Comparative Vibration analysis of Nylon Phased, non- Phased Spur Gears and ABS Integrated, Non-Integrated Phased Spur Gears

R. E. Kedare[1], S. B. Patil[2]

[1] PG Student, Department of Mechanical Engineering, MET's IOE, Nashik, Maharashtra, India
[2]Associate Professor, Department of Mechanical Engineering, MET's IOE, Nashik, Maharashtra, India

ABSTRACT

Plastic gears are finding increasing applications in variety of engineering applications, like 2-D printing machine, 3-D printing machine, offset printers, packaging machines etc. The application demands a vibration free drive. Earlier application of metal gears such applications has been replaced by that of moulded plastic gears. Moulded plastic gears used in such application offer a similar vibration characteristic similar to metal gears hence vibration reduction techniques need to apply to solve vibration problem. The internal excitation caused by the variation in tooth mesh stiffness is an important characteristic in causing vibration. In this new method variation in mesh stiffness will be reduced the by adding another pair of gears with phasing. Phasing reduces the variation in the mesh stiffness of the gear, because each gear compensates for the variation in the other's mesh stiffness. To find out the effect of phasing, the experimental set-up was built and the overall vibrations of gears are measured over a wide range of speedsThe gears geometry for phasing is developed using Unigraphics Nx-8, and strength analysis is done using ANSYS workbench 16.0. The vibration characteristics such as displacement and acceleration are measured in either cases using a Vibrometer VB-27. The experimental investigations showed comparative analysis of reduction in vibration gear pairs using proposed method.

Keyword: - *Nylon, ABS Polymer, FDM, Gear Phasing, Spur Plastic Gear, Vibration, Vibrometer.*

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1. INTRODUCTION

Gears generate vibrations that decreases durability, reliability, and fatigue life. Gear noise, a result of vibration excited by the meshing gear teeth, has adverse effects on the perceived quality. Vibration reduction, therefore, has been of tremendous practical importance. In this present work experimental set up is developed to study effect of phasing on spur gears produced by Injection moulding and FDM process.

1.1 Relevance & Significance

The reduction of gear vibration and noise has received much attention because gears are basic components in many common mechanical systems. Because the internal excitation caused by the variation in tooth mesh stiffness is a key factor in causing vibration, most of this attention has been directed to the modification of gear teeth. However, such passive methods have limitations due to the load dependence of the modifications. A new method of reducing gear vibration was analysed using a simple spur gear pair with phasing. In this new method variation in mesh stiffness will be reduced the by adding another pair of gears with phasing. This reduces the variation in the mesh stiffness of the gear, because each gear compensates for the variation in the other's mesh stiffness[1, 2, 3].

1.2 Need of Investigation

- Plastic gears are used in variety of applications like 2-D printing machine, 3-D printing machine, offset printers, packaging machines etc. which demands vibration free drive. Hence to reduce vibrations, new methods of reduction in vibration needs to be investigated.
- Phasing of gears in metal spur gears has shown reduction in vibrations. Hence it's important to study effect of phasing on plastic spur gears.

- To do comparative analysis Nylon, ABS polymer material are chosen to study effect of phasing on spur gears

1.3 Phasing Gears

During meshing variation of tooth mesh stiffness is a principal source of internal excitation force and vibration. To reduce the variation in m1.3esh stiffness modifications of the optimal tooth shape and contact ratio (CR) can be studied. Major variations in stiffness are caused by changes in meshing pair numbers, usually in the range 1.0–2.0 for normal spur gears. Due to the integer numbers of gear teeth, it is impossible to avoid this variation. To reverse the stiffness functions of the two pairs, another meshed and phased gear pair is added, these phasing gears will complement the primary gears and reduce the mesh stiffness variation. The phasing gear pair is composed of two gears half the width and half the pitch phasing of the primary gears. Fig. 1 shows Model of gears with phasing [1, 2, 3, 4, 5, 6, 7, 8].

Fig -1 Model of gears with phasing

1.4 Fused Deposition Modelling

(FDM) is a rapid prototyping (RP) process that integrates computer aided design, polymer science, computer numerical control, and extrusion technologies to produce three dimensional solid objects directly from a CAD model using a layer by layer deposition of molten thermoplastics extruded through a very small nozzle. FDM is one of the few commercially available rapid prototyping technologies offers the possibilities of producing solid objects in different materials like metals and composites [9,10].

The FDM systems, currently fabricate parts in ABS, investment casting. FDM machines which is used in this study, allows building layer thickness from 0.178 mm to 0.356 mm and the achievable accuracy in the parts is ±0.127 mm. The process starts with the creation of a part on a CAD system as a solid model or a closed surface model. The models converted into an STL file using a specific translator on the CAD system. The STL file is then sent to the FDM slicing and pre-processing software called up-mini, where the designer selects proper orientation, creating supports and slicing and other parameters to prepare the part program for sending to FDM machine. A proper orientation of STL model is necessary to minimize or eliminate supports. The STL file is then sliced into thin cross sections at a desired resolution, creating an SLC file. Each slice must be a closed curve. So any unclosed curves are edited and closed. Supports are then created if required, and sliced.

The application of the FDM process to the phasing concept is with the view that gears manufactured in the phased condition will act as an integral unit as compared to the separate units as in case of moulded gear, which can further help reduction in vibration. [9, 10, 11, 12, 13].

2. PROBLEM STATEMENT & OBJECTIVE

Plastic gears are finding increasing applications in variety of engineering applications, like 2-d printing machine, 3-d printing machine, offset printers, packaging machines etc. The application demands a vibration free drive. Earlier application of metal gears such applications has been replaced by moulded plastic gears. Moulded plastic gears used in such application offer a similar vibration characteristic as that of metal gears hence vibration reduction techniques need to apply to solve vibration problem.

A new method of reducing gear vibration was analysed using a simple spur gear pair with phasing. Reduction in the variation in mesh stiffness is achieved by adding another pair of gears with half pitch phasing.

2.1 Objectives

- Modeling and analysis of the spur gear with moulded (Nylon) material and integral gears produced by 3-D printing process (Acrylonitrile butadiene styrene (ABS) polymer).
- Design and development of test-rig & its components to test the either gear pair in non-phased and phased condition.
- Test & Trial on the gear arrangement with and without phasing for the moulded gear and FDM gears of integral unit in phasing condition to determine vibration parameter values such as displacement and acceleration.
- To do Comparative analysis of four cases such as Nylon Gears with and without phasing, ABS gears integrated and non-integrated with phasing.

In the current work a simple Spur Gear pair produced by following two different production processes will be used for analysis purpose.

i. Injection Moulding Process- In this process the gears will be produced using Nylon-6 material with and without phasing. Two separate gears will be used to make a phasing unit of gear.

ii. FDM Process- In this process the gears will be produced using ABS (Acrylonitrile Butadiene Styrene) Polymer material. In this case the FDM process will be used to make an integral part of phased condition gear instead of two separate gears as in the case of moulded gears. The results in both cases will be compared.

The project will deal with modeling and analysis of vibration reduction mechanism using moulded gear pair with and without phasing using Nylon-6 and the integrated non-integrated phased spur gears produced by FDM Process using ABS polymer

2.2 Flow Chart of Methodology

Literature review
↓
Defining the problem and objectives
↓
Selection of different parts of test rig
↓
Design and analysis of Input and Output shaft on Ansys
↓
Design and analysis of Nylon and ABS Spur gears on Ansys
↓
Manufacturing and fabrication of different parts of test rig
↓
Manufacturing of Nylon (Injection Moulding) & ABS (3D Printing) gears
↓
Testing of Nylon Spur gear without Phasing
↓
Testing of Nylon Spur gear with Phasing
↓
Testing of ABS Polymer Integrated phased Spur gear
↓
Testing of ABS Polymer Non-Integrated phased Spur gear
↓
Result and Discussion

3. PARTS OF TEST RIG

- Input Shaft
- Output Shaft
- Bearings
- Bearing Housings
- Base Plate
- Dynamometer Pully
- Motor
- Base Frame
- Spur Gears(Nylon)
- Spur Geras(ABS)
- Digital Tachometer
- Vibrometer

Different parts of test rig are designed, developed and analyzed in Ansys. Standard parts are selected as per need and purchased.

3.1 Analysis of Nylon-6 Spur gear

Geometry was developed using Unigraphix Nx-8 and the step file was used as input to Ansys Work bench. Ansys workbench free mesher was used for meshing and the obtained mesh parameters and boundary conditions are as shown in Fig. 2.

Statistics	
Nodes	28122
Elements	15756
Mesh Metric	None

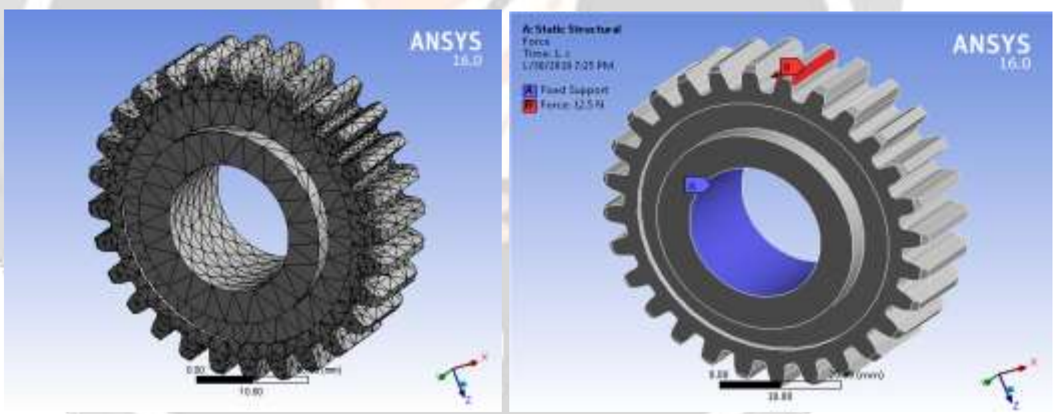

Fig -2 Meshing & Boundary conditions of Nylon Spur gear in Ansys

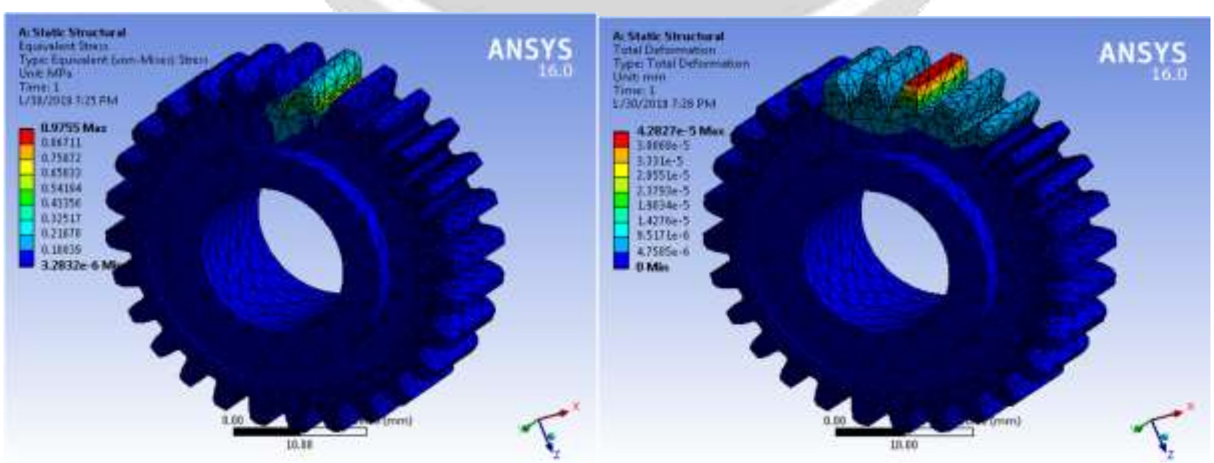

Fig -3 Maximum Stress induced & Maximum deformation in Nylon Spur gear

The maximum Von-misses stresses in the part are 0.975 MPa, which is far below the allowable value 66 MPa hence the part, is safe under given loading conditions. The maximum deformation in the part is 4.287e-5-mm , which is very negligible hence the part is safe.

3.2 Analysis of Integrated Phased Spur gear

Geometry was developed using Unigraphix Nx-8 and the step file was used as input to Ansys Work bench. Ansys workbench free mesher was used for meshing and the obtained mesh parameters and boundary conditions are as shown in Fig. 4.

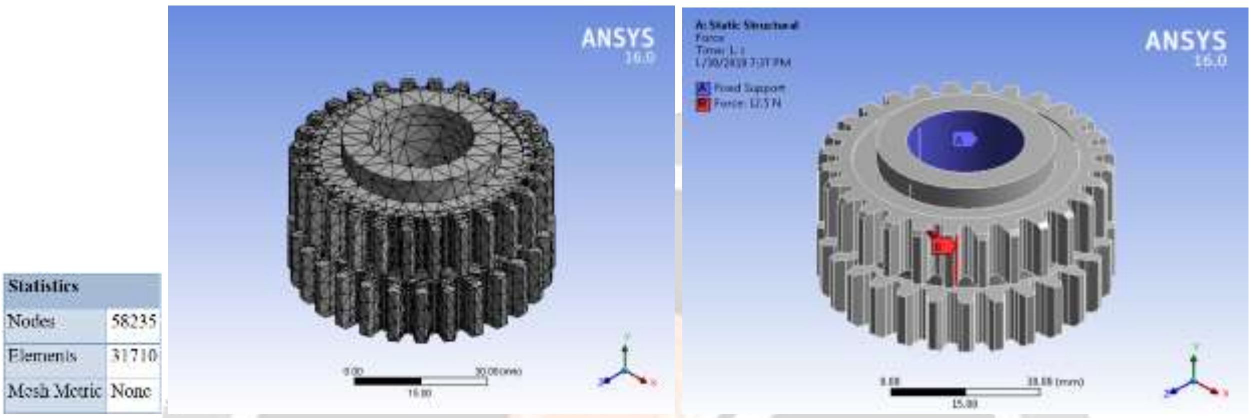

Fig -4 Meshing and Boundary conditions of ABS integrated phased Spur gear in Ansys

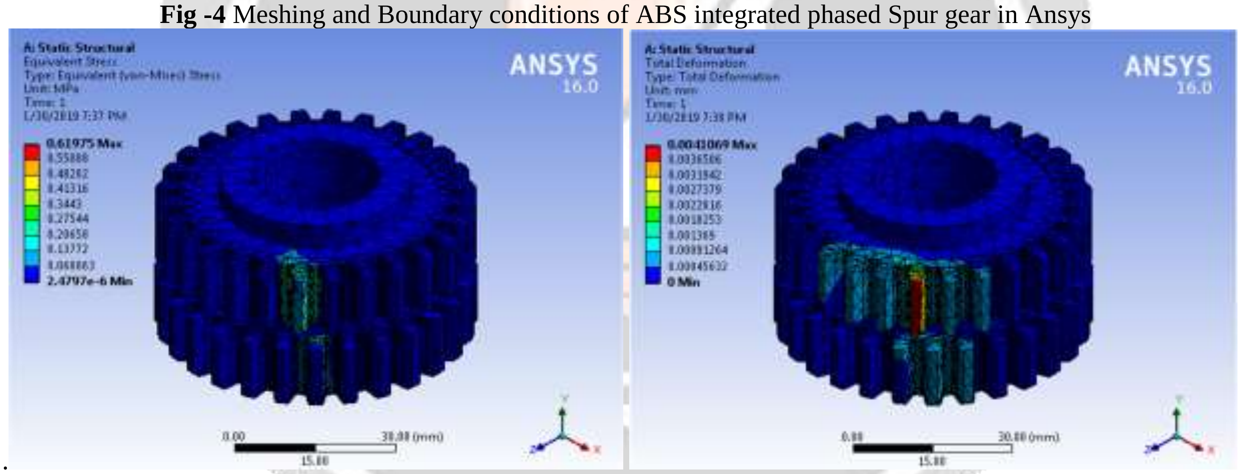

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Fig -5 Maximum Stress induced & Maximum deformation in Nylon Spur gear ABS integrated phased Spur gear

The maximum Von-misses stresses in the part are 0.61975 MPa, which is far below the allowable value 36 MPa hence the part, is safe under given loading conditions.The maximum deformation in the part is 0.004mm, which is very negligible hence the part is safe.

4. EXPERIMENTATION AND MEASURMENT

4.1 Experiment Sequence

[1]Analysis of Input and Output shafts using Ansys.

[2]Analysis of Nylon and ABS spur Gears using Ansys.

[3]Testing of Nylon Spur gear without Phasing on experimental set up

[4]Testing of Nylon Spur gear with Phasing on experimental set up

[5]Testing of ABS Polymer Integrated phased Spur gear on experimental set up

[6]Testing of ABS Polymer Non-Integrated phased Spur gear on experimental set up

4.2 Experimental Setup

All parts are manufactured and assembled as shown in fig. 8. Reading using vibrometer are taken for different load & speed conditions.

Fig -6 Nylon Spur gear with and without Phasing arrangement

Fig -7 ABS Polymer Integrated and non-integrated phased Spur gear arrangement

5. RESULT & DISCUSSION

Vibration data are collected from a gear-set keeping all operating conditions similar for a comparison between all four cases in order to gain further insight into the vibration signatures. To study the effect of phasing number of trial were conducted by using Vibrometer by varying load from 1.5Kg to 5Kg and changes in speed, torque and resulting vibration displacement and vibration acceleration recorded.

Table 1 Readings for Nylon Gears without Phasing

Sr. No	Load (kg)	Speed (rpm)	Torque (N-m)	Vibration(disp) mm	Vibration(acc) mm/sec2
1	1.5	1389	0.50031	1.1568	4.639902
2	2	1382	0.66708	1.1592	4.542582
3	2.5	1370	0.83385	1.1698	4.528025
4	3	1358	1.00062	1.2042	4.463579
5	3.5	1352	1.16739	1.2183	4.40264
6	4	1271	1.33416	1.3212	4.233575
7	4.5	1096	1.50093	1.6832	3.86412
8	5	956	1.6677	2.0613	3.56434

Table 2 Readings for Nylon Gears without Phasing

Sr. No	Load (kg)	Speed (rpm)	Torque (N-m)	Vibration (disp) mm	Vibration(acc) mm/sec2
1	1.5	1394	0.50031	1.145168	4.529902
2	2	1388	0.66708	1.152117	4.502582
3	2.5	1376	0.83385	1.166248	4.448025
4	3	1364	1.00062	1.1807	4.393579
5	3.5	1358	1.16739	1.18805	4.366399
6	4	1284	1.33416	1.28608	4.033575
7	4.5	1104	1.50093	1.598632	3.244962
8	5	964	1.6677	1.952839	2.656389

Table 3 Readings for ABS Polymer Integrated phased Spur gear

Sr. No	Load (kg)	Speed (rpm)	Torque (N-m)	Vibration (disp) mm	Vibration (acc) mm/sec2
1	1.5	1400	0.50031	1.021	4.272
2	2	1384	0.66708	1.08	4.27
3	2.5	1376	0.83385	1.102	4.268
4	3	1368	1.00062	1.118	4.296
5	3.5	1360	1.16739	1.125	3.867
6	4	1296	1.33416	1.126	3.642
7	4.5	1120	1.50093	1.128	2.861
8	5	1080	1.6677	1.142	2.322

Table 4 Reading for ABS Polymer non-integrated phased Spur gear

Sr. No	Load (kg)	Speed (rpm)	Torque (N-m)	Vibration (disp) mm	Vibration (acc) mm/sec2
1	1.5	1398	0.50031	1.131	4.243
2	2	1378	0.66708	1.142	4.295
3	2.5	1368	0.83385	1.156	4.306
4	3	1358	1.00062	1.164	4.322
5	3.5	1352	1.16739	1.178	4.031
6	4	1286	1.33416	1.202	3.861
7	4.5	1092	1.50093	1.356	3.082
8	5	972	1.6677	1.512	2.454

- The comparison of the Nylon Gears with and without phasing shows that the Nylon gears with phasing show lower displacement and acceleration.
- The comparison of the Nylon Gears with the ABS –non integrated gears shows that the ABS gears show lower displacement and accelaration at higher load (reduced speed) thereby showing better performance than the nylon gears.
- The comparison of all four arrangements shows that the ABS integrated phased gears shows lowest displacement and accelaration as compared to other three arrangements.
- ABS integrated phased gears shows better perfomance among all arrangements.

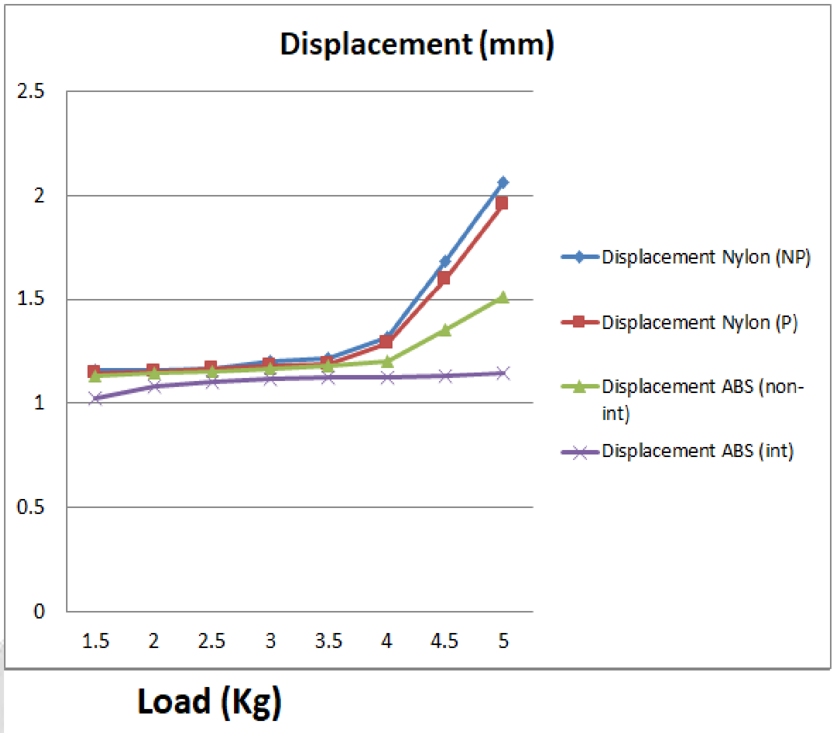

Chart 1 Displacement Vs Load (Comparison)

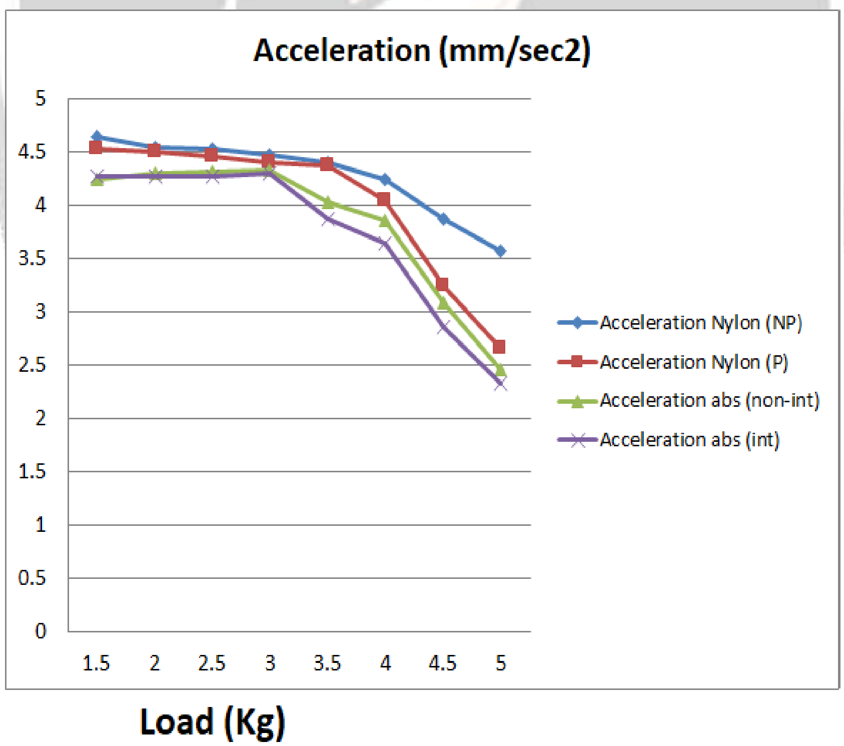

Chart 2 Acceleration Vs Load (Comparison)

5.1 Optimization of Results

Based on the experimental results, ABS integrated phased gears shows best results. Both displacements and acceleration values are lower. Hence ABS integrated phased gears arrangement is selected for optimization. Important parameters load, input speed have been selected for Taguchi‟s design of experiment technique.

Table 5: Process Variables and their Levels

Parameter	Level-1	Level-2	Level-3	Level-4
load (kg)	1	2	3	4
Speed rpm	600	800	1000	1200

Table 6: Response Table for Signal to Noise Ratios

Level	Load	Speed
1	1.26097	0.29865
2	0.99403	0.38724
3	0.34256	0.89498
4	-1.0031	0.01357
Delta	2.26409	0.8814
Rank	1	2

Table 6: Response Table for Means

Level	Load	Speed
1	0.865	0.9725
2	0.8925	0.96
3	0.9625	0.905
4	1.125	1.0075
Delta	0.26	0.1025
Rank	1	2

5.2 Validation of Optimization result

After finding optimal values of load and input speed by Taguchis DOE method. Vibration displacement is recorded for ABS integrated phased gears arrangement.

Table 7 Reading for Optimal Values of Load and speed

Sr. No	load(kg)	Speed (rpm)	Vibration (disp) mm
1	1	1000	0.85

As the optimal value of displacement for derived optimal parameters of Load and speed is in good agreement with the experimental value derived after test under optimal conditions by experiments and hence validated.

Conclusion

The main objective of this study was to prepare the experimental set-up to compare the vibration parameters in spur gear pair produced by injection moulding and FDM process with normal and phasing arrangement using Vibrometer. This objective was achieved with the help of extensive experimental investigations. Experimental results showed a significant reduction in overall vibration level at different speeds for phasing gears with closed match. It is observed that vibrations in gears produced by 3D printing process i.e. FDM process shows lower vibrations as compared to gears produced by injection moulding process. Thus, a new method of phasing gears is proposed for reduction of vibration in spur gears by reducing the variation in mesh stiffness, which is a principal source of internal excitation in gear systems. Hence this method can be used to suppress the vibrations in small plastic gearboxes used in precise appliances like 2D, 3D printing machines.

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