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Static, Dynamic and Fatigue Damage of Spline Coupling in Wind Turbine Rotor

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ABSTRACT

This article evaluates the stress distribution along the spline length for partial contact length and the load distribution along the spline tooth length. Includes measurements of load distribution along the length of the spline. Torque is provided by a torque loading arm, and strain gauges are installed on the teeth to measure strain. The system is programmed to monitor tooth strain readings. Different contact lengths and load variations have been investigated in relation to the fixed contact length for the spline hub connection. The effects of varying the contact length in various torque situations have been studied. A single channel strain indicator system is used to determine the strain at the connection in the experimental setup. Using miniature strain gauges, strain at the connection is measured. On the spline teeth, strain sensors were installed to record the localised stress along the length. The spline shaft is constructed with EN19 hub material specifications. Observations indicate that in-volute spline geometry can support greater loads than rectangular and trapezoidal spline geometry.

Keywords: Wind Turbine, Rotor, Ansys Workbench, Fatigue And Spline Coupling.

I. INTRODUCTION

When it is necessary to transmit a great deal of power, using spline couplings is one of the most typical ways that two rotating shafts can be connected to one another. These components are responsible for motion transmission by utilising a predetermined number of engaging teeth. Because of the variable amplitude loadings and relative sliding, these teeth experience both fatigue and wear over time. When it comes to industrial transmissions, splines generally transmit more torque for their size than any other type of coupler or joint. However, when they operate with a relatively small shaft diameter, a common type of failure is caused by the shaft shear stresses. Because the connection is so vital to the functioning of the engine, the development process for every new engine must include testing on a full-scale rig. They are carried out to demonstrate that the shaft will be secure for the remainder of its design life, despite the cost of such testing being incurred. Because of this, it was difficult to predict what would ultimately lead to the failure of spline couplings, especially considering the fretting fatigue failure behaviour of these couplings. As a consequence of this, numerous researchers have resorted to utilising naturally cautious design methods. The earlier experimental testing work that was carried out at the University of Nottingham to address this weakness utilised a coupling specimen that had 18 teeth on a smaller diameter. This replicated the tooth contact conditions that are found in full-size engine couplings by utilising the same spline shape along with torque, axial, and bending stresses. Following a number of fretting fatigue failures, the outcomes of laboratory-scaled spline test programming are examined in greater detail. Even if this programmer were to produce some data that was extremely helpful, it would still be very expensive to construct the lab-sized spline specimens. As a means of resolving this issue, the concept of the representative specimen (RS) was developed as a potential solution. This solution made it possible to conduct more in-depth experimental investigations. In order to replicate the critical fretting fatigue elements of a particular spline area, a test specimen needs to be fabricated first (often on a scale lower than that of the original component). It is not possible to build an RS without first successfully matching the FE expected variables for the spline coupling and the RS. At the University of Nottingham, parallel research on the scaled spline coupling was carried out; the findings of this research are going to be presented in the following chapter. It is possible to illustrate the behaviour of splines when subjected to heavy cycle loads by employing a uni-axial representative specimen (URS), which additionally incorporates contact coordinate conventions. As a consequence of the load arms deflecting in this direction, the relative slip happens in this particular path. As a result of the interaction between heavy and light cycle loads, the spline coupling, when put to its intended use, goes through a complex multiracial state of contact slip. This state can be described as "contact slip with multiple races." Due to the URS's capability of simulating spline behaviour under major cycle loading, a multiracial representative specimen (MRS) was able to be created. This MRS is able to reproduce spline behaviour under superimposed major and minor cycle loading. The fretting is included in the MRS, and it is here that the coordinate conventions are described. The statement of the loading direction also results in the development of a multidirectional sliding condition between the fretting bridges and the specimen. In addition, testing with the cylinder on the flat helps to improve the RS approach [1-6].

II. LITERATUTR REVIEW

In gas turbine engines, the transfer of torque from one shaft to another can be accomplished with the help of spline couplings in a way that is both practical and effective. There is always a drive for improved performance because of the competition in the aerospace industry and the need to reduce fuel consumption from aircraft carriers. This need for reduced fuel consumption from aircraft carriers boosts the requirements for the coupling. Because of the minor oscillatory relative motions that occur between the intensely stressed teeth, aeroengine spline couplings, and in particular main-shaft low pressure (LP) splines, are complicated parts that run the risk of failing for a variety of reasons due to the oscillatory relative motions. These splines are more likely to experience fretting fatigue and wear than others (FF). This study investigates the application of the representative specimen concept for predicting fretting-induced damage between spline teeth. Full-scale testing of splines is extremely expensive, which is why this concept is being investigated. [1]

This study will concentrate primarily on investigating the fretting wear of spline couplings as its principal area of inquiry. In addition, fretting wear, a specific kind of surface deterioration that can occur in combination with fretting fatigue, will be explored as a component of this study. In a combined experimental and computational representative specimen (RS) methodology, a multi-axial representative specimen (MRS) concept and a uni-axial representative specimen (URS) concept, each with varying degrees of complexity, are used to address various aspects of the spline fretting wear-fatigue problem. The MRS and URS concepts are referred to as multi-axial representative specimens (MRS) and uni-axial representative specimens (URS), respectively. Both MRS and URS are abbreviations that stand for "multi-axial representative specimen" and "uni-axial representative specimen," respectively. The configuration of the URS test includes two pairs of specimens that are in touch with one another. This arrangement simulates all of the primary torque and axial loads that occur over the entirety of the flight cycle, as well as the damage that occurs as a direct result of those loads. The MRS rig consists of a fretting bridge arrangement that simulates the combination of the same basic stresses along with high-cycle bending loads from in-flight fluctuations (gyroscopic and carcass flexing), as well as the damage that results from these interactions. In other words, the MRS rig is designed to replicate the damage that occurs as a direct result of the interactions. The URS was successfully utilised to experimentally characterise a variety of potential material combinations for aero engine transmissions and splines, including coated and uncounted combinations [2].

III. OBJECTIVES

In this study, the stress that develops in the Spline shaft as a result of the various loading scenarios and the velocity is the primary focus. The Finite Element Method was used to review this research's findings for the static structural, dynamic analysis, and life estimation.

- Carrying out a static linear analysis on the spline connection that is found between a shaft and a sleeve. Utilizing the Ansys Workbench as the application programme.
- Figuring out the modes and the natural frequency that are between a shaft and a sleeve.
- Development of FEM model to demonstrate the spline tooth width in the axial direction for evenly distributing the load across the structure. Investigations are being conducted into a wide variety of tooth forms, sizes, and variants.
- Utilizing finite element method to derive an estimate of the spline coupling's fatigue life.

IV. METHODOLOGY

The explanations that came before this one emphasis how important it is to understand how spline couplings fret when they get fatigued. This objective is what this paper's methodology aims to accomplish. Both experimental methods and a technique that combines both experiments and computing are given. Hyde invented the uni-axial representative specimen (URS), which has since been redesigned multiple times. This configuration results in significant cycle contact pressure (from torque and axial load), significant fatigue stress, and significant contact slip for a conventional low pressure (LP) spline connection. The multi-axial representative specimen (MRS), which additionally considers the effect of spline rotational bending loads, is described below, along with any adjustments made. According to the numerical technique, the two typical specimens are simulated using the finite element (FE) method. A global FE model is built in order to examine the critical rig parts, such as the URS and MRS. By comparing the specimens to prior scaled spline finite element modelling, the representativeness of the samples is then assessed. Figare-1 indicates work process of flow chart.

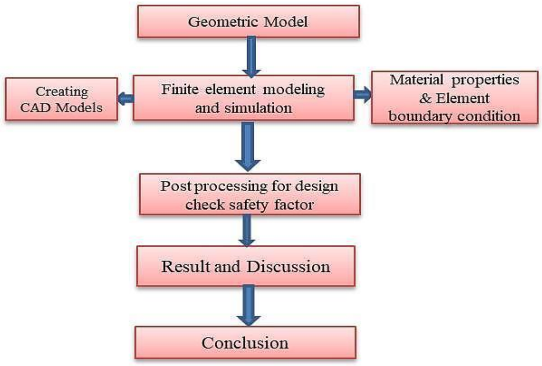


Fig-1: Flow chart

Preliminary Design Considerations:

Gearboxes in wind turbines may not always achieve their planned design life, despite frequently meeting or exceeding the current design specifications and regulations in the gear, bearing, and wind turbine industries, as well as third-party certification standards. The National Renewable Energy Laboratory (NREL) established the Gearbox Reliability Collaborative (GRC) in 2006. Using a combination of dynamo-meter testing, field testing, and modelling, its primary objective is to identify the factors that contribute to early gearbox failures and improve gearbox dependability. Other objectives of the GRC include promoting an increase in the precision of existing gearbox design and modelling tools, developing these tools if necessary, and conducting research on gearbox dependability. This study, which is part of the GRC programme, examines the design of spline couplings, which are commonly used to connect the planetary and helical gear stages in modern wind turbine gearboxes. In addition to providing the driving force, articulating spline couplings promote load sharing in the planetary stage by permitting the sun to "float." Planetary gear mesh contact patterns are less affected by defects, misalignments, and non-torque stresses when the sun is in free flight. On the other hand, loads may be distributed unevenly and gearbox misalignment may occur even without the floating sun. Consequently, planet-bearing forces and edge loading on the gears increase, shortening their lifespan and increasing the probability of an early failure. The distance the sun can float depends on the flexibility of the sun shaft and the design of the spline, both of which are subject to operational forces. The AGMA 6123-B06 design guide for single articulation couplings contains the most comprehensive instructions. Various standards address the design requirements for spline couplings in varying depths. Using a reduced-order mathematical formulation and high-fidelity finite element (FE) modelling techniques, as well as contact, bending, and shear safety factors based on fatigue and yield, the operating loads and stresses imposed on a test gearbox's spline coupling are calculated in this study. Additionally, this study offers a novel comparison to a different model [7-14].

V. FINITE ELEMENT ANALYSIS (FEA)

Finding a numerical solution to a variety of engineering problems can be accomplished effectively by using the finite element method, which is a powerful tool. Because of the broad application of the method, it can handle any complex shape or geometry for any material under a variety of boundary and loading conditions. This is because of the breadth of the method's applicability. In today's complex engineering systems and designs, where it can be difficult to obtain closed form solutions to the governing equilibrium equations, the generality of the finite element approach satisfies the analytical requirements. This is because finite elements can be broken down into a large number of smaller elements. In addition, it is an efficient design tool that enables designers to conduct parametric design studies. These studies involve taking into account a variety of design circumstances (different shapes, materials, loads, etc.) and analysing them in order to determine the design that is the most effective. The aerospace industry was the first to develop this method as a tool for analysing the effects of stress on complex aircraft parts. It was derived from a technique known as matrix analysis that was used in the design of aeroplanes. Academics and professionals alike are resorting to the strategy more frequently at an increasing rate. According to the fundamental principle underlying the finite element method, a body or structure can be broken down into a number of smaller, "finite element"-style components that have finite dimensions. Therefore, the initial body or structure can be understood as a collection of distinct components that are linked together at a limited number of nodes [15-22].

GEOMETRIC MODELING

The study of methods and algorithms for the mathematical representation of shapes is what we mean when we talk about geometric modelling. Although it is common practise in the field of geometric modelling to investigate sets of three-dimensional shapes, it is possible for sets of any finite dimension to be taken into consideration. The majority of the time, the completion of the process is accomplished through the use of computers and software that runs on computers. Technical drawing and computer-assisted typography are both based on two-dimensional issues, whereas computer-aided design (CAD/CAM) is focused on issues relating to three dimensions.

STATIC ANALYSIS OF WIND TURBINE ROTOR

5.1, Geometry Boundary Condition Load Applied – Temperature and Rotational Velocity

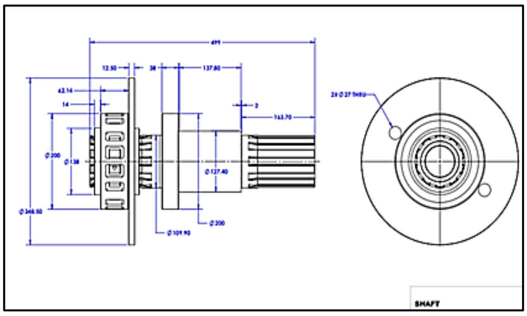


Fig-2: Geometrical dimension of outer casing of aircraft turbo engine

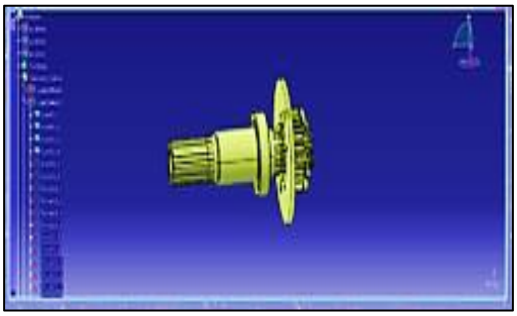
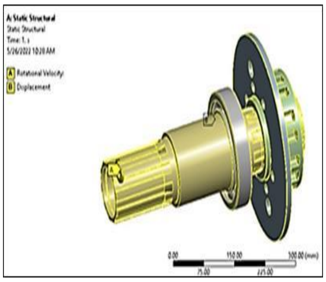


Fig-3: Isometric view of outer casing of aircraft turbo engine

Both the geometrical dimensions of the outer casing of an aircraft turbo engine as well as an isometric view of the casing can be seen in Figures 2 and 3, respectively. The statistical analysis model of the outer casing of an aircraft turbo engine is depicted in Figure 4. The model of the casing with the mesh is shown in Figure 5. Utilizing the dominant meshing technique results in the production of a free hexa dominant mesh. This choice will be made if there are bodies that cannot be swept away by the other options. Although tetra and pyramid cells can also be found in the mesh, hexagonal cells make up the majority of the structure. In order to decrease the total number of elements, hex-dominant meshing was utilised.

It was decided that the rotational velocity should be in the range of 2000 to 10000 RPM, the torque should be 500 N-m, and the displacement of X and Y should be equal to zero. The load is expressed as a rotational velocity measured in radians per second. The load is increased gradually, going from 0% to 50% to 100% to 121% to 100% to 50% to 0%. At full load, the rpm is 6920, which equates to 724.75 rad/s. The amount of load that was utilised is recorded in tabular form. On the Bladed Disc assembly, the load is being applied along the Z-axis. Figure 6 illustrates the final geometric model of the outer casing that was used for the analysis. The equivalent von mises stress distribution can be seen depicted in figure 7, which was obtained from a static analysis of the outer casing. The highest level of stress that was measured was found to be 57.6 MPa. The total deformation is shown in Fig. 8, which was created under fully loaded conditions. When the plots of deformation obtained under loaded conditions are examined, it can be seen that the point at which there was the greatest amount of deformation was 69.54 MPa[23-25].



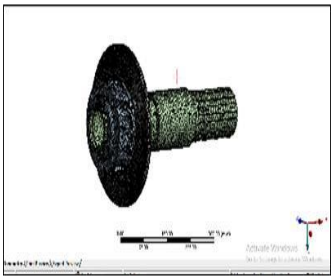
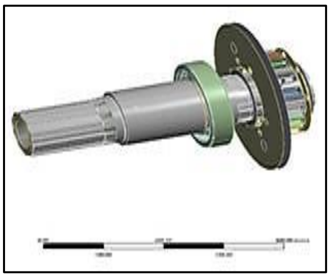


Fig-4: Static analysis Model **Fig-5:** Mesh model



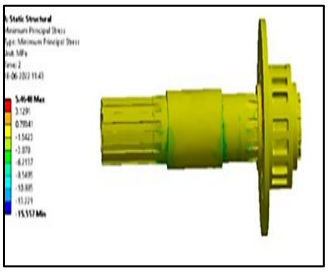


Fig-6: Geometric model **Fig-7:** Equivalent von –mises

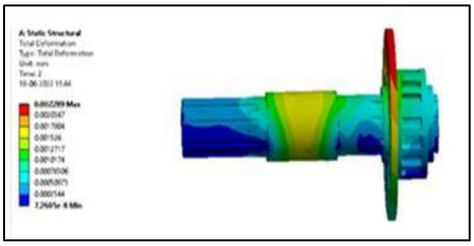


Fig-8: Total Deformation

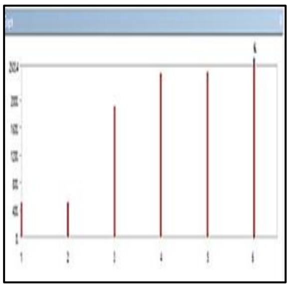
Dynamic analysis

The frequency and frequency variations that were recorded in the various modes are presented in Table 1. When the number of modes is increased, there is also an accompanying increase in the frequency value. The graphical representation of the same frequency values can be found in Figure 9. The plot of the deformation for the dynamic analysis is shown in figure 10. It has been determined that the maximum amount of deformation that has been observed is 14.799.

Fig.11 shows a plot of the deformation that was performed using the second mode of dynamic analysis. The value of deformation that is considered to be the highest is 14.83.

Table:1 Frequency variation at different modes

SL	MODE	Frequency(Hz)
1	1.	494.21
2	2.	498.28
3	3.	1908.4
4	4.	2382.2
5	5.	2393.3
6	6.	2503.4



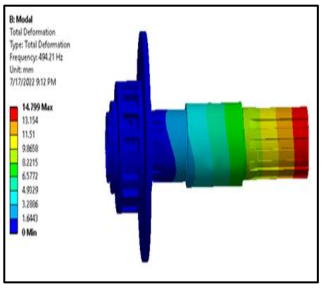


Fig-9: (Dynamic Mode Graph)

Fig-10: Dynamic Mode-Dynamic model analysis maximum 14.799

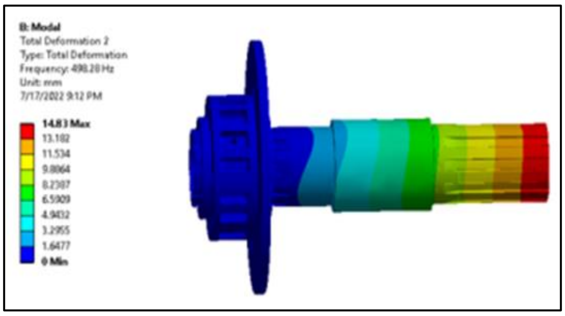


Fig-11: Dynamic Mode- Dynamic model analysis maximum 14.83

Fatigue Life Assessment

Procedures that have been developed over the course of the past century are utilised in the creation of modern building designs that include fatigue analysis. The development of strain-based methodologies to address the impacts of local plasticity has allowed for the ongoing improvement of these strategies over the course of time. It is essential to have a solid understanding of the accuracy problem before attempting to calculate the fatigue life of a component using finite element (FE) models. The vast majority of finite element analysis (FEA) based fatigue systems use the stress-life, strain-life, and crack-propagation methods when conducting their life assessment calculations. These are the three primary life assessment approaches. Fig.12 demonstrates the fatigue life evaluation model used in this investigation.

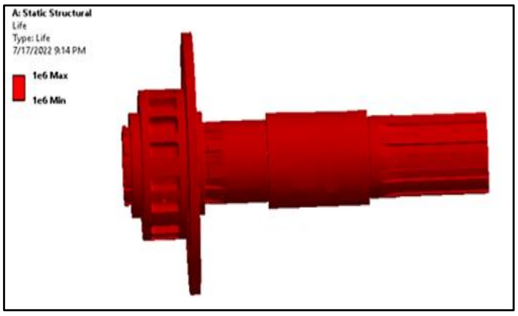
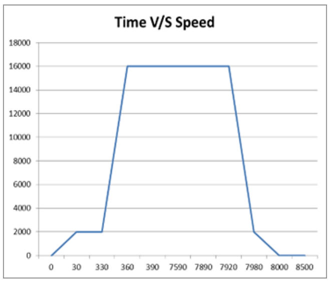


Fig-12: Fatigue life Model

Analysis of transient responses:

Static analysis does not take into account how the load varies in relation to the passage of time. The output in the form of stress or displacement with regard to time can be predicted with the help of a technique called transient response analysis. Figure 13 depicts the variations in time versus speed, and Figure 14 depicts the variations in time versus pressure for the fatigue life of outer casing that was studied in this investigation.



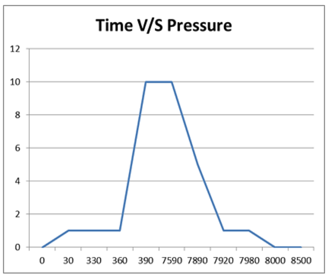


Fig-13: shows Time V/S Speed variations

Fig-14: Time V/S Pressure variations

VI. CONCLUSION

In In addition to the calculation of spline safety factors, the analytical method that is presented in this paper provides much of the same information as modern gearbox design tools. The analytical formulation, by virtue of its very nature, provides greater clarity than the other methods on the impact of the spline coupling design parameters on the performance of the spline and subsequent safety issues. This is because the analytical formulation takes into account all of the design parameters simultaneously. If parametric research is used in the early stage of design, it may be possible to calculate solutions two orders of magnitude more quickly than when using models of higher quality. The maximum tooth load, the load distribution along the splines, and the safety factors are all influenced by torque. It is necessary to conduct an analysis of the spline design across the entire torque range. Crowning raises both the maximum load that can be placed on a tooth and the load sharing factor. However, because it also raises the stresses that are brought into contact with the teeth, it may have an adverse effect on safety considerations.

VII. REFERENCES

[1]. A.G. Ermatchenko, R.M. Kashaev “Production of Aircraft Engine Compressor Rotor Discs with Desired Service Life in Titanium Alloys “

[2]. K.Kumar, Dr.Ajit Prasad, Dr.K. Ramachandra “Computational Technique for Weight Reduction of Aero- Engine Rotor “

[3]. V. Mallikarjuna, G. Krishna Kishore, B. Rama Bhupal Reddy “ Fatigue Analysis and Design Of Different Compressor Rotor Blade of An Orpheus Engine

[4]. Jürgen Broede “ Titanium Rotors in Military Aero Engines - Designed to Weight and Life”

[5]. Strain Posavljak, Katarina Maksimović “Initial Fatigue Life Estimation in Aero Engine Discs”

[6]. Cuffaro V., Curà F., Mura A., Test Rig for Spline Couplings Working in Misaligned Conditions, Journal of Tribology 136(1) (2014), 011104, doi:10.1115/1.4025656.

[7]. Curà F., Mura A., Evaluation of the fretting wear damage on crowned spline couplings. 2nd International Conference on Structural

Integrity, ICSI 2017, 4-7 September 2017, Funchal, Madeira, Portugal.

[8]. DIN 5466-1 (2000-10). Splined joints calculation of load capacity. Part 1 - general basis.

[9]. DIN 5480-1 (2006-3). Splined connections with involute splines based on reference diameters. Part 1 - principles

[10]. DIN 6892 (2012-08). Drive Type Fastenings Without Taper Action - Parallel Keys - Calculation And Design

[11]. Dudley D W, How to design involute splines. 1957; October: 75-80.

[12]. Dudley D W, When splines need stress control, Product Engineering. 1957; December: 56-61.

[13]. R. Costruzione di machine, vol. 1(in Italian). Casa Editrice Patron 1965. Bologna (Italia)A.G. Ermatchenko, R.M. Kashaev "Production of Aircraft Engine Compressor Rotor Discs with Desired Service Life in Titanium Alloys "

[14]. K.Kumar, Dr.Ajit Prasad, Dr.K. Ramachandra "Computational Technique for Weight Reduction of Aero- Engine Rotor "

[15]. V. Mallikarjuna, G. Krishna Kishore, B. Rama Bhupal Reddy " Fatigue Analysis and Design Of Different Compressor Rotor Blade of An Orpheus Engine

[16]. Jürgen Broede " Titanium Rotors in Military Aero Engines - Designed to Weight and Life"

[17]. Strain Posavljak, Katarina Maksimović "Initial Fatigue Life Estimation in Aero Engine Discs"

[18]. Cuffaro V., Curà F., Mura A., Test Rig for Spline Couplings Working in Misaligned Conditions, Journal of Tribology 136(1) (2014), 011104, doi:10.1115/1.4025656.

[19]. Curà F., Mura A., Evaluation of the fretting wear damage on crowned spline couplings. 2nd International Conference on Structural Integrity, ICSI 2017, 4-7 September 2017, Funchal, Madeira, Portugal.

[20]. DIN 5466-1 (2000-10). Splined joints calculation of load capacity. Part 1 - general basis.

[21]. DIN 5480-1 (2006-3). Splined connections with involute splines based on reference diameters. Part 1 - principles

[22]. DIN 6892 (2012-08). Drive Type Fastenings Without Taper Action - Parallel Keys - Calculation And Design

[23]. Dudley D W, How to design involute splines. 1957; October: 75-80.

[24]. Dudley D W, When splines need stress control, Product Engineering. 1957; December: 56-61.

[25]. R. Costruzione di machine, vol. 1(in Italian). Casa Editrice Patron 1965. Bologna (Italia)

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