Explicit Dynamic Analysis of Spur Gear Mesh at Different Speed Conditions

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ABSTRACT

Gears are among the basic elements in every mechanical device. Spur gears are one type of gears which are mostly used to transmit power between two parallel shafts. The gear cut on Spur gears is also parallel to the shaft axis. The design of a gear has a direct effect on the efficiency of the system they are containing in it. This leads to giving an attention to the appropriate design and testing of the gear system. Since laboratory testing is too costly, simulation get a wider acceptance recently. In this paper, Explicit Dynamic Analysis of Spur Gear is performed to demonstrate the response of the gear to the variation of rotational speed. ANSYS workbench is used as a simulation tool. The gear is driven by a pinion gear with an angular velocity ranging from 100 to 1000 rpm for the gear ratio of 4. The 3D model is first developed in Autodesk inventor software and the imported to ANSYS workbench. In ANSYS model environment the 3D model is meshed with special mesh near the gear tooth surface for accuracy. Appropriate boundary conditions and loadings are applied. The results of the simulation for Total Deformation are provided with their maximum value at the tooth tip or tooth root.

Index Terms – Explicit Analysis, Spur Gear, Parallel shafts, Pinion, Simulation.

1. INTRODUCTION

Gear is a mechanical element which is used for transmitting the relative motion between shafts in a controlled manner [1]. They are employed in a wide range of applications such as aeronautics, automobile, ships, wind turbines, machine tools and other areas owing to their good features such as great load capacity, high efficiency and low backlash [2–4].The gear design mainly consider the design satisfaction such as strength, pitting resistance, bending stress, scoring wear, interference in involute gears, weight, volume, material etc.[5]. It is critical for smooth functioning of any machine. Among the various types of gears, spur gears are the simplest in design and manufacturing, used to transmit motion between parallel shafts. The gear teeth are extended to the axis of the shaft. Spur gears are best for the speed reduction and torque multiplication related applications [6]. They are used in washing machines, aircraft engines, trains, bicycles, metal cutting machines, power plants, automobile gear boxes, marine engines, rolling mills, steel mill etc. [6,7]. The advantages of spur gears are; high power transmission efficiency, compactness, constant velocity ratio, reliability etc.[7]. Spur gear pairs are subjected to cyclic bending and cyclic contact stresses even though the stresses attain their maximum at different point [8]. The bending stress is given by the flexural formula [9] in equation (1).

$$\sigma_b = \frac{6Fh}{bt^2} \qquad (1)$$

The contact stress is given by Hertzian Equation [10-12] in equation (2).

$$\sigma_c = \sqrt{\frac{F\left(1+\frac{r_1}{r_2}\right)}{\pi b r_p\left[\frac{(1-\nu_1{}^2)}{E_1}+\frac{(1-\nu_2{}^2)}{E_2}\right]\sin\phi}} \quad (2)$$

As long as these stresses are the major problems in spur gears, adequate care should be given to consider all factors contributing to these stresses [10].

Designing spur gear is needed to maintain a balance between cost and requirements. The designed gear is then manufactured and tested. Laboratory testing is used in critical conditions, but it is too costly. To avoid this extra cost, different simulation packages are evolving in today's world in ANSYS is the one. Explicit Dynamics is a package in ANSYS. It is used to simulate the dynamic nature of spur gears in motion [11].

2. MATERIAL AND METHODS

2.1. Material

In this paper Structural Steel is taken as a gear material which is used for gear manufacturing in most cases. Its properties are given in Table 1 below.

Properties	Values
Density	7850 kg/m^3
Young's Modulus	200 GPa
Poison's ratio	0.3

Table 1 Properties of Structural Steel

2.2. Methods

The following Gear mesh data [12] is used for the analysis

- Number of teeth on gear = 64
- Number of teeth on pinion = 16
- Module = 8 mm
- Face width = 30 mm
- Pressure angle = 20° full depth involute
- Angular velocity of Pinion ranges for the speed of 100-1000 rpm

Gear mesh model is developed in Autodesk inventor and converted in to IGES CAD format to be accessed by ANSYS Workbench. The 3D model is shown in Figure 1 below.

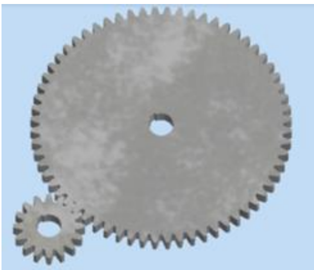

Figure 1 3D CAD Model

After the model is imported in to ANSYS workbench it is meshed. To ensure the accuracy of the analysis critical locations are fine meshed as shown in the Figure 2 below.

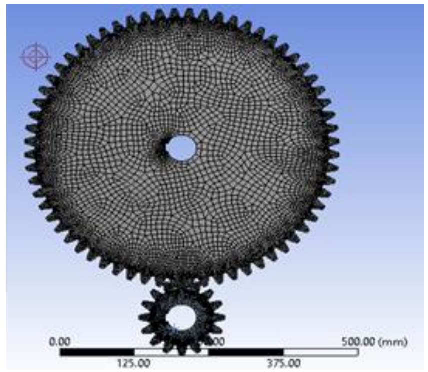

Figure 2 Meshed Model

In order to applying the appropriate Boundary conditions and Loading , a 'Remote Displacement' is applied to the center of the gear with rotation about z-axis free and all other rotations and translations are fixed as shown in Figure 3.

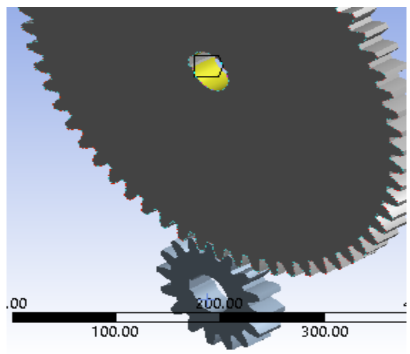

Figure 3 Boundary Condition

Angular velocity with a value ranging from 100-1000 rpm is applied to the pinion in the Z-axis for the 10^4 Number of cycles and End Time 0.001.

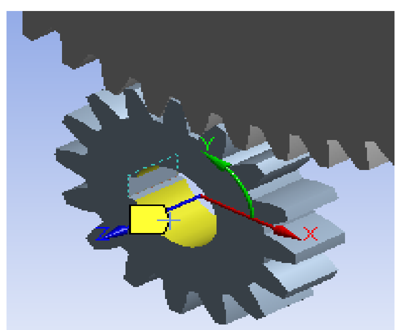

Figure 4 Angular Velocity

3. RESULTS AND DISCUSSIONS

3.1. Total Deformation

Total deformation occurred with respect to varying in speed is list in Table 2. Total deformation at minimum and maximum speed range is illustrated in Figure 5 and 6.

The total deformation achieves its maximum value at the tip of the gear teeth; this implies the tip of the gear needs to be designed to resist deformation. In this research work, total deformation increases as rotational speed increases which is shown in Figure 7.

Rotational Speed (RPM)	Total Deformation (mm)
100	0.76033
200	1.5775
300	2.3639
400	3.1984
500	4.0576
600	4.9752
700	5.7120
800	6.9143
900	8.9308
1000	9.3071

Table 2 Variation of Total Deformation with Rotational Speed

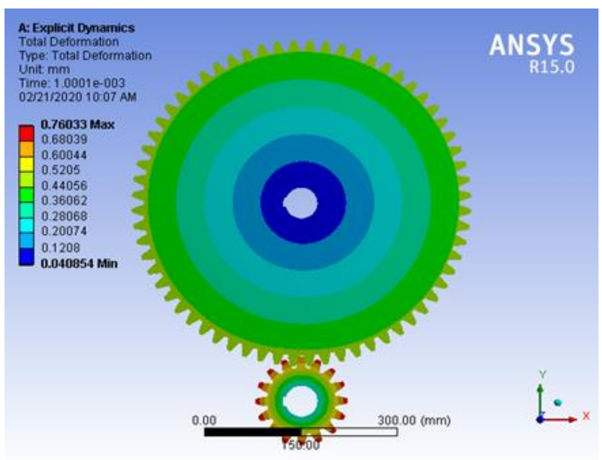

Figure 5 Total Deformation at 100 rpm

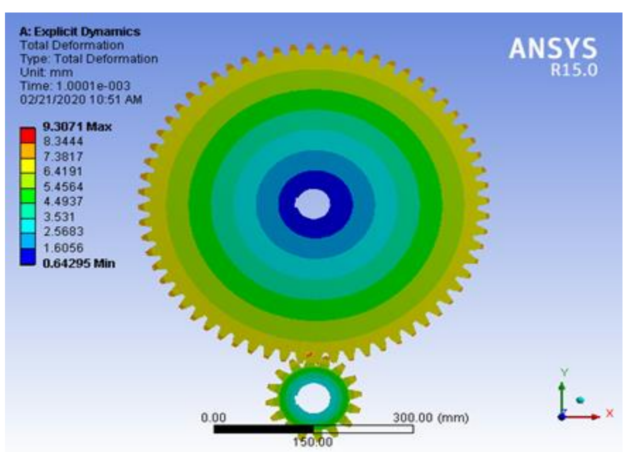

Figure 6 Total Deformation at 1000 rpm

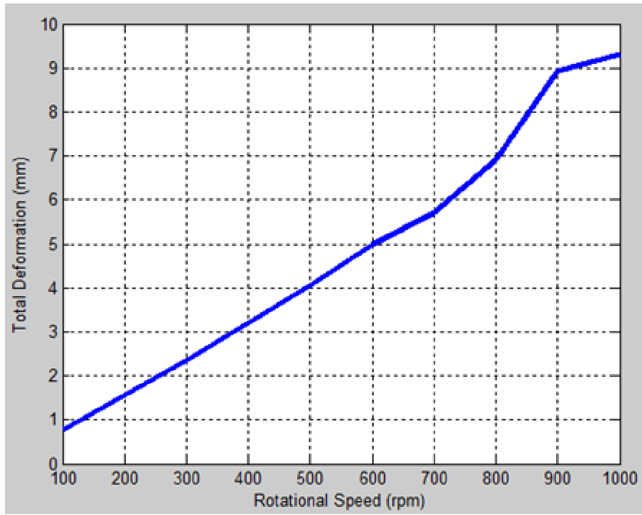

Figure 7 Total Deformation vs. Speed

3.2. Equivalent Stress

Equivalent Stress occurred with respect to varying in speed is list in Table 3. Equivalent Stress at minimum and maximum speed range is illustrated in Figure 8 and 9.

The equivalent stress achieves its maximum value at the tip of the gear teeth; this implies the tip of the gear needs to be designed to resist equivalent stress. In this research work, equivalent stress increases as rotational speed increases till 800 rpm which is shown in Figure 10. After that, equivalent stress has reduced due to uncertainties.

Rotational Speed (rpm)	Equivalent Stress (MPa)
100	765.5
200	1010.1
300	1014.0
400	1480.9
500	2168.3
600	2597.1
700	4407.0
800	5990.8
900	3149.3
1000	3151.3

Table 3 Variation of Equivalent Stress with Rotational Speed

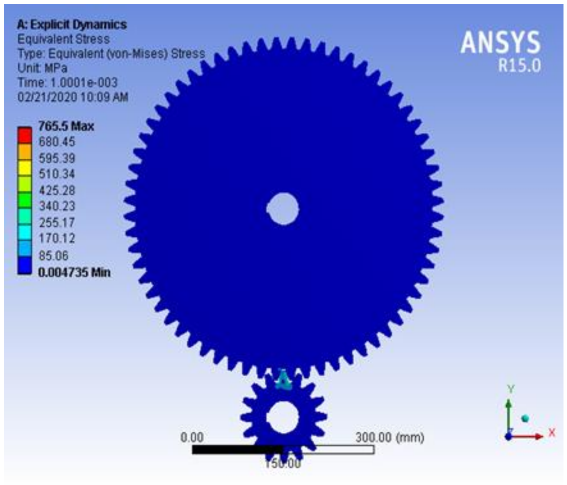

Figure 8 Equivalent Stress at 100 rpm

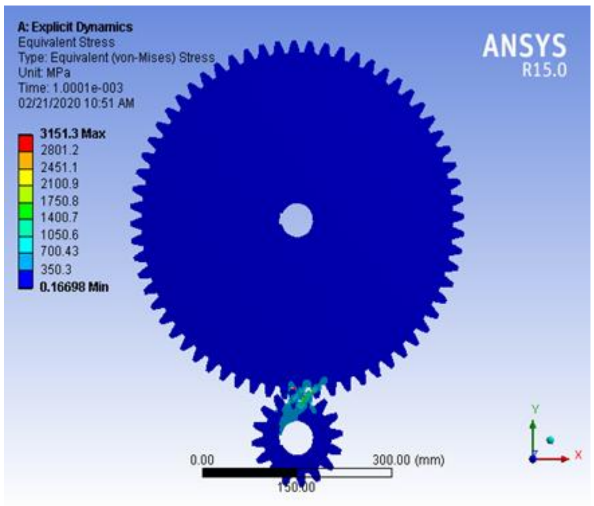

Figure 9 Equivalent Stress at 1000 rpm

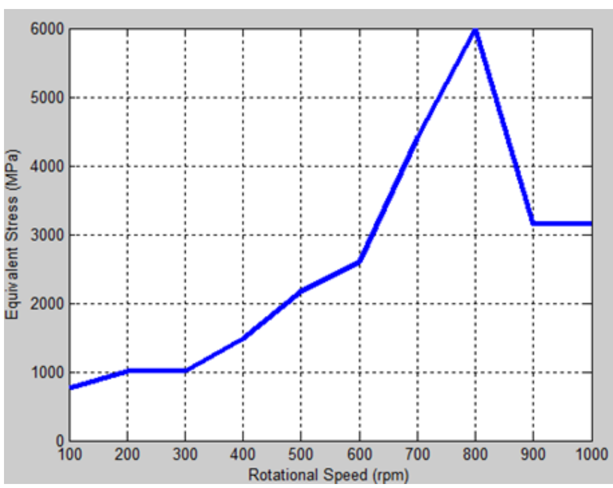

Figure 10 Equivalent Stress vs. Speed

3.3. Maximum Principal Stress

Maximum Principal Stress occurred with respect to varying in speed is list in Table 4. Maximum principal stress at minimum and maximum speed range is illustrated in Figure 11 and 12.

The maximum principal stress achieves its maximum value at the tip of the gear teeth; this implies the tip of the gear needs to be designed to resist maximum principal stress. In this research work, maximum principal stress increases as rotational speed increases till 800 rpm which is shown in Figure 13. After that, maximum principal stress has reduced due to uncertainties.

Rotational Speed (rpm)	Max. Principal Stress (MPa)
100	366.35
200	465.78
300	438.18
400	649.42
500	817.28
600	800.73
700	1482.70
800	3917.40
900	2822.10
1000	2516.40

Table 4 Variation of Maximum Principal Stress with Rotational Speed

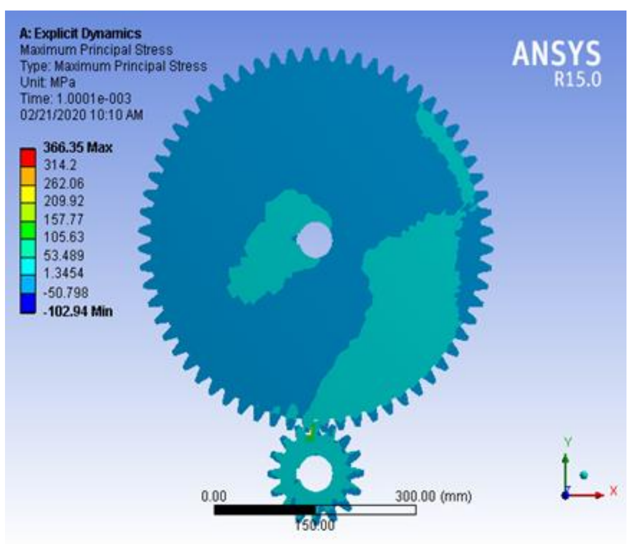

Figure 11 Max. Principal Stress at 100 rpm

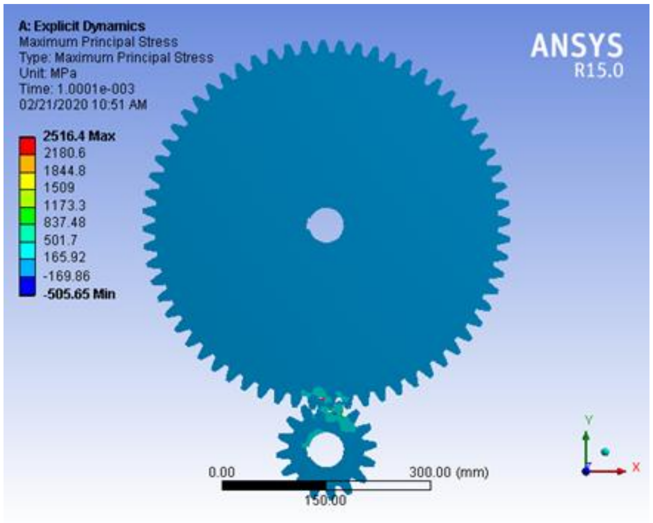

Figure 12 Max. Principal Stress at 1000 rpm

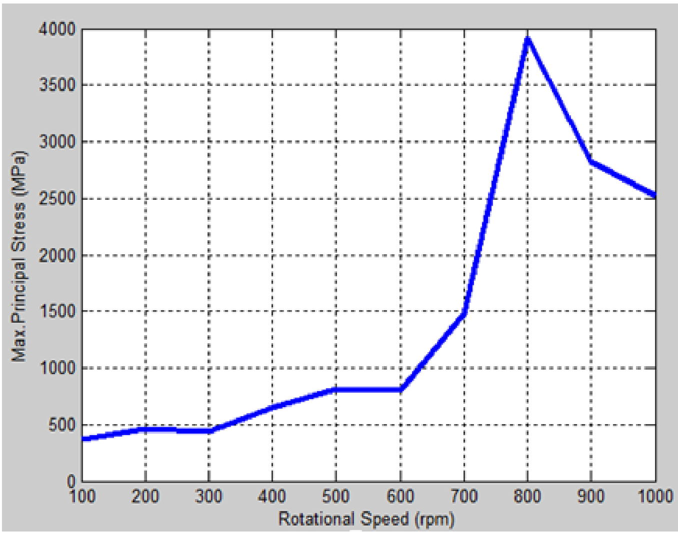

Figure 13 Max. Principal Stress vs. Speed

3.4. Maximum Shear Stress

Maximum Shear Stress occurred with respect to varying in speed is list in Table 5. Total deformation at minimum and maximum speed range is illustrated in Figure 14 and 15.

The maximum shear stress achieves its maximum value at the tip of the gear teeth; this implies the tip of the gear needs to be designed to resist maximum shear stress. In this research work, maximum principal stress increases as rotational speed increases till 800 rpm which is shown in Figure 16. After that, maximum principal stress has reduced due to uncertainties.

Rotational Speed (rpm)	Maximum Shear Stress (MPa)
100	435.38
200	567.70

300	568.36
400	782.38
500	1129.40
600	1441.30
700	2231.90
800	3178.60
900	1669.50
1000	1649.50

Table 5 Variation of Maximum Shear Stress with Rotational Speed

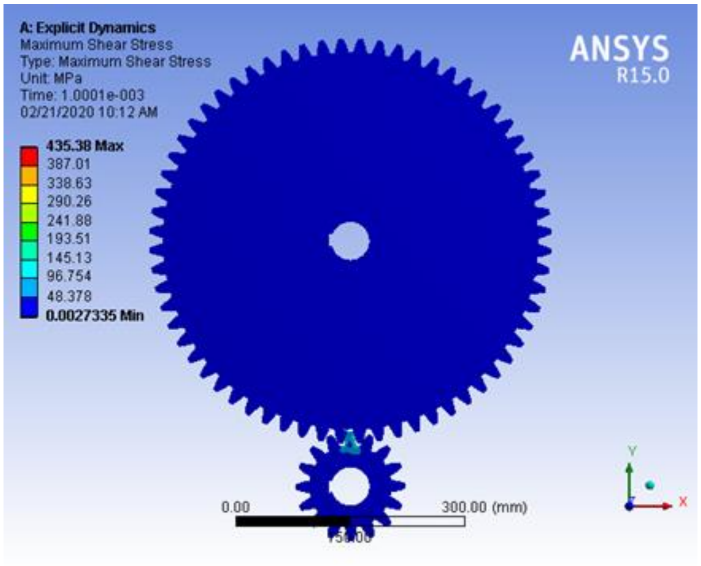

Figure 14 Maximum Shear Stress at 100 rpm

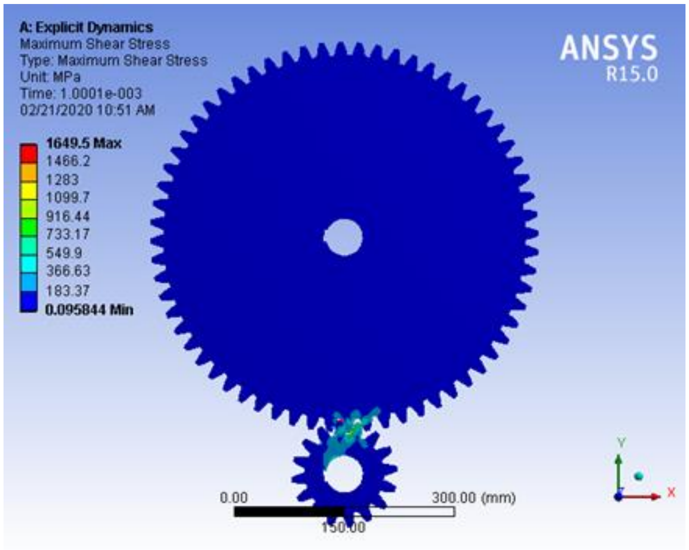

Figure 15 Maximum Shear Stress at 1000 rpm

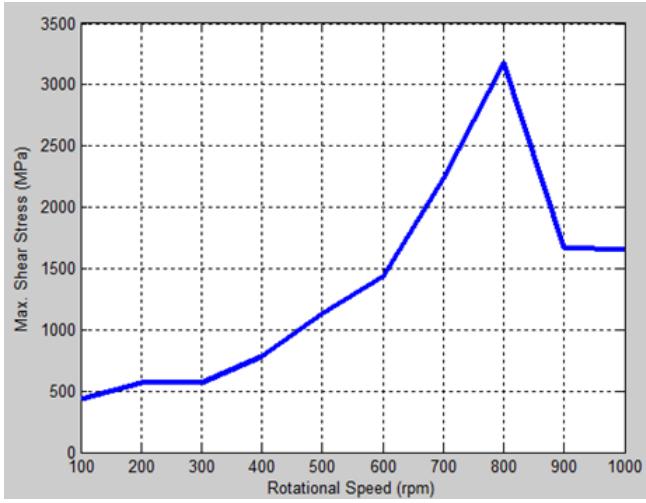

Figure 16 Max. Shear Stress vs. Speed

3.5. Equivalent Elastic Strain

Equivalent Elastic Strain occurred with respect to varying in speed is list in Table 6. Equivalent Elastic Strain at minimum and maximum speed range is illustrated in Figure 17 and 18.

The equivalent elastic strain achieves its maximum value at the tip of the gear teeth; this implies the tip of the gear needs to be designed to resist equivalent elastic strain. In this research work, equivalent elastic strain increases as rotational speed increases till 800 rpm which is shown in Figure 19. After that, equivalent elastic strain has reduced due to uncertainties.

Rotational Speed (rpm)	Equivalent Elastic Strain (mm/mm)
100	0.0038497
200	0.0046521
300	0.0053377
400	0.0074045
500	0.0108410
600	0.0129850
700	0.0220490
800	0.0309940
900	0.0209560
1000	0.0177440

Table 6 Variation of Equivalent Elastic Strain with Rotational Speed

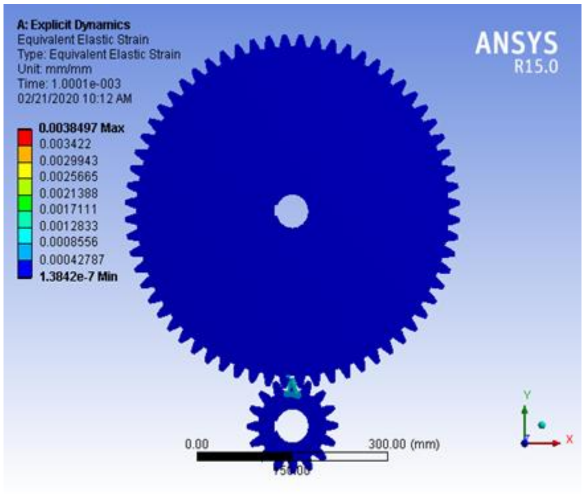

Figure 17 Equivalent Elastic Strain at 100 rpm

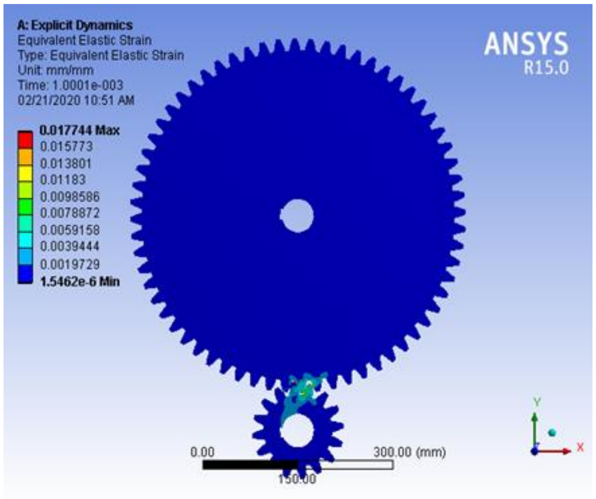

Figure 18 Equivalent Elastic Strain at 1000 rpm

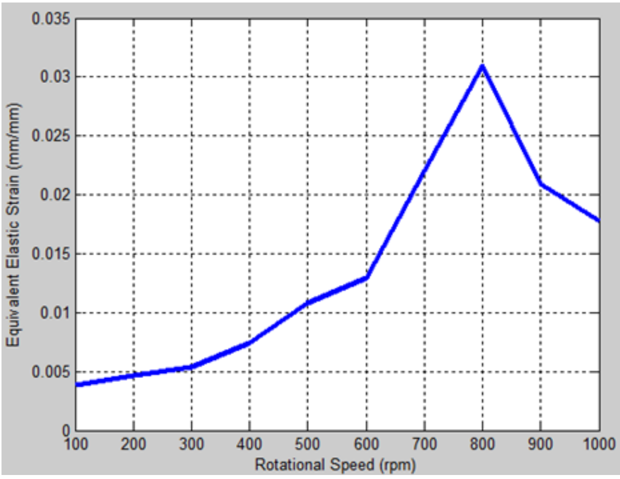

Figure 19 Equivalent Elastic Strain vs. Speed

4. CONCLUSION

Spur Gears are one of the common mechanical power transmission mediums. They have to be carefully designed, manufactured and tested. Due to the costliness of laboratory testing simulations are employed in various applications. Simulation is a current economic way of testing components in virtual environment. Spur Gears are under Explicit Analysis in ANSYS workbench. The simulation is successfully performed which shows tooth root is the critical part of a spur gear. This part is highly affected by bending stress. The tooth tip corner is another critical part of the gear which is highly affected by the contact stress. Hence, the effect of increasing rotational speed has a direct relationship with total deformation, equivalent stress, maximum principal stress, maximum shear stress and equivalent elastic strain. From the results, it is observed that 800 rpm is the critical speed for this spur gear mesh analysis.

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