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Gearbox Noise Reduction using Engineering Plastics Gears

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***Abstract:-* Our research has been engaged in the study of gear noise in a planetary gearbox used in miniature motion technologies. It is centered on analysis and relation between gear material and gear noise. To accomplish this work, a four stage planetary gearbox with four planet gears per stage was employed. The work aimed at investigating the difference between noise of a gearbox with metallic planet gears and the one with engineering plastic gears in low torque region. Variation in transmission error (TE) with plastic and metallic gears at different loads is also simulated, where it is observed that at lower load, the value of transmission error in plastic gear is very close to that of metallic gear, however at higher load TE in plastic gear increases substantially. Lower elastic modulus of plastic gears makes them resilient while meshing which helps them to damp the gear noise. Validation is done through noise test in an acoustic chamber. Test result confirms considerable reduction in gearbox noise when switched to engineering plastic gears due to their inherent noise dampening property. The paper reflects influence of gear material on noise and vibration spectrum. Analysis was also done to evaluate gear safety factors for the given operating torque which confirms engineering plastic gears to serve the given application life requirement.**

INTRODUCTION:

Today medical industrial segments demand miniature and portable equipment. Additionally the gearboxes used in medical field should necessarily be quiet in operation. The unpleasant noise in surgical instruments such as geared motor will have an adverse impact on its intended application. Low noise version of gearbox thus must be developed to fit the demand.

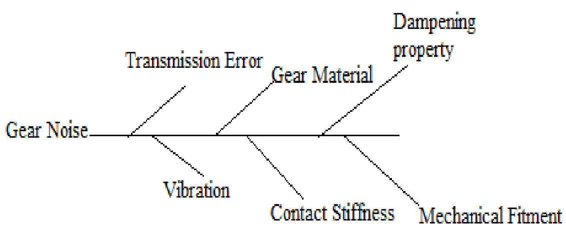

Fig 1. Factors influencing gear noise.

Various factors that can possibly affect the gear noise were studied. The focus was to select the best suited alternative among transmission error, gear material, surface roughness and bearing types to improve noise performance of gearbox. One cannot be certain of the exact reason of noise in the gearbox. So instead of trying to reduce the noise, an attempt has been made to damp it. Gear material was targeted to improve the noise performance of the gearbox. Moving further the study of gear materials directed us towards various alternatives including engineering plastics. Opportunities with plastic gears when compared with metal ones were lower elastic modulus, higher resilience, low weight and cost effectiveness. Low noise property of plastic gears explains their use in medical industrial equipment. This inherent property of engineering plastic gears is due to their low elasticity modulus and high resilience at meshing point [1] [2]. Noise and vibration measurement and signal analysis are important tools when experimentally investigating, gear noise because gears create noise at specific frequencies, related to number of teeth and the rotational speed of the gear [10]. Responsible factors for gear noise in general terms are inaccuracies, changes in magnitude, direction or the point of application of the force being transmitted by the gear teeth or combination of these factors [3]. Coefficient of friction of metal gear with plastic gear is higher as compared to metal gear with metal gear and increases with operating temperature. Furthermore the properties like elastic modulus decreases with temperature, alters the stiffness of gears and affects the kinematic behavior of gear teeth [4]. Besides these properties of plastic gear, its excellent noise dampening properties result in a quieter-running gear. A study on transmission error showed that the correlations between transmission error, sound pressure level and load of plastic to plastic and metallic to metallic gears are quiet similar [5] whereas the TE in plastic gears increases with load. A four stage planetary gearbox with four planet gears per stage was put for noise and vibration test. Noise level test with metallic planet gears and that with engineering plastic planet gears was carried out. An engineering plastic Polyoxymethelene (POM) material is used for planet gears. The noise level comparison between the two materials showed significant lower noise with POM planet gears than the metallic ones. The excellent noise dampening properties of plastics result in a quieter-running gear.

Transmission Error Simulation.

Dr. Donald R. Houser explains, the teeth contact occurs off the line of action due to excessive tooth deflection in plastic gears and directly affects the transmission error behavior [6]. According to several studies, there is a correlation between mesh harmonics of transmission error and sound pressure level generated by metal gears. This study presents results used to check this correlation in plastic gears. Transmission error, the main excitation mechanism in gears is one that is prominently responsible for gear noise. Thus it was studied and simulated using KISSsoft - Gear simulation and analysis software, which gives the following results.

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Working points:

Gearbox type = planetary
Operating torque = 0.0075Nm
Gear materials (Under Test)

- Engineering plastic(POM)-with Steel
- Steel with Steel

Motor input speed = 10000 rpm.
No. of stages = 4
Operating voltage of motor = 55V

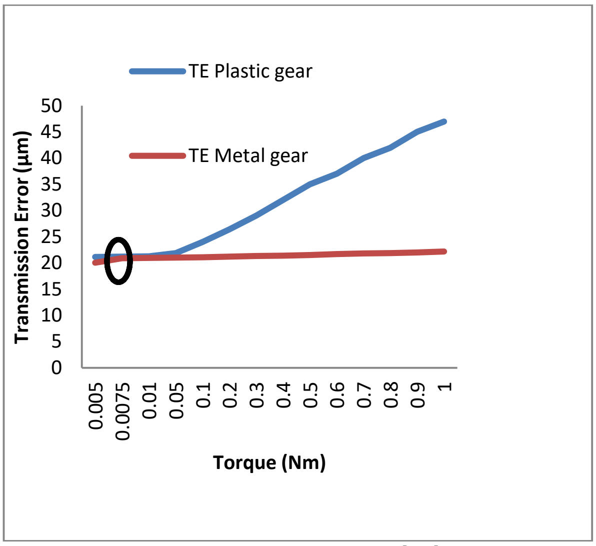

Fig 2. Transmission error vs load

KISSsoft simulation for transmission error was carried out using engineering plastic and metallic gears with different torques. The simulation result suggests that the transmission error value in engineering plastic gears is close to that of metallic gears at the given operating torque of 0.0075 Nm.The value increases substantially when the torque is increased above 0.1Nm. this is due to lower modulus of engineering plastic making them less stiff, thus increasing transmission error.
In case of metallic gears the transmission error remains almost unchanged even at higher torque of 0.1Nm. Infering this, if the operating torque is in the low torque region which in this case is 0.0075 Nm, metallic gears can be replaced by engineering plastic gears with same transmission error for the said application.

Gear Life and load on gear.
K Mao states, through extensive experimental investigations and modelling on gear surface temperature variations, a general relation has been built up between gear surface temperature and gear load capacity. An approach for acetal gear transition torque prediction has been proposed and this method is based on the link between polymer gear wear rate and its surface temperature. The method has been related to test results under different operating speeds and gear geometries. Good agreements have been achieved between the proposed method predictions and experimental test results [11]. Gear stress and Life analysis simulation was carried using KISSsoft software.For Plastic gear, simplified calculation as per ISO-6336-3-2007 was completed.

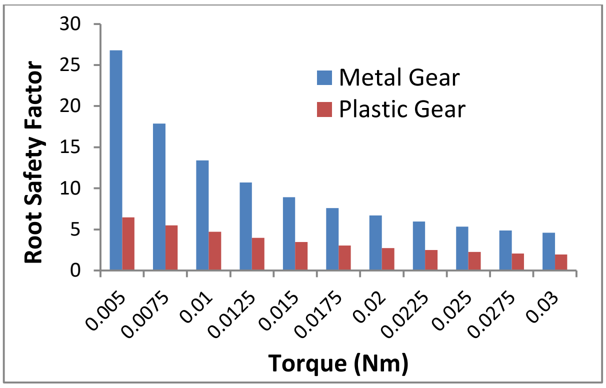

Fig 3(a).Root safety factor of plastic & metal gears with torque.

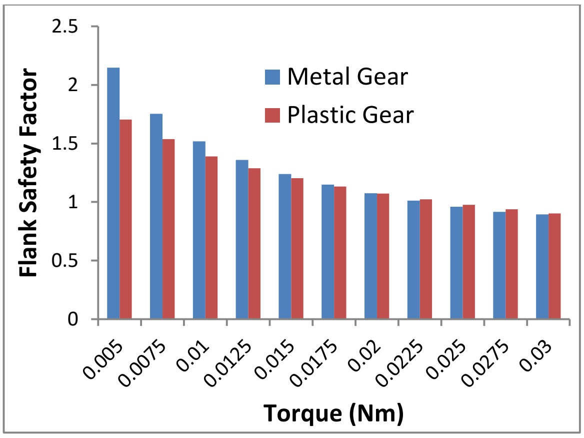

Fig.3(b).Flank safety factor of plastic & metal gears with torque.

Criteria		Tooth Root Safety	Tooth Flank Safety
Gear Material	Metal	18	1.7
	Plastic	6	1.5

Table 1. Safety factors of steel & plastic gears.

There is considerable reduction in Tooth root safety and slight redction in Tooth Flank Safety , However above Safety Factors are within the acceptable limit specified according to ISO/DIN Criteria of “Safeties depending on size” for these kind of precision gearing module. The torque that acts in the initial stage is very low as compared to the torque applied at the output stage. This makes it possible to use engineering plastic planet gears in this low torque stage. The graphs [3(a) & 3(b)] determine the safety factors of metal and plastic gears to confirm the sustainability of both the materials at the applied torque of 0.0075Nm. The simulation assures life for continnuous operation of 1200 hours of plastic gears at the specified torque.

Gearbox Noise measurement.
Noise from the gears in the gearbox is produced mainly i) at the instant of change over of contacting teeth and ii) During the process of meshing of gear teeth [9]. So maximum gear noise has to be damped at the time of meshing. This idea of dampening gear noise leads to the use of engineering plastic gears. Noise and vibration test has been conducted in an acoustic chamber. The set up consists of

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1. Motor and gearbox assembly
2. Fast Fourier Transform(FFT) Analyser
3. Noise sensor
4. Power supply
5. Vibration sensor and cable assembly
6. Acoustic chamber

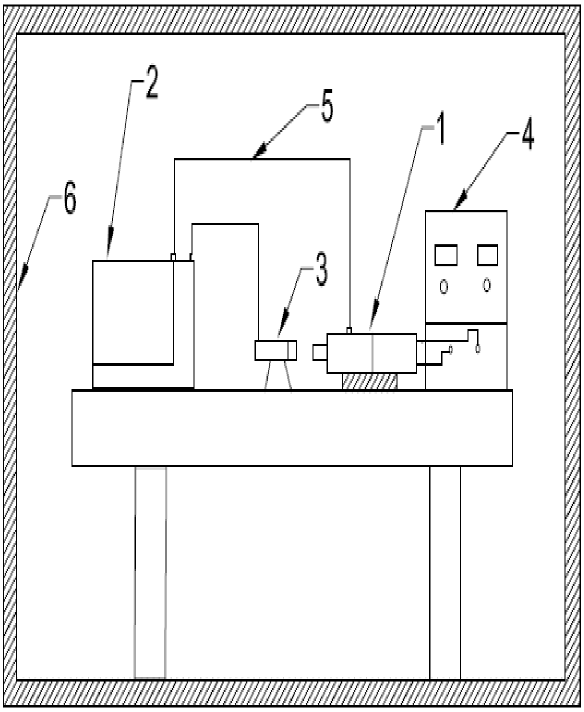

Fig 4. Noise and vibration set up.

Gearbox and motor composite was connected to the power supply. A vibration sensor was mounted on gearbox and the connection was made with FFT analyser to plot the vibration graph. Noise sensor connected to the FFT analyser was put at a distance of 10 mm from the gearbox to sense the gear noise. The input speed to gearbox was 5000 rpm, the gearbox used was a 32 mm diameter four stage planetary gearbox with four planet gears per stage. The motor gear assembly was in no load condition, and a voltage of 20V was applied to the motor. The readings of noise and vibration were noted using metal planet gears and engineering plastic planet gears in the initial stage i.e. in low torque zone while keeping materials of Sun and Ring gear same as earlier i.e in metal.

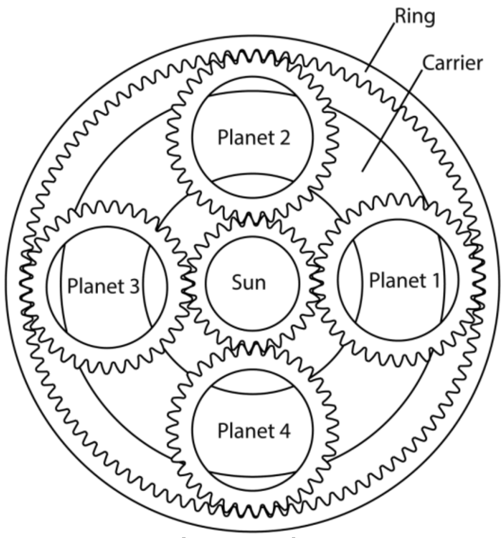

Fig 5. Planetary gearbox section

The test graphs were plotted showing the variation in noise and vibration of steel and plastic gears.

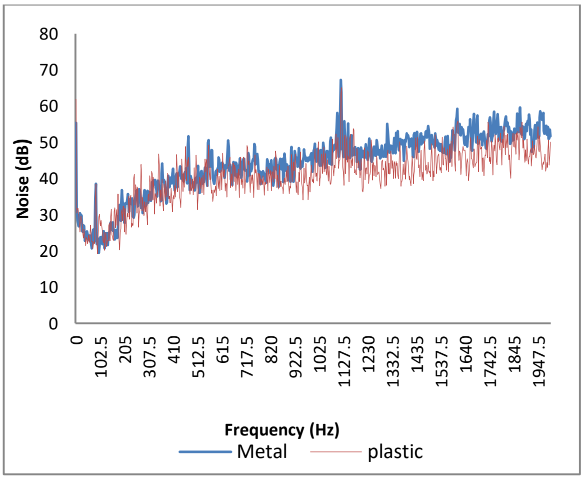

Fig 6. Noise vs frequency of metal and plastic gears

Observation

It was observed from the plot shown in Fig. 5 that the noise fluctuation in plastic gears with frequency on a frequency band of 2000Hz is more as compared to metallic gears. However the the overall noise level in metal gears is more than plastic gears. Moreover the noise in metallic gears increases with frequency more steeply compared to engineering plastic gears. The frequency band was selected based on the fundamental frequency at which the gears were operating. The overall noise level using engineering plastic gears is 73.83dB and that using metallic planet gears at same frequency and working points is 77.15dB.

Contact stiffness:

Comparing contact stiffness of metal and engineering plastic gears, we found during simulation that contact stiffness of metallic gears is on higher side.

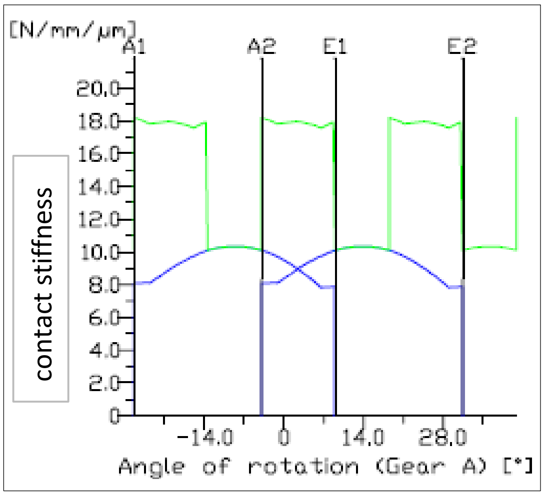

Fig 7(a) Contact stiffness of metallic planet gear.

Metallic planet gears shows minimum contact stiffness of 10.2 N/mm/µm, maximum of 18.2 N/mm/µm, and mean 14.2 N/mm/µm.

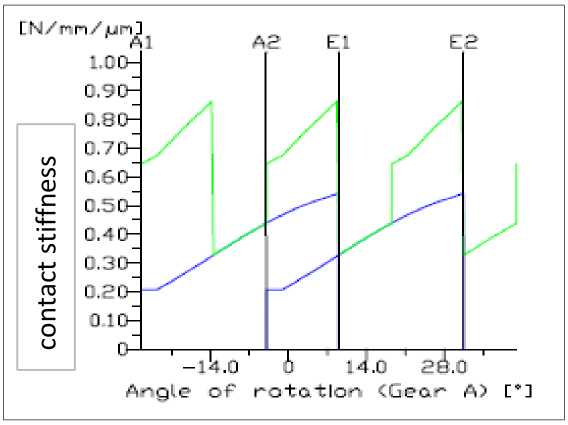

Fig 7(b). Contact stiffness of engineering plastic planet gear.

Whereas for the same working points plastic gears show minimum contact stiffness of 0.33 N/mm/µm, maximum of 0.88 N/mm/µm, and mean 0.605 N/mm/µm. Due to lower elastic modulus of engineering plastic gears, the stiffness is low. This make them competent to damp the noise and vibration when we opt for plastic gears at lower loads.

CONCLUSIONS:

Based on the simulations done and experiments conducted, following conclusions can be drawn.

1. Engineering Plastic(POM) gears can be used in the low torque zone in this case between 0.007Nm to 0.07Nm at a speed of 10000 rpm.
2. From the results of the simulation it is observed that, transmission error in plastic gears and metallic gears is same at low torque, however it increases more rapidly in plastic gears when torque applied is increased.
3. Plastic gears have an inherent noise dampening property due to lower elastic modulus. Based on results of experiment it can be stated there is reduction of upto 3 dB noise level with the use of engineering plastic (POM) as compared to metallic gears.

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