthunjaya 2018 Yoke Shaft is a mechanical component which is mainly used in the steering assembly. They are used to transmit the power or motion of the driveline system. Each automobile consist of different power transmission system depending upon the vehicle's driveline system. While transmitting the torque the large amount of variable stress is induced in the steering yoke shaft. The objective of this research paper is to study the root cause for the failure of the yoke shaft in steering assembly. For determination of the critical stress formation at the failed section, fatigue analysis is carried out using Finite Element Method. Finally the existing model is evaluated under different crack behaviour condition, based on the life estimation the improvement in the design or fabrication process is suggested.

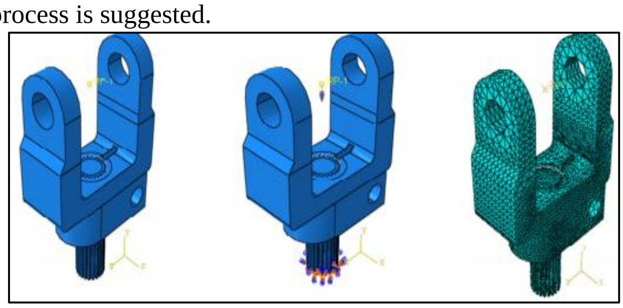

Fig. 6 : (a) 3 D Model of Steering Yoke Shaft, (b) Load and Boundary Condition, (c) Mesh Model. Suresh and Mruthunjaya 2018

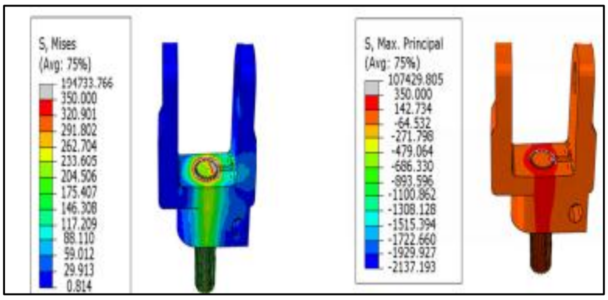

Fig. 7: (a) Von Mises Stress for Yoke Shaft, (b) Principal Stress for Yoke Shaft. Suresh and Mruthunjaya 2018

Shen and Lohrengel 2013 The dynamically loaded spline shaft-hub connection that without macro relative movement between shaft and hub are exposed to the danger of fretting fatigue in the contact zone of teeth flank and plain fatigue at teeth fillet at the same time. The competition of fretting fatigue and plain fatigue determines that which one dominates the failure of it and therefore the fatigue performance of it. In order to deal with this plain–fretting fatigue coexisted situation, a plain–fretting fatigue unified prediction model is introduced in this paper and implemented in the representative spline teeth pair. Predicted by this model, the failure of involute spline shaft-hub connection teeth DIN 5480 45 × 2 × 21 is plain fatigue at teeth fillet dominated. Corresponding to the theoretical modeling efforts, a representative teeth pair fatigue test apparatus was developed. With this test apparatus, the initiation and propagation of fatigue cracks can be detected on line by monitoring the change of resonant frequency. The test results also showed that the crack occurs at teeth fillet at first.

Fig. 8: Spline shaft design with spline run-out or shaft shoulder Shen and Lohrengel 2013

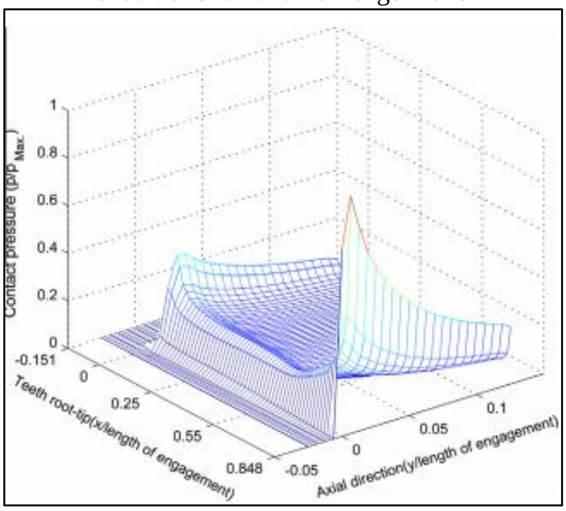

Fig. 9: Distribution of contact pressure on the concerned teeth flank Shen and Lohrengel 2013

Yongyi et al. 2013 The principle and deformation characteristic of the traditional open-die extrusion process of spline shaft are analyzed firstly, and then a novel open-die warm extrusion process of spline shaft with 42CrMo steel is proposed to solve the process problems such as high forming loads, poor material plasticity and tooth filled quality. Next, the material characteristic of 42CrMo steel during the warm forming process is investigated through the isothermal compression tests, the microstructure with tempered sorbite and high accuracy constitutive equations of 42CrMo steel are obtained. Besides, the effects of the main process parameters on the forming loads and tooth filled quality during the open-die warm extrusion process are studied, the optimum die angle of entrance section and warm forming temperature are established as 20 C and 650 C, respectively. Finally, the relevant improvement of tooth divided flow method (TDFM) is employed to eliminate the negative effects of the large blank diameter on this novel process

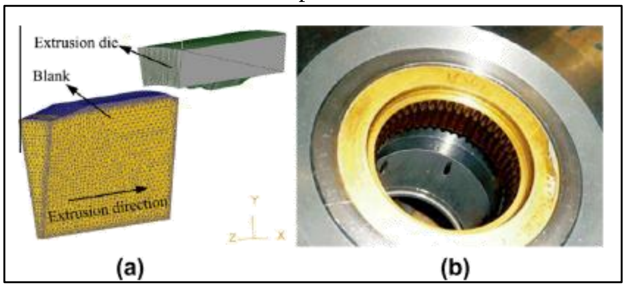

Fig. 10: Diagram of the finite element models and practical extrusion die: (a) finite element models and (b) assembled extrusion die of FLESS Company. Yongyi et al. 2013

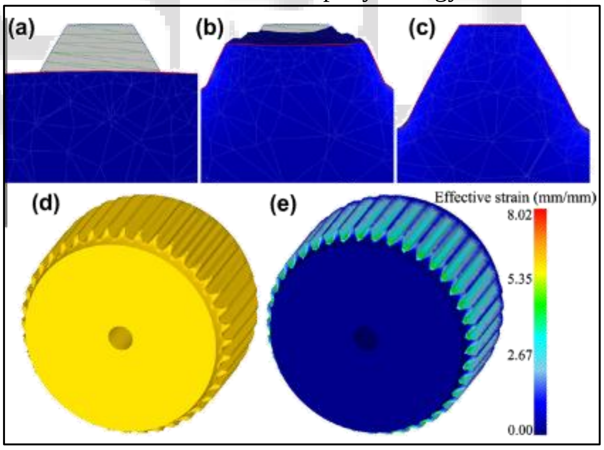

Fig. 11: Tooth filling situations at different times and the final formed spline shaft: (a) t = 0 s, (b) t = 0.4 s, (c) t = 0.55 s, (d) without any contour and (e) with effective strain contour. Yongyi et al. 2013

Zhang et al. 2017 investigate the differences between the OCF and CCF, forming experiment, hardness test and micro observation were performed. In consideration of the different friction condition and variational velocity, a friction modal considering sliding and velocity was used in simulation. The force-stroke curve got from the horizontal oscillating extrusion machine shows that OCF can reduce the load about 25% than CCF and that oscillating frequency affects the friction as well as the forming force. Moreover, the results of experiment and simulation indicate the surface quality of OCF is better than CCF because lower friction leads to less metal pileup.

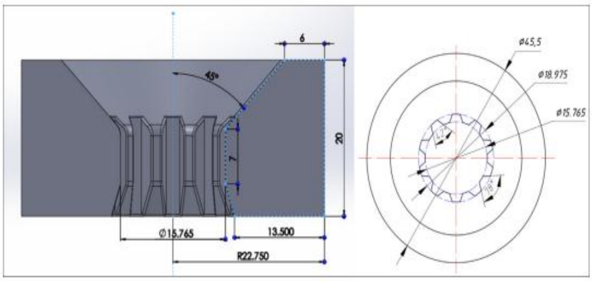

Fig. 12: The size of the die (Unit: mm). Zhang et al. 2017

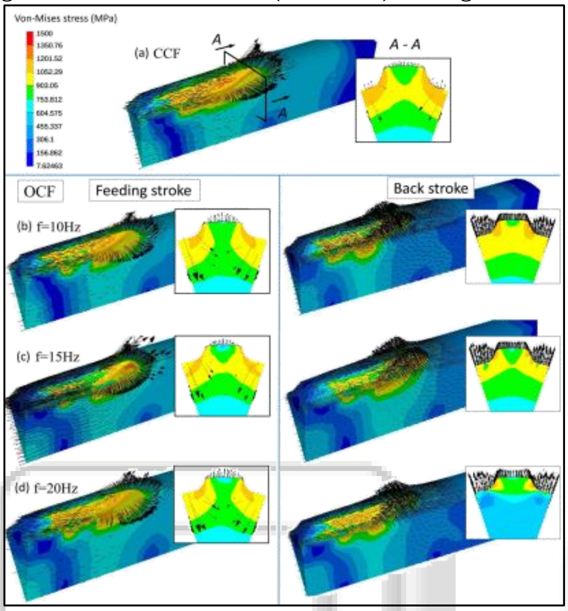

Fig. 13: Von-Mises stress and velocity distribution of the workpiece in different condition Zhang et al. 2017

Xiaolan et al. 2018 study, the TVMS of gear systems that use two different spline assembly methods, namely, the-side-fit and the-major-diameter-fit, is predicted by finite element contact analysis. Subsequently, the nonlinear dynamic model of the spline–gear system is established and its accuracy is verified through a vehicle vibration experiment. The numerical results reveal that the system assembled through the-side-fit and without spline exhibits a diverse range of periodic, sub-harmonic, and chaotic behaviours at high speed, whereas no bifurcation is observed through the-major-diameter-fit. As the magnitude of interference increases in the-major-diameter-fit, the dynamic transmission error decreases. Therefore, different assembly methods can affect the nonlinear characteristic. Moreover different magnitudes of interference in the-major-diameter-fit also have effects on the nonlinear characteristics and vibration performance of spline–gear systems.

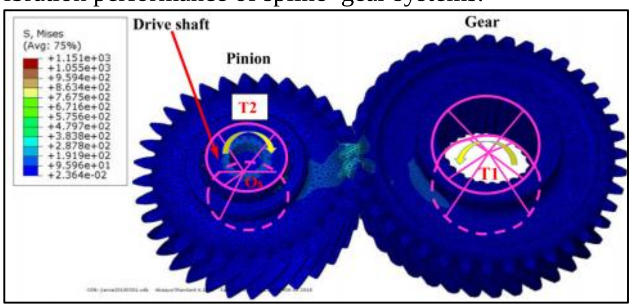

Fig. 14: FE model of spline–gear system. Xiaolan et al. 2018

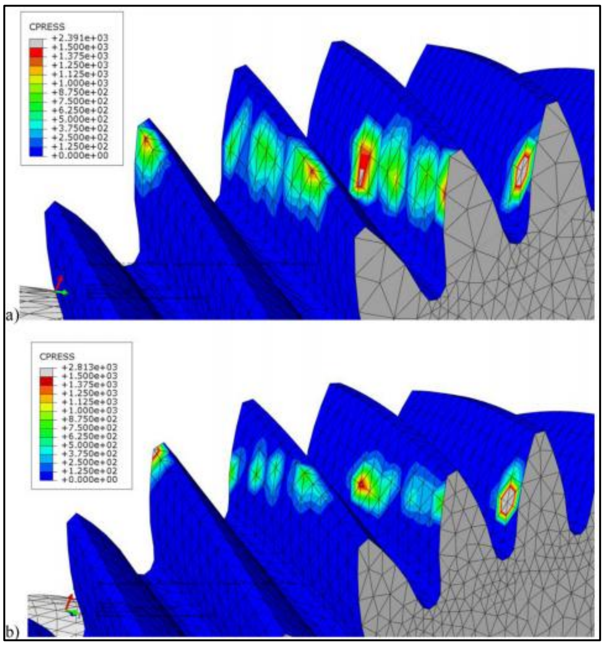

Fig. 15: Contact stress of the spline–gear system Xiaolan et al. 2018

II. CONCLUSION

– The failed splined-shaft is made of 20MnCr5 steel. The surface hardness and the case depth correspond to the specification.
– Internal oxidation phenomenon occurred on the carburized splined-shaft to lead to the formation of intergranular oxides of Cr, Mn, Si enveloping a ‘‘soft’’ zone of non-martensitic structure alongside the grain boundaries of the carburized layer. The formation of grain boundary ‘‘cavities’’ associated with the intergranular oxidation. Grain boundary ‘‘cavities’’ promotes that crack initiation and propagation. (3) The fracture mechanism of the splined-shaft was ductile intergranular cracking. The premature failure of the splinedshaft was promoted by the occurrence of intergranular internal oxidation.
– Presence of intergranular internal oxidation in the case layer is not enough to cause the shaft to rupture prematurely. However, in combination with greater stress concentration at the fracture location resulting from over-short axial free length between the tooth portion and the cylinder portion, the probability of such an event is considerably increased
– Exchange the material of splined-shaft and select the steels containing alloy elements (e.g. Mo, Ni) unsusceptible for internal oxidation. Reduce the content of gases containing oxygen in the furnace.
– Improve the design of the splined-shaft and obtain a suitable transition between the tooth portion and shaft portion to decrease the degree of stress concentration.

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