International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-08, Special Issue, MAY 2022

Determination of Optimum Scanning Speed to Regulate Performance Characteristics of Spur Gear Through Simulation of 3D Printing

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ABSTRACT: Gears are commonly used for transmitting power. They develop high stress concentration at the root and the point of contact. We have performed the 3D printing simulation to spur gears to study the effect of laser scanning speed on capturing the geometry and minimum stresses and displacements. The laser transferred energy decreased with the increase of scan speed, which cause more holes and cracks in the alloy. The smaller scan speed causes low bond strength and leads to porosity. Due to presence of porosity in the gear will affect strength and life of the spur gear. To avoid these problems, we have optimized the scanning speed to decrease the porosity in the final printed component. Due to increase in scanning speed dimensional accuracy of the final printed part will decrease due to overrun of the laser. If the scanning speed decreases over melting of the power will occur and larger melt pools will be created and surface roughness will be increased due to this very rough surface generates. To avoid these problems, we have optimized the laser power for optimized scanning speed.

Key words: Optimization, Scanning speed, Simulation, 3D printing, overrun

I. INTRODUCTION

Gears are used for a wide range of industrial applications. They have varied application starting from textile looms to aviation industries. They are the most common means of transmitting power. They change the rate of rotation of machinery shaft and also the axis of rotation. For high-speed machinery, such as an automobile transmission, they are the optimal medium for low energy loss and high accuracy. Their function is to convert input provided by prime mover into an output with lower speed and corresponding higher torque. Toothed gears are used to transmit the power with high velocity ratio. During this phase, they encounter high stress at the point of contact. A pair of teeth in action is generally subjected to two types of cyclic stresses:

i) Bending stresses inducing bending fatigue

ii) Contact stress causing contact fatigue.

Both these types of stresses may not attain their maximum values at the same point of contact. However, combined action of both of them is the reason of failure of gear tooth leading to fracture at the root of a tooth under bending fatigue and surface failure, due to contact fatigue. When loads are applied to the bodies, their surfaces deform elastically near the point of contact. The highest stresses exist at regions where the lines are bunched closest together.

The highest stress occurs at two locations:

A. At contact point where the force F acts

B. At the fillet region near the base of the tooth.

The surface failures occurring mainly due to contact fatigue are pitting and scoring. It is a phenomenon in which small particles are removed from the surface of the tooth due to the high contact stresses that are present between mating teeth. Pitting is actually the fatigue failure of the tooth surface. Hardness is the primary property of the gear tooth that provides resistance to pitting. In other words, pitting is a surface fatigue failure due to many repetitions of high contact stress, which occurs on gear tooth surfaces when a pair of teeth is transmitting power. Gear teeth failure due to contact fatigue is a common phenomenon observed. Even a slight reduction in the stress at root results in great increase in the fatigue life of a gear.

 DOI : 10.35291/2454-9150.2022.0259

For many years, gear design has been improved by using improved material, hardening surfaces with heat treatment and carburization, and shot peening to improve surface finish etc. Few more efforts have been made to improve the durability and strength by altering the pressure angle, using the asymmetric teeth, altering the geometry of root fillet curve and so on. Some research work is also done using the stress redistribution techniques by introducing the stress relieving features in the stressed zone to the advantage of reduction of root fillet stress in spur gear. This also ensures interchangeability of existing gear systems. The studies in which combination of circular and elliptical stress relieving features are used obtained better results than using circular stress relieving features alone which are used by earlier researchers. In this research work, an aero-fin shaped stress relieving feature is tried. A finite element model with a segment of three teeth is considered for analysis and a stress relieving feature of various sizes are introduced on gear teeth at various locations.

Purpose:

Gearing is one of the most critical components in mechanical power transmission systems. The transfer of power between gears takes place at the contact between the mating teeth. During operation, meshed gears‟ teeth flanks are submitted to high contact pressures and due to the repeated stresses, damage on the teeth flanks, in addition to tooth breakage at the root of the tooth is one of the most frequent causes of gear failure. This fatigue failure of the tooth decides the reliability of the gear. However, by introducing stress relieving features to the gear, the points of stress concentration can be decreased which enhances life of gear. A study is done on spur gear with involute profile by adding stress relieving features of different shapes and best among them is proposed.

Hardware used: Intel core i3 processor of 2.2GHz, 4GB of RAM.

Software used: All the modelling is done in Autodesk fusion360, Mesh generation is done in Altair inspire.

II. LITERATURE REVIEW

Investigators analysing the gear tooth for stresses have done several studies:

A. Manoj Hariharan [4] conducted stress analysis on 8 different gears by determining the highest point of contact for all gears. Stress analysis for the load contact point travelling along the involute curve is done for gears. The point of contact where maximum stress occurs is determined for all eight test gears and the variation of this H (Highest point of Contact) diameter for contact ratio greater than one is studied. Then the gear ratio where it is maximum is taken for application of force for all studies. From the results, he compared the stresses on each gear with their respective highest point of contacts and selected the weak gear among those for stress relief studies. He introduced circular holes as stress relieving features at different locations and also varied the diameters of holes. He concluded with an optimization study of

drilling two circular holes, each on two mating teeth at the same location relative to each tooth, stress can be reduced. M.S. Hebbel, V.B. Math and B.G. Sheeparamatti [6] used elliptical and circular holes as a stress relieving feature. Analysis revealed that, combination of elliptical and circular stress relieving features at specific, locations are beneficial than single circular, single elliptical, two circular or two elliptical stress reliving features. Shanmugasundaram Sankar, Maasanamuthu Sundar Raj, Muthusamy Nataraj [7] did a study using circular root fillet instead of the standard trochoidal root fillet. The result reveals that the circular root fillet design is particularly suitable for lesser number of teeth in pinion and whereas the trochoidal root fillet gear is more opt for higher number of teeth. Ashwini Joshi, Vijay Kumar Karma [2] did a work which deals with the effect on gear strength with variation of root fillet design using FEA. Circular root fillet design is considered for analysis. The loading is done at the highest point of single tooth contact (HPSTC).

Fredette and Brown [3] used holes drilled across the entire tooth as a function of size and location. The ultimate objective of this work was to find the overall effect of hole size and location on the critical stresses in the gear. Sorin Cănănău-Based [8] on an exact geometry design of the involute gear tooth, a set of profile gears is obtained in order to calculate the 2D contact. A stress analysis was performed for CAD profiles results using the finite element procedure. The paper investigates the 2D analysis versus 3D analysis for stress in the root region of teeth. By this approach, is also investigated the influence of non-uniform load along contact line to the fillet stress.

Ali Raad Hassan [1] did a research study in which Contact stress analysis between two spur gear teeth was considered in different contact positions, representing a pair of mating gears during rotation. A programme has been developed to plot a pair of teeth in contact. Each case was represented a sequence position of contact between these two teeth. The programme gives graphic results for the profiles of these teeth in each position and location of contact during rotation. Finite element models were made for these cases and stress analysis was done. The results were presented and finite element analysis results were compared with theoretical calculations, wherever available.

This paper is an extension of work done by A. Manoj Hariharan. He has taken a weak profile gear from his studies and conducted stress analysis on it by inserting circular holes as stress relieving features at different locations. The gear with all its dimensions is replicated and the highest point of contact is calculated in the similar way in the contemporary work. In this paper, an aerodynamic fin

 DOI : 10.35291/2454-9150.2022.0259

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shaped hole is used as a stress relieving feature which differs from circular holes used in the former one. It yielded better results comparatively but this aerodynamic shaped hole is limited to uni-directional gears only.

III. RESULTS AND DISCUSSION

The simulation of 3D printing of spur gear at different scanning speeds is carried out to study the effects of laser scanning speed on capturing the geometry.

The following simulation results for different scanning speeds of 1m/s, 1.2m/s, 1.4m/s.

simulation result for scanning speed of 1 m/s

The fig 1 shows the displacement of spur gear at scanning of 1m/s. The maximum value of displacement is **"**3.889x10^{-3} m**"**.

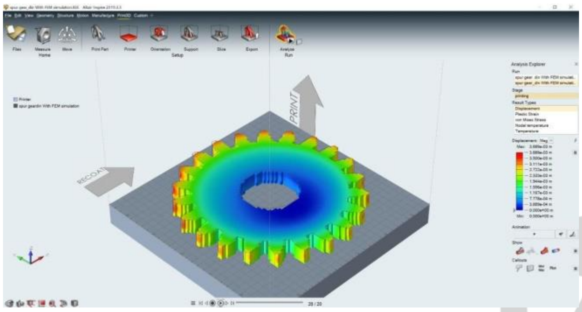


Fig1: displacement of spur gears at scanning speed of 1 m/s

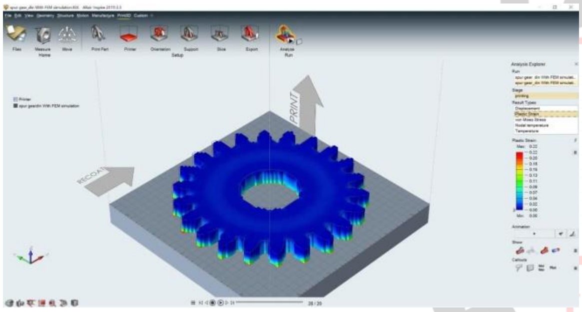
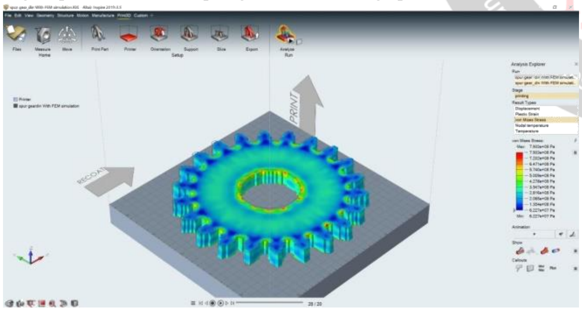
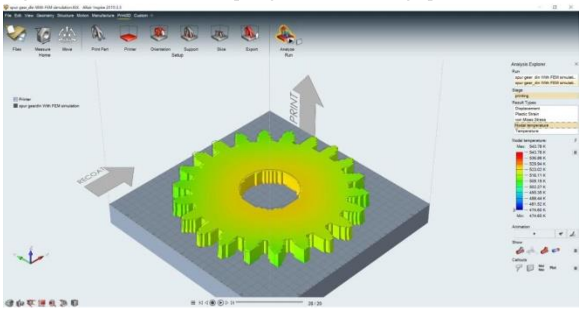


Fig 2: plastic strain of spur gears at scanning speed of 1 m/s



The fig 2 shows the plastic strain of spur gear at scanning of 1m/s. The maximum value of plastic strain is **"**0.22**"**.

Fig 3: von mises stress of spur gears at scanning speed of 1 m/s



The fig 3 shows the von mises stress of spur gear at scanning of 1m/s. The maximum value of von mises stress is **"**7.933x10^{08} Pa**"**.

Fig 4: nodal temperature of spur gears at scanning speed of 1 m/s

The fig 4 shows the nodal temperature of spur gear at scanning of 1m/s. The maximum value of nodal temperature is **"**543.78 K**"**.

The fig 5 shows the temperature distribution of spur gear at scanning of 1m/s.

The maximum value of temperature distribution is **"**5.264x10^{02} K**"**.

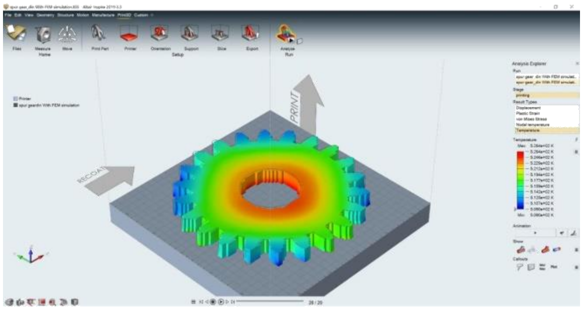


Fig 5: temperature distribution of spur gears at scanning speed of 1 m/s

Simulation result for scanning speed of 1.2 m/s

The fig 6 shows the displacement of spur gear at scanning of 1.2m/s. The maximum value of displacement is **"**3.306x10^{-03}m**"**.

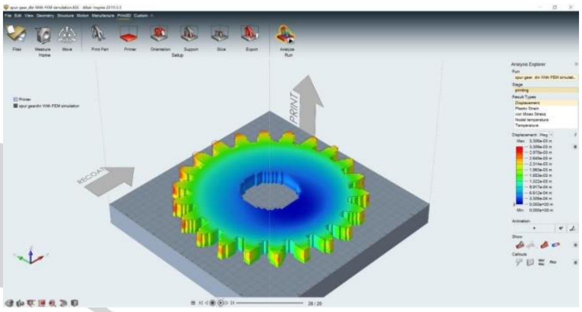


Fig 6: displacement of spur gears at scanning speed of 1.2 m/s

The fig 7 shows the temperature distribution of spur gear at scanning of 1.2m/s.

The maximum value of temperature distribution is **"**5.134x10^{2} K**"**.

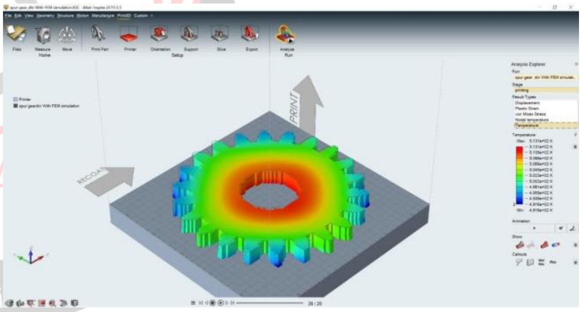


Fig 7: temperature distribution of spur gears at scanning speed of 1.2 m/s

Simulation result for scanning speed of 1.4 m/s

The fig8 shows the displacement of spur gear at scanning of 1.4m/s. The maximum value of displacement is **"**3.198x10^{-3}m**"**.

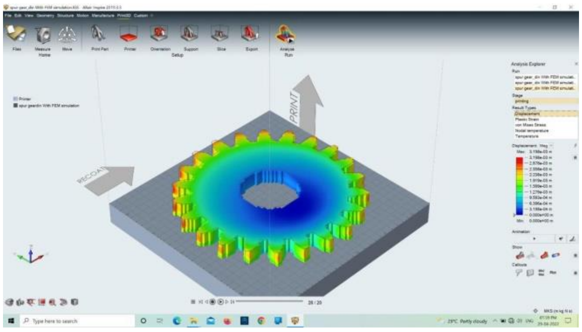


Fig 8: displacement of spur gears at scanning speed of 1.4 m/s

The fig 9 shows the nodal temperature of spur gear at scanning of 1.4m/s. The maximum value of nodal temperature is **"**516.97K**"**.

 DOI : 10.35291/2454-9150.2022.0259

ISSN : 2454-9150 Vol-08, Special Issue, MAY 2022

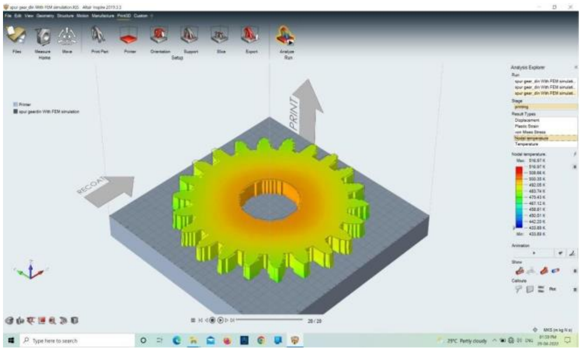


Fig 9: nodal temperature of spur gears at scanning speed of 1.4 m/s

The fig10 shows the temperature distribution of spur gear at scanning of 1.4m/s.

The maximum value of temperature distribution is “5.005×10^2 K”.

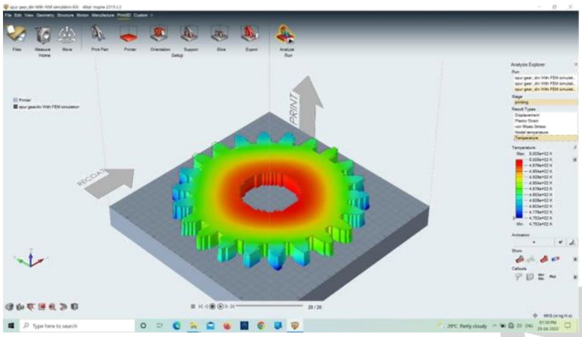


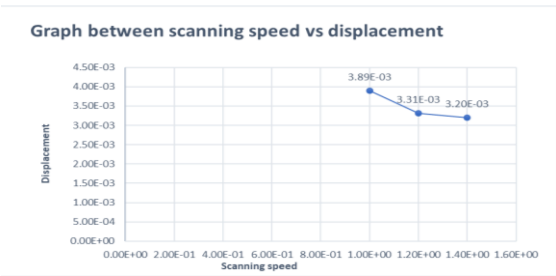
Fig 10: temperature distribution of spur gears at scanning speed of 1.4 m/s

Table 1 Maximum output values of performance characteristics at different scanning speeds

Scanning Speed(m/s)	Displacement (m)	Plastic Strain	Von mises Stress (Pa)	Nodal Temperature (K)	Temperature Distribution (K)
1.0	3.889×10^{-3}	0.22	7.933×10^8	543.78	5.264×10^2
1.2	3.306×10^{-3}	0.21	6.727×10^8	530.31	5.131×10^2
1.4	3.198×10^{-3}	0.25	6.396×10^8	516.97	5.005×10^2

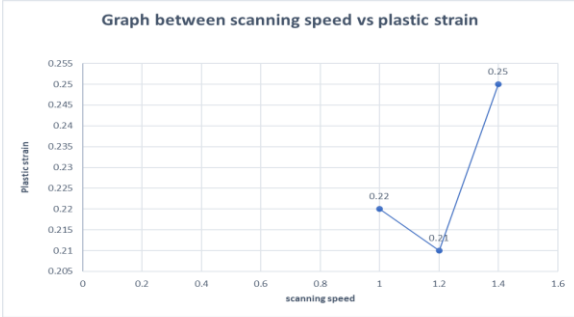
Graphical representation of mechanical properties with respect to scanning speeds

The graph 1 is representation of displacement at different scanning speeds. scanning speed is taken on x-axis and displacement on y-axis. The maximum value of displacement of 3.889×10^{-3}m is obtained at scanning speed of 1m/s. The minimum value of displacement of 3.198×10^{-3}m is obtained at scanning speed of 1.4m/s.



Graph1: Graph between scanning speed vs displacement

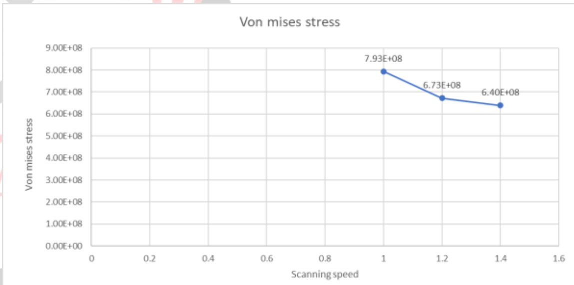
As the scan speed is less the metal powder fuses more than the requirement and it leads to more displacement.



Graph 2: Graph between scanning speed vs plastic strain

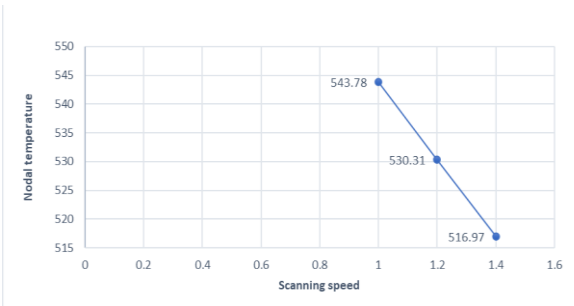
The graph 2 is representation of plastic strain at different scanning speeds. scanning speed is taken on x-axis and plastic strain on y-axis. The maximum value of plastic strain of 0.25 is obtained at scanning speed of 1.4 m/s. The minimum value of plastic strain of 0.21 is obtained at scanning speed of 1.2 m/s. Due to this, there will be a very large permanent deformation in the component after removing the part from the build plate.

The graph 3 is representation of von mises stress at different scanning speeds. scanning speed is taken on x-axis and von mises stress on y-axis. The maximum value of von mises stress of 7.933×10^8Pa is obtained at scanning speed of 1.0 m/s. The minimum value of von mises stress of 6.396×10^8Pa is obtained at scanning speed of 1.4 m/s.



Graph 3: Graph between scanning speed vs von mises stress

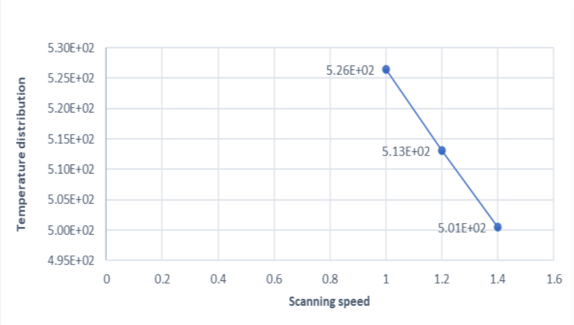
Stresses are decreased gradually when the laser speed is increased. As the scanning speed increases, the contact time of laser with the metal powder decreases. Hence, less stress value is obtained by increase in scan speed.



Graph 4: Graph between scanning speed vs nodal temperature

 DOI : 10.35291/2454-9150.2022.0259

The graph 4 is representation of plastic strain at different scanning speeds. scanning speed is taken on x-axis and nodal temperature on y-axis. The maximum value of nodal temperature of 543.78K is obtained at scanning speed of 1.0 m/s. The minimum value of nodal temperature of 516.97K is obtained at scanning speed of 1.4 m/s.



Graph 5: Graph between scanning speed vs temperature distribution

The graph 5 is the representation of plastic strain at different scanning speeds. scanning speed is taken on x-axis and temperature distribution on y-axis.

The maximum value of temperature distribution of 5.264×10^2K is obtained at scanning speed of 1 m/s. The minimum value of temperature distribution of 5.005×10^2K is obtained at scanning speed of 1.4 m/s. Nodal Temperature and temperature distribution are also decreased as the scanning speed is increased due to less concentration of laser with powder particles.

IV. CONCLUSION

3D printing technology is advanced manufacturing process in the field of production and rapid prototyping. The quality and dimensional accuracy of the 3D printed depends on the so many factors depend on the geometrical conditions of the component.

We have performed the 3D printing simulation to spur gear at different scanning speeds to study the effects of laser scanning speed on capturing the geometry.

By performing the optimization and 3D printing simulation we concluded that

1. The scan speed at 1m/s has large displacement value when compare to other scan speeds.
2. When compare to other scan speeds the plastic strain is more at scan speed of 1.4m/s.
3. At scan speed of 1m/s stress value is increased when compare to other scan speeds.
4. Nodal Temperature and temperature distribution are also decreased as the scanning speed is increased due to less concentration of laser with powder particles.

From above results even we get minimum values at scanning speed of 1.4m/s, it is observed that part with 1.2 m/s scanning would give us better quality of product because the part with 1.4m/s scan speed have more plastic deformation which leads to mechanical failure of spur gear.

So, it is concluded that the spur gear at scan speed of 1.2m/s will give better quality of the component.

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