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Design, Analysis & Development of Spur Pinion of Rotary Actuator With Different Materials

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Abstract: *In mechanical power transmission system and industrial rotating machinery, gears are major component used for the power transmission. The Spur Gear used in such applications undergoes different types of stresses like bending stresses, contact stresses and also are subjected to Torque which further results in failure of teeth at the time of meshing. In pneumatic rotary actuators gears are used in opening and closing of the valve along with the rack and pinion. Failure of the gear is high due to high pressure load acting on pinion. These conditions make the gear less reliable. Hence, minimizing the root tensile stress results in increasing the fatigue life. By using different materials for such gears, stresses can be minimized, weight can be reduced and with heat treatment and shot penning better surface finish can be obtained.*
Keywords: *Spur pinion, steel, aluminum, material, weight optimization.*

I. Introduction

Gears are used for a variety of applications. They have numerous applications starting from textile looms to aviation industries. They are the most frequent ways of transmitting power. They will change the rate of rotation of machinery shaft as well as the axis of rotation. For high speed machine, such as a motor vehicle transmission, they are the optimum medium for low energy loss, high accuracy and reliability. Their function is to convert input provided simply by prime mover into an output with lower velocity and corresponding higher speed. Toothed gears are being used to transmit the power with high velocity ratio. In this phase, they face large stress at the point of contact. A set of teeth for is generally subjected to two types of cyclic stresses:
i. Bending stresses inducing bending fatigue
ii. Contact stress causing contact fatigue.

Fig.1.1- Pneumatic Rotary Actuator

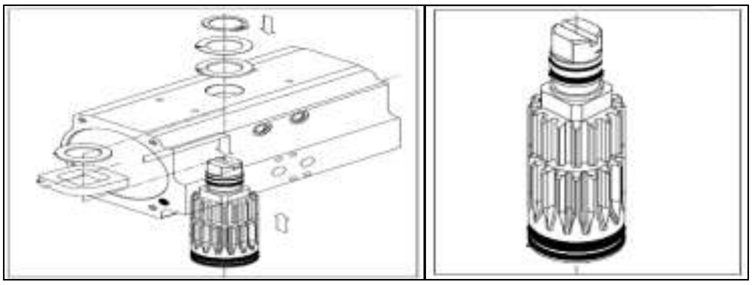


Fig.1.2- Disassembly of Pneumatic Rotary Actuator

Both equally these kind of stresses may well not achieve their maximum values at the exact same point of contact. Nevertheless, combined action of that they are all the reason of failure of gear tooth leading to fracture at the bottom layer of a tooth underneath bending fatigue and surface area failure. When load will be applied to the body, their surfaces deform elastically near to the peak point. Stresses developed by normal force in a photo-elastic type of gear teeth are displayed in the Fig.1.3. The highest stresses can be found at the region where the lines are bunched nearest together. The maximum stress arises at two locations:
i. At contact point exactly where the force F work.
ii. At the fillet region near to the base in the tooth.

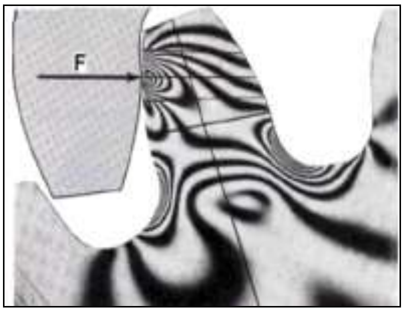


Fig.1.3- Photoelastic Type Gear Teeth

The simplest actuator is purely mechanical, where linear motion in one direction gives rise to rotation. The most common actuators though are electrically powered. Other actuators may be powered by pneumatic or hydraulic power, or may use energy stored internally through springs. The motion produced by an actuator may be either continuous rotation, as for an electric motor, or movement to a fixed angular position as for servomotors and stepper motors. A further form, the torque motor, does not necessarily produce any rotation but merely generates a precise torque which then either causes rotation, or is balanced by some opposing torque.

In thesis we mostly focus on only pinion but pneumatic rotary actuator having pneumatic rack and pinion actuators that can be used to control valves in pipeline transport. The actuators in the picture on the right are used to control the valves of large water pipeline. In the top actuator, a gray control signal line can be seen connecting to a solenoid valve (the small black box attached to the back of the top actuator), which is used as the pilot for the actuator. The solenoid valve controls the air pressure coming from the input air line (the small green tube). The output air from the solenoid valve is fed to the chamber in the middle of the actuator, increasing the pressure. The pressure in the actuator's chamber pushes the pistons away. While the pistons are moving apart from each other, the attached racks are also moved along the pistons in the opposite directions of the two racks. The two racks are meshed to a pinion at the direct opposite teeth of the pinion. When the two racks move, the pinion is turned, causing the attached main valve of the water pipe to turn.

A. Bending Stresses of Spur Pinion at maximum loading Condition:

There are several failure mechanisms for spur gears. Bending failure of the teeth is one of the main failure modes. The bending stress in a spur gear is another interesting problem. When loads are too large, bending failure will occur. Bending failure in gears is predicted by comparing the calculated bending stress to experimentally-determined allowable fatigue values for the given material. This bending stress equation was derived from the Lewis formula. Wilfred Lewis (1892) was the first person to give the formula for bending stress in gear teeth using the bending of a cantilevered beam to simulate stresses acting on a gear tooth. The Lewis equation considers only static loading and does not take the dynamics of meshing teeth into account. Different factors are required for the calculations, these factors can be obtained from the books on machine design. This analysis considers only the component of the tangential force acting on the tooth and does not consider effects of the radial force, which will cause a compressive stress over the cross section on the root of the tooth. In fact, the maximum stress at the root of tooth occurs when the contact point moves near the pitch circle because there is only one teeth pair in contact and this tooth pairs carries the entire torque. When the load is moving at the top of the tooth, two teeth pairs share the whole load if the ratio is (> 1 & < 2). If one tooth pair was considered to carry the whole load and it acts on the top of the tooth this is adequate for gear bending stress fatigue. Fatigue or yielding of a gear tooth due to excessive bending stresses is one important gear design considerations. In order to predict fatigue and yielding, the maximum stresses on the tensile and compressive sides of the tooth, respectively are required. In the past, the bending stress sensitivity of a gear tooth has been calculated using photo elasticity or relatively coarse FEM meshes. However, with present computer developments We can make significant improvements for more accurate FEM simulations.

B. Stress Relieving Features

The stress features like circular holes are being used for many years to reduce the stresses in the components. These stress relieving features can also be used for reduction of bending stresses in gears. Nowadays various other features like combination of different types or sizes of holes are being studied. The reduction in the bending stresses in the components will lead to increased factor of safety. Thus study of various types of stress relieving features for the components like gears are important.

II. Problem Definition

The Failures of pinion occurs at worst loading conditions, due to improper lubrications, corrosions, etc.

- Failures start from the root fillets radius and crack may be observed.
- Bending stresses occurs in the spur pinion.
- When the spur pinion mesh tangential, stresses enervates in the gear tooth.

III. Objective

One of the main causes for failure of the gear tooth is bending stresses near the root of the gear and the contact stresses where the gears meet. The main objective of this thesis is to analyze the bending stresses and acting torque in the spur pinion. This thesis investigates bending stress developed in pinion worst loading condition set while transmitting for both the steel and Aluminum as gear material. Both above said material find many applications and also each material exhibits their own characteristics during service condition, high strength, durability and load carrying capacity creates an opportunities to use Steel as gear material and in contrast aluminum as a gear material shows up unique characteristics like corrosion resistance, light weight and easy of machining.

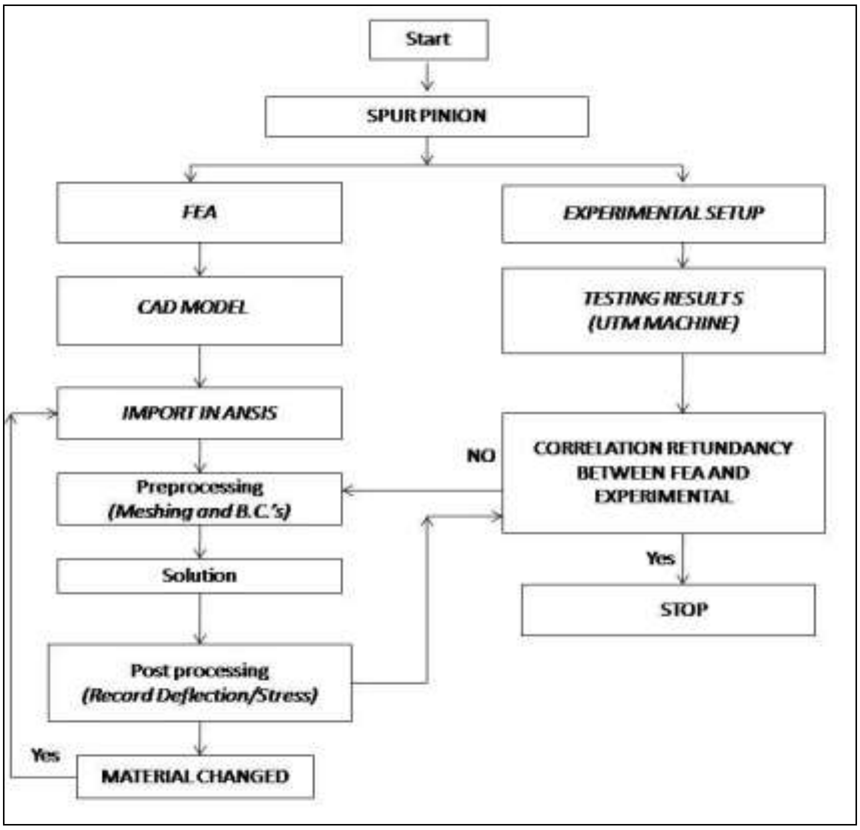


Fig. 3.1- FlowChat of Methodology

IV. Design Calculation

Table No 1- Input Data

Type	Size in (mm)	Pressure (Bar) P	Factor Of Safety
Rotary Pneumatic Actuator	52	8.0	1.3

Table No 2- Data Calculation Sheet

Sr No	PARAMETER	SYMBOL	CALCULATION
1	Module	m	1.25mm
2	Number Of Teeth	z	16
3	Face Width	b	32mm
4	Form Factor	y	0.304
5	Pinion PCD	d= m*z	20mm
6	Beam Strength	Fb= m*b*Sa*z	2327.42N
7	Torque(TH.) Transmitting Capacity	T= F*(d/2)*2	46.55nm
8	Bore Diameter	D	52mm
9	Pneumatic Pressure	P	8bar
10	Perpendicular Distance	dp	20mm
11	Pneumatic Force	F= (∏/4)*d^2*P	1784.15N
12	Torque(Act.) To Be Transmitted	Tact= F*d	35.68Nm

V. Finite Element Analysis

Finite element analysis (FEA) is a method crossing the boundaries of Mathematics, Physics, Engineering and computer science. The method has wide application and enjoys extensive utilization in the structural, thermal and fluid analysis areas. Finite element analysis (FEA) is a computer based numerical technique for calculating strength and behavior of engineering structure. It can also be used to calculate deflection, stress, vibration, buckling behavior and many other phenomena. It also can be used to analyze either a small or large scale deflection. It uses a numerical technique called the finite element analysis method (FEA), in finite element method the actual continuum is represented by the finite element. These elements are considered to be joined at specified joints called nodes or nodal solution. As the actual variation of the field variables (like displacement, temperature, pressure and velocity) inside the continuum is not known, the variation of the field inside a finite element is approximately by a simple function. The approximating functions are also called as interpolation models and are defined in terms of field variables at nodes. When the equilibrium equations for the whole continuum are known, the unknowns will be the nodal values of the field variable. In this paper, fatigue analysis (Stress, Displacement and Torque) was carried out using FEA software ANSYS.

Preprocessing & Postprocessing: As the name indicates, preprocessing is something before processing analysis. The Preprocessing involves the preparations of data, such as nodal coordinates, connectivity, boundary conditions, loading and material information. The preparation of data require considerable effort if all data are to be handled manually. If the model is small, the user can often just write a text file and feed it into the processor, but as the complexity of the model grows and the number of elements increases, writing the data manually can be very time consuming and error-prone. It is therefore necessary a computer preprocessor which help with mesh plotting and boundary conditions plotting. Here you can change loads, boundary conditions, mesh, element properties and material. All this is done graphically to minimize the chances of error. The only limitation is that you cannot draw your own geometry, you have to select one of the pre-generated geometries.

Meshing: It is probably the most important part in any of the computer simulations because it can show drastic changes in results. Meshing means you create a mesh of some grid-points called 'nodes'. The results are calculated by solving the relevant governing equations numerically at each of the nodes of the mesh. The governing equations are almost always partial differential equations and Finite element method is used to find solutions to such equations. The pattern and relative positioning of the nodes also affect the solution, the computational efficiency & time. This is why good meshing is very essential for a sound computer simulation to give good results.

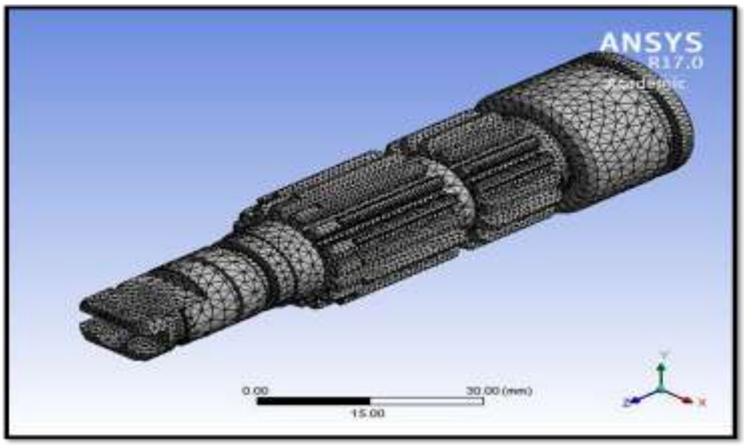


Fig. 5.1- Meshing Of Spur Pinion

Material Properties:
Structural Steel

Properties of Outline Row 3: Structural Steel

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	7850	kg m^-3		
3	Isotropic Secant Coefficient of Thermal Expansion				
6	Isotropic Elasticity				
12	Alternating Stress Mean Stress	Tabular			
16	Strain-Life Parameters				
24	Tensile Yield Strength	250	MPa		
25	Compressive Yield Strength	250	MPa		
26	Tensile Ultimate Strength	460	MPa		
27	Compressive Ultimate Strength	0	MPa		

Fig.5.2- Steel Material Detail

Aluminum Alloy

Properties of Outline Row 3: Aluminum Alloy

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	2770	kg m^-3		
3	Isotropic Secant Coefficient of Thermal Expansion				
6	Isotropic Elasticity				
12	Alternating Stress R-Ratio	Tabular			
16	Tensile Yield Strength	280	MPa		
17	Compressive Yield Strength	280	MPa		
18	Tensile Ultimate Strength	310	MPa		
19	Compressive Ultimate Strength	0	Pa		

Fig.5.3- Aluminum Alloy Material Detail

VI. Analysis Results

The post processing stage deals with the representation of results. Typically, the deformed configuration, mode shapes, temperature and stress distribution are computed and displayed at this stage.

The analysis will deliver two different material pinions, in this analysis we are focused on equivalent (Von-Mises) stresses and deformation which will be helpful for comparative study of the result.

The results obtained by FEA are as follows:

- Total Deformation:

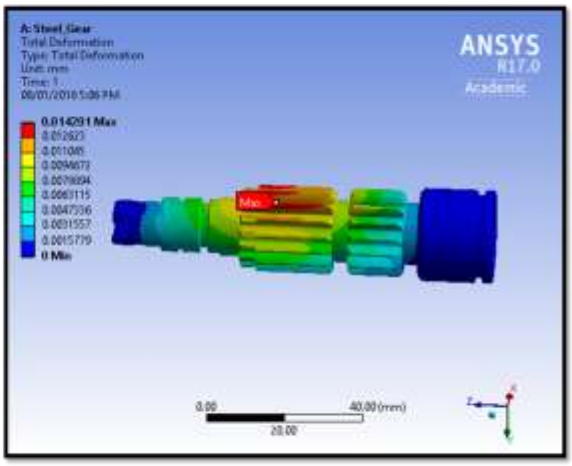


Fig.6.1- Steel Deformation

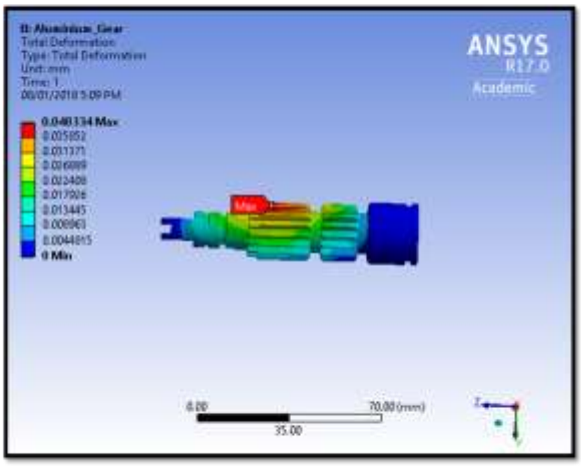


Fig.6.2- Aluminum Deformation

- Equivalent Stress (Von-Mises):

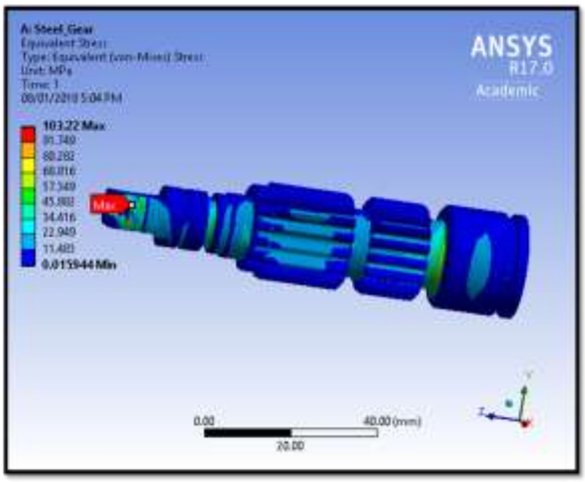


Fig.6.3- Steel Material Von-Mises Result

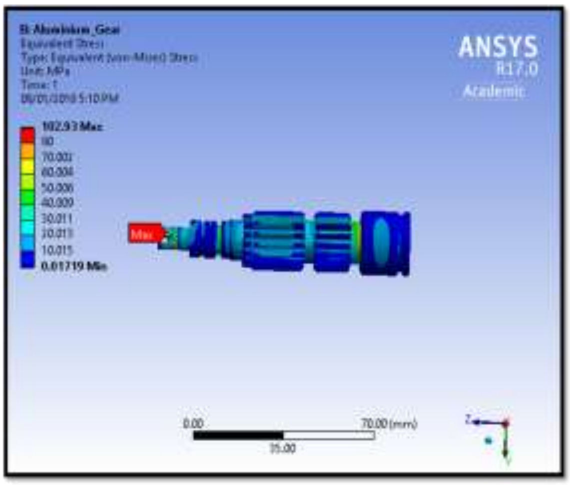


Fig.6.4- Aluminum Material Von-Mises Result

- Total Deformation- Torque:

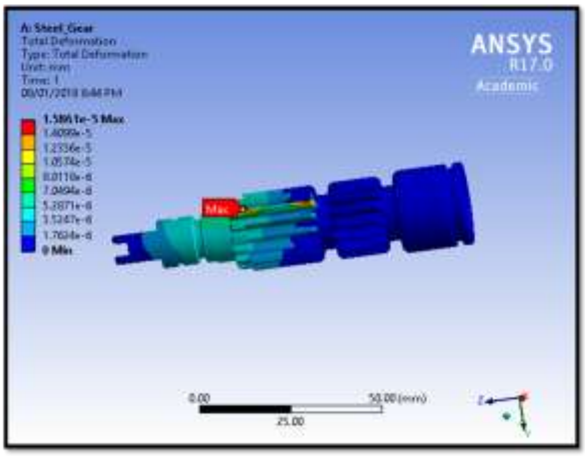


Fig.6.5-Total Deformation- Torque- Steel Results

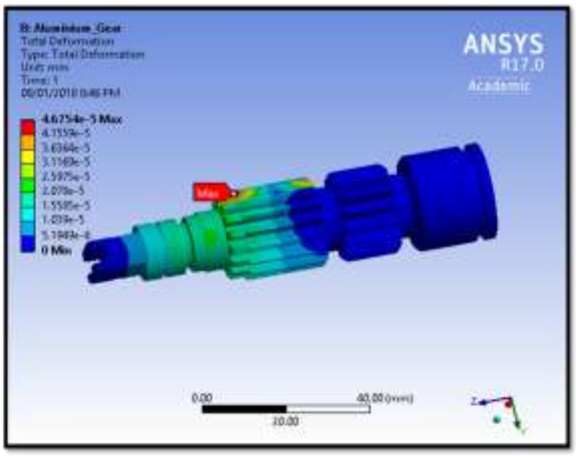
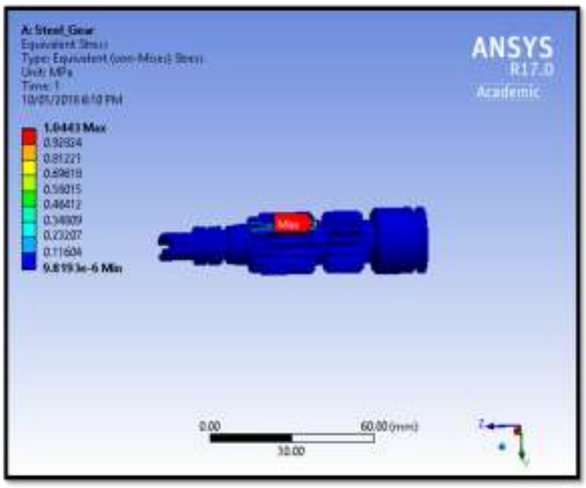


Fig.6.6-Total Deformation- Torque- Aluminium Results

- Equivalent Stress (Von-Mises)- Torque:



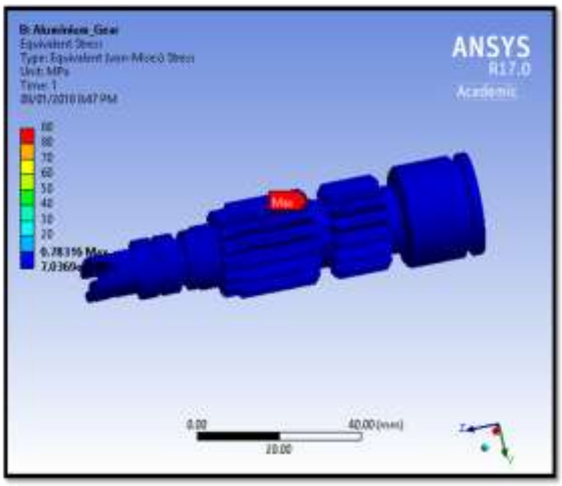


Fig.6.7- Steel Material Von-Mises(Torque) Result Fig.6.8- Aluminium Material Von-Mises(Torque) Result

Table No 3- Result Table

Sr. No.	Type	Materials	
		Steel	**Aluminum**
1.	Total Deformation(mm)	0.0142021	0.040334
2.	Equivalent Stress(Von-Mises)(MPa)	103.22	102.93
3.	Total Deformation-Torque(mm)	1.5861e-5	4.6754e-5
4.	Equivalent Stress(Von-Mises)-Torque(MPa)	1.0443	0.78316

VII. Conclusion

In this, analysis is used to find out the total amount of stresses and deformation of gear tooth. With reference to Ansys results, it is observed that stress in steel is higher than the aluminum spur pinion. After studying the behavior of gear set by considering steel and aluminum as gear material, aluminum provides reliability because of strength of in worst condition. By analysis it is found that no more stress changes occurs for different material. Stresses occur are in safety limits. Hence, the aluminum gear is most feasible than the steel material spur pinion in a worst condition with the properties such as high corrosion resistance, less weight and better surface finish.

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