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Optimisation of Helical Gear Power Transmission using Genetic and Pid Controller Hybrid Algorithm

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Abstract **– This Review Paper gives the information about Bending and Contact Stress Analysis of Helical Gear. Thus, this review paper mainly focus on the MATLAB, finite element methods and GA standards for computation of bending and contact stress on a root of helical gear. In this paper the bending stress and contact stress of the gear tooth are examined and are to be one of the main contributors for the failure of the gear in a gear set. Thus, the analysis of stresses has become popular as an area of research on gears to minimize or to reduce the failures and for optimal design of gears. Authors have use various Approaches and means to conclude their main objective of finding out the contact stresses and gear failure causes in static condition using Finite Element Analysis, GA Standards and MATLAB. This review paper contains theoretical, numerical and analytical methods for the helical gear pair analysis.**

Keywords **– Helical gear; Ansys; GA,PSO Standards; Creo; FEA analysis; Bending strength; Helix angle; Pressure angle.**

I. INTRODUCTION

Gear design is a complex phenomenon requiring consideration of several items such as gear geometry, material heat treatment, manufacturing, etc., to satisfy. Functional requirement, of high strength, high accuracy, low noise, and compactness of the drive. Traditionally, gear designers have been concerned with requirements of strength, noise, life, and accuracy of kinematic transmission. The recent focus of research however is the optimal design of compact gear pairs (gear boxes) for minimum weight and space requirements Designing a new product consists of several parameters, which differ according to the depth of design, input data, design strategy, procedures, and results. Mechanical design includes an optimization process in which designers always consider certain objectives such as strength, deflection, weight, wear, corrosion depending on the requirements. Among these objectives the weight of a new product is one of the best considerable design parameter[1,2].

The problem of minimum volume design of simple gear trains has been a subject of considerable interest, since many high-performance power transmission applications (e.g., automotive, aerospace, machine tools, etc.) require low weight. Gears plays an important role in transmit the necessary power for the proper function of the machines. The use of power is desirable at various angles to perform the various tasks like lifting, digging, cutting and pulling etc. This work describes the importance of helical gear in machinery and optimization of center distance using algorithm. The helical gears are employed to transmit motion between parallel shafts. These gears can also be used for transmitting motion between non-parallel, non-intersecting shafts. Helical gears are similar to spur gears except that the gears teeth are at an angle with the axis of the gears.

II. HELICAL GEARS

Helical gears are similar to spur gears except that their teeth are cut at an angle to the hole (axis) rather than straight and parallel to the axis like they are in the teeth of a spur gear. Helical gears are manufactured as both right and left-handed gears. The teeth of a left-handed helical gear lean to the left when the gear is placed on a flat surface. The teeth of a right-handed helical gear lean to the right when placed on a flat surface. In spur gears Fig.1.1 (a), the teeth are parallel to the axis whereas in helical gears Fig.1.1 (b) the teeth are inclined to the axis.

Both the gears are transmitting power between two parallel shafts. [3,4,5] At any time, the load on helical gears is distributed over several teeth, resulting in reduced wear. When two helical gears are engaged as, the helix angle has to be the same on each gear, but one gear must have a right-hand helix and the other a left-hand helix. In helical gear the line contact is diagonal across the face of the tooth.

Hence gradual engagement of the teeth and the smooth transfer of load from one tooth to another occur. Helical gears are capable of providing smoother and quieter operations at the same time transmit heavy loads. They are useful for high speed and high power applications, quiet at high speeds. Helical gears operate with less noise and vibration than spur gears. At any time, the load on helical gears is distributed over several teeth, resulting in reduced wear. Due to their angular cut, teeth meshing results in thrust loads along the gear shaft. This action requires thrust bearings to absorb the thrust load and maintain gear alignment. They are widely used in automobile industries in manufacturing of vehicles and marine ships [6,7,8].

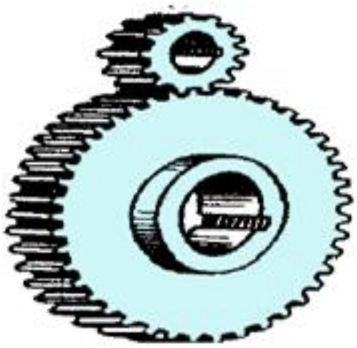

Fig.1.1: (a) Spur gear.

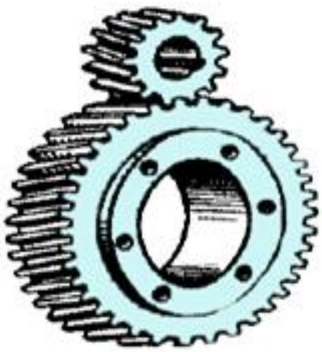

Fig.1.1: (b) Helical gear.

III.THE DESIGN PROCESS

The design of many engineering systems can be a complex process. Assumptions must be made to develop realistic models that can be subjected to mathematical analysis by the available methods, and the models must be verified by experiments. Many possibilities and factors must be considered during problem formulation. Economic considerations play an important role in designing cost-effective systems. To complete the design of an engineering system, designers from different fields of engineering usually must cooperate. For example, the design of a high-rise building involves designers from architectural, structural, mechanical, electrical, and environmental engineering as well as construction management experts. Design of a passenger car requires cooperation among structural, mechanical, automotive, electrical, chemical, hydraulics design, and human factors engineers.

Thus, in an interdisciplinary environment considerable interaction is needed among various design teams to complete the project. For most applications the entire design project must be broken down into several sub problems, which are then treated somewhat independently. Each of the sub problems can be posed as a problem of optimum design [9, 10, 11].

IV. OPTIMIZATION TECHNIQUES FOR OPTIMUM DESIGN PROBLEM

Modeling and optimization of process parameters of any manufacturing process is usually a difficult work where the following aspects are required: knowledge of manufacturing process, empirical equations to develop realistic constrains, specification of machine tool capabilities, development of an effective optimization criterion, and knowledge of mathematical and numerical optimization techniques.

A human process planner selects the proper machining parameters using his own experience or from the handbooks. Performance of these processes, however, is affected by many factors and a single parameter change will influence the process in a complex way. Because of the many variables and the complex and stochastic nature of the process achieving the optimal performance, even for a highly skilled operator is rarely possible. An effective way to solve this problem is to discover the relationship between the performance of the process and its controllable input parameters by modeling the process through suitable mathematical techniques and optimization using suitable optimization algorithm.

The first necessary step for process parameter optimization is to understand the principle governing the manufacturing process by developing an explicit mathematical model which may be mechanistic and empirical. The functional relationship between input-output and in-process parameters is determined analytically is called mechanistic model. However, as there is lack of adequate and acceptable mechanics models in for manufacturing processes, the empirical models are generally used in manufacturing processes. The modeling techniques of input-output and in-process parameter relationships are mainly based on statistical regression, artificial neural network, and fuzzy set theory [12,13].

V. REVIEW OF PAST RESEARCH

ParidhiRai et al (2018) minimized the volume of helical gear pair by including profile shaft coefficients as design variables along with module, face width and number of teeth using RCGA. Transverse load factor, face load factor, form factor, stress factor and zone factor are affected by profile shift and hence profile shift influences the design optimization result for helical gear pair. Tooth contact and bending strength are the two constraints used in the optimization procedure. It has been found that volume with profile shift is smaller compared to that of without profile shift. For further validation of RCGA results, commercially used software KISSsoft has been used.

Daniel Miler (2018) conducting a multi-objective optimization of gear pair parameters with a goal of reducing the transmission volume and power losses. Gearing efficiency primarily depends on the normal load, sliding velocities, and the friction coefficient. Gearing efficiency was calculated analytically, using the approximate load distribution formulae and efficiency formulation developed by Schlenk. The resulting formula was included in the genetic algorithm as an objective. To verify it, results were compared to the ones obtained by other authors. Optimization variables consisted of the gear module, the face width, the pinion and wheel profile shift coefficients and the number of teeth of the pinion. Solutions have shown that the trade-off between volume and efficiency is obligatory and a combi- nation of the lower gear module, the lower face width, the higher profile shift coefficients and the higher number of teeth of the pinion yield good results regarding both objectives.

Ashish V Kadu and Sanjay S Deshmukh (2015) experimented that the transmission error in the actual gear system which arises because of an irregular tool geometry or imperfect geometry or imperfect mounting the characteristic of the involutes spur gear are analyzed by using finite element method. The contact stresses are examined by using 2D FEM Model. And the bending stresses in the tooth root are examined by using 3D FEM Model. The conventional method of calculating gear contact stress using Hertz's theory for verification by 2D FEM analyzer using ANSYS, the stiffness relationship between two contact area is usually established using a spring place between source and target surfaces for the contact generation between two gears. The stresses are compared with theoretical result. The static transmission error and analysis of load sharing method using displacement vector and the effect of this error in the actual transmission power of mesh gear.

Deva Ganesh et al. (2015) studied that the meshing between two gears contact stresses are evolved, which are determined by using analyzing software called ANSYS. Finding stresses has become most popular in research on gears to minimize the vibrations, bending stresses and also reducing the mass percentage in gears. These stresses are used to find the optimum design in the gears which reduces the chances of failure. The model is generated by using Catia and ANSYS is used for numerical analysis. The analytical study is based on Hertz's equation. Study is conducted by varying the geometrical profile of the teeth and to find the change in contact stresses between gears. It is therefore observed that more contact stresses are obtained in modified gears. Both the results calculated using ANSYS and compared according to the given moment of inertia.

Sarfraz Ali N. Quadri and Dhananjay R. Dolas (2015) experimented an attempt to summarize about stresses developed in a mating spur gear which has involute teeth. A pair of spur gears are taken from a lathe gear box and progressed onward to calculate stresses. Conventionally the analysis is carried out analytically using Lewis formulae and then Finite Element Analysis is used for the same. Some stress relieving features have been incorporated in the teeth to know their effect on the stress concentrations. A finite element model of teeth is considered for analysis and geometrical features of various sizes are introduced at various locations and their effect is analyzed.

1. Summary of Past Research

The beam strength of helical gears is an important criterion for its designing as it also decides the force and power to be transmitted. If optimization of various influencing factors like contact ratio, gear ratio, helix angle, face width, module, pressure angle is done considering their combined effects then it will certainly enhance the effectiveness and performance of the helical gear. GA can also solve the objective functions and constraints that are not stated as explicit function of design variables that are hard to be solved by classical methods. Since genetic algorithm method of optimization is easy, effective and time-saving, it must be used by the researchers to optimize various engineering designs. Also we can conclude that the use of GA Toolbox given in MATLAB is easy to use as well as effective for such design optimization problems.

2. Objectives of Present Work

In this work a helical gear pair design optimization problem is solved. It is a multi-variable, complex non-linear problem with derived objective function and constraints.

- The main objective is to minimize the volume of the gear.
- The design parameters considered are module, face width, number of teeth on drive and driven and helix angle. MATLAB solvers fmincon and GA will be used.
- Simulation results will be analysed and compared to ParidhiRai et al. 2018.

3. Helical Gear Materials

Material of helical gear depends upon the application.
Following are the some general materials used for helical gear manufacturing:- steel, cast iron, stainless steel, brass, aluminium, bronze etc. Cast iron is widely used due to good wearing properties, good machinability and ease of producing complex shapes by casting method. Steel is

used for high strength gears. Phosphorous bronze is used for worm gears to reduce wear.

VI. DESIGN METHODOLOGY

A heavy duty helical gear pair is considered. Data used are: power to be transmitted = 120 kW, gear ratio = 5.18, pressure angle = 20°, helix angle = 12°, material is case hardened steel (20MnCr5). Using Lewis equation, module is obtained as 14mm. DIN Standards [12, 13] and parameters for pinion, wheel and strength based factors are considered [8]. MATLAB solvers fmincon and GA are used for performing design optimization. In this procedure, module mn (or x1), face width, mm (b or x2), gear teeth on drive and driven (Z1 or x3), (Z2 or x4) and helix angle, deg (β or x5) are used as design variables.
Upper and lower bounds of design variables are: 14≤mn≤15, 50≤b≤250, 25≤Z1≤56, 130≤Z2≤290, 4º≤β≤19.5º.

1. Objective Function

Gear can be designed either on the basis of minimum centre distance, or minimum weight. Here we are designing a gear on the basis of minimum volume. It is required to minimize the volume because smaller gears are easy to design, requires less material, less space and will run smoothly due to smaller inertial loads.
The volume of the gear train is given by

$$V=\frac{\pi}{4}\frac{m_n^2\, b(Z_1^2+Z_2^2)}{Cos^2\beta}$$

The objective function can be written as

$$F(x) = V = f(m_n, b, Z_1, Z_2, \beta) = f(x_1,x_2,x_3,x_4,x_5) = \frac{\pi}{4}\frac{m_n^2\, b(Z_1^2+Z_2^2)}{Cos^2\beta}$$

2. Constraints

Following constraint are taken in study bending stress, compressive stress, normal module, gear ratio, centre distance between pinion & gear and factor of safety from pitting constraints.

3. Condition of bending stress:

Failure in bending is generally catastrophic; hence appropriate care in the designing process is prudent and appropriate. To avoid tooth breakage, the bending stress should be limited to the maximum allowable bending stress of the material. The induced bending stress in an involute gear is calculated from the formula.
The induced bending stress is represented below

$$\sigma_b = 0.7\frac{(i+1)}{(a\, m_n b\, y_v)}\times[M_t]$$

$$\sigma_b \le [\sigma_b]_{al}$$

$$[Mt] = M_t \times k \times k_d$$

4. Condition of compressive stress:

The induced Compressive stress is represented

$$\sigma_c = 0.7\left(\frac{i+1}{a}\right)\times\sqrt{\frac{i+1}{ib}\times E\times[M_t]}$$

$$\sigma_c \le [\sigma_c]_{al}$$

5. Normal Module

$$m_{min} = 1.15\, cos\beta \times \sqrt[3]{\frac{[M_t]}{(y_v[\sigma_b]\Psi_m Z_1)}}$$

$$m_n \ge m_{min}$$

6. Gear Ratio:

Gear ratio constraint is represented below

$$i = \frac{Z_2}{Z_1} = 2$$

7. Centre distance between Pinion and Gear:

The minimum center distance is represented

$$a \ge a_{min}$$

$$a = \frac{m_n}{2cos\beta}[Z_1+Z_2]$$

$$a_{min} = (i+1)\times\sqrt[3]{\left(\frac{0.7}{[\sigma_c]}\right)^2\times\left(\frac{E[M_t]}{i\Psi}\right)}$$

$$\Psi = \frac{b}{a}$$

8. Factor of safety from pitting constraints

In our work we have introduce this constraints. Pitting is a fatigue failure of a material commonly seen in gears. Pitting occurs when fatigue cracks are initiated on the tooth surface or just below the surface. Constraints of pitting are deduced from contact stress, elasticity, contact ratio and poison's ratio for pinion and wheel. They are as follows:-

$$g_1(x) = 1.2 - \frac{1261.82}{189.81 X \sqrt{\frac{1}{\varepsilon_{\alpha 1}+\varepsilon_{\alpha 2}}} X \sqrt{\cos x_5} X 38.251 X \sqrt{\frac{1}{x_2}} X 1.14} \le 0$$

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$$g_2(x) = 1.2 - \frac{1262.44}{189.81 \times \sqrt{\frac{1}{\varepsilon_{\alpha 1}+\varepsilon_{\alpha 2}}} \times \sqrt{\cos x_5} \times 38.251 \times \sqrt{\frac{1}{x_2}} \times 1.14} \leq 0$$

Where:
$\varepsilon\alpha 1$= Transverse contact ratio for pinion
$\varepsilon\alpha 2$= Transverse contact ratio for wheel

$$\varepsilon_{\alpha 1} = \frac{x_3 \left[0.681 - tan\left[\cos^{-1}\left[\frac{\frac{1}{x_1 \cos x_5}(x_3+x_4)}{595.94}\right]\right]\right]}{6.28}$$

$$\varepsilon_{\alpha 2} = \frac{x_4 \left[0.531 - tan\left[\cos^{-1}\left[\frac{\frac{1}{x_1 \cos x_5}(x_3+x_4)}{595.94}\right]\right]\right]}{6.28}$$

9. Classical Optimization Techniques

The classical optimization techniques are useful in finding the optimum solution or unconstrained maxima or minima of continuous and differentiable functions. These are analytical methods and make use of differential calculus in locating the optimum solution. The classical methods have limited scope in practical applications as some of them involve objective functions which are not continuous and/or differentiable. Yet, the study of these classical techniques of optimization form a basis for developing most of the numerical techniques that have evolved into advanced techniques more suitable for today's practical problems. These methods assume that the function is differentiable twice with respect to the design variables and the derivatives are continuous. Three main types of problems that can be handled by the classical optimization techniques are:

1. Single variable functions
2. Multivariable functions with no constraints,
3. Multivariable functions with both equality and inequality constraints.

In problems with equality constraints the Lagrange multiplier method can be used. If the problem has inequality constraints, the Kuhn-Tucker conditions can be used to identify the optimum solution. These methods lead to a set of nonlinear simultaneous equations that may be difficult to solve.

10. Numerical Methods of Optimization

1. Linear programming: It is a method to achieve the best outcome in a mathematical model whose requirements are represented by linear relationships. Linear programming is a special case of mathematical programming. More formally, linear programming is a technique for the optimization of a linear objective function, subject to linear equality and linear inequality constraints.
2. Integer programming: An integer programming problem is a mathematical optimization or feasibility program in which some or all of the variables are restricted to be integers. In many settings, the term refers to integer linear programming, in which the objective function and the constraints are linear.
3. Quadratic programming: Quadratic programming is a special type of mathematical optimization problem. It is the problem of optimizing a quadratic function of several variables subject to linear constraints on these variables.
4. Nonlinear programming: In mathematics, nonlinear programming is the process of solving an optimization problem defined by a system of equalities and inequalities, collectively termed constraints, over a set of unknown real variables, along with an objective function to be maximized or minimized, where some of the constraints or the objective functions are nonlinear. It is the sub-field of Mathematical optimization that deals with problems that are not linear.
5. Stochastic programming: In the field of mathematical optimization, stochastic programming is a framework for modeling optimization problems that involve uncertainty.

VII. CONCLUSION

Global market has brought increasing awareness to optimize gear design. Current trends in engineering globalization require results to comply with various normalized standards to determine their common fundamentals and those approaches needed to identify best practices in industries. This can lead to various benefits including reduction in redundancies, cost containment related to adjustments between manufacturers for missing part interchangeability and performance due to incompatibility of different standards. Specific sliding velocity can be used for future work as an additional constraint or can be used as a fitness function. More uniformity in pinion and wheel wear can be achieved by balancing the specific sliding velocity. Another possibility of future work is to include gear efficiency as objective function in the design optimization problem. Future work can be extended using different optimization technique such as particle swam optimization, simulated annealing etc.

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