Comparative Vibration analysis of Spur Gears with Phasing Produced by Injection Moulding and FDM Process

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 Earlier application of metal gears such applications has been replaced by that of moulded plastic gears.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 speeds. Readings are taken for nylon moulded gear pair, and integrated ABS polymer gear pair produced using FDM Process. The 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 RMS displacement and acceleration are measured in either cases using a Vibrometer VB-27. The experimental investigations showed considerable reduction in vibration in both Nylon phased gear pair & ABS integrated phased gear pairs using proposed method.

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

---

1. INTRODUCTION

Several vibration reduction techniques are proposed by various researches considering that vibrations in spur gear drives is a persistent and dominant problem in many a gear drives. Thus the subsequent section throws light on the necessity of project and the problems with the existent methods of vibration reduction.

1.1 Necessity

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. Active methods for adapting to changing operating conditions using piezoelectric actuators or magnetic bearings have also been proposed. However, these methods also have limitations in that they require additional actuators, external power, and signal processing [1, 2, 3, 4].

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 Phasing Gears

During meshing variation of tooth mesh stiffness is a principal source of internal excitation force and vibration. To reduce the variation in mesh 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].

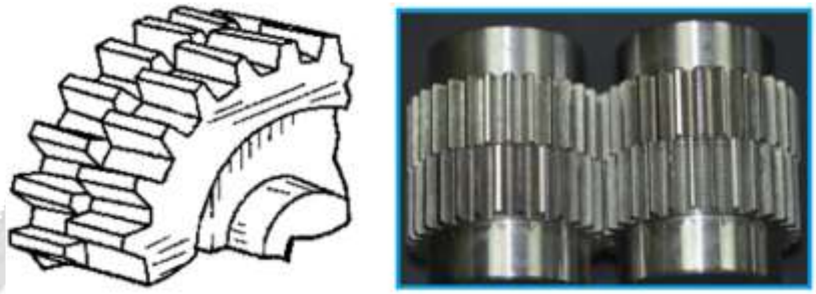


Fig -1 Model of gears with phasing

1.3 What is 3-D Printing Technology?

Fused deposition modelling (FDM) is an additive manufacturing technology namely used for modelling, prototype creation, and production applications. It is well known technique used for 3D printing. FDM works on an "additive" methodology in which material layers are laid down; a plastic filament or metal wire is unwound from a coil and supplies material to produce a part. The technology was developed by S. Scott Crump in the late 1980s and was commercialized in 1990. It is also sometimes called Plastic Jet Printing (PJP). [9, 10].

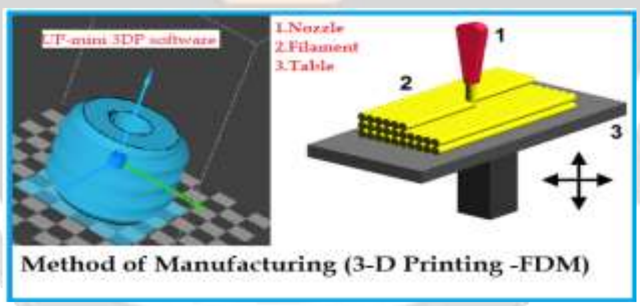


Fig -2 FDM Method

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. Supports can also be created as part of the CAD model and imported as part of the STL file. FDM machine tip to follow specific tool paths, called roads, to deposit the extruded material to create each cross section material on a foam foundation until the part is completed. The part is then taken out supports are detached carefully, and is ready for use.

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].

1.5 What is ABS Plastic?

Acrylonitrile Butadiene Styrene (ABS) is an opaque thermoplastic and amorphous polymer. "Thermoplastic" has to do with the way the material responds to heat. Thermoplastics become liquid at a certain temperature. They can be heated to their melting point, cooled, and re-heated again without significant degradation. Instead of burning, thermoplastics like ABS liquefy which allows them to be easily injection molded and then subsequently recycled [12].

1.6 ABS for 3D Printing and Prototype Development

Creative Mechanisms uses the Fused Deposition Modeling 3D printing process over other "printing" technologies (such as SLA, SLS, and SLM) because ABS parts are readily available. Our FDM machine uses ABS plastic which allows us to be certain that there will be no major hold-ups due to material when transitioning from prototype to production. It is often chosen because it is a good middle-ground option for a huge number of applications. ABS is easily machined, sanded, glued and painted. This makes it a great material for prototyping [12].

2. PROBLEM FORMULATION & 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. Presently no method for vibration reduction is available and with moulded gear introduction of vibration in gear drive leads to gear tooth failure and or subsequent failures of drive.

2.1 Solution

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.

2.2 Objectives

Following are the objectives of proposed work

- Modeling and analysis of the spur gear with moulded (Derlin) material and integral gears produced by 3-D printing process (Acrylonitrile butadiene styrene (ABS) polymer).
- Design and development of test-rig components to test the gear pairs in phased condition.
- Test & Trial on the gear arrangement with phasing for the moulded gear and FDM gears of integral unit in phasing condition to determine vibration parameter values such as displacement and acceleration.
- Determination of vibration reduction factor

3. METHODOLOGY

3.1 Mechanical Design and Development:

- System design as to arrangement of gears in phasing conditions. Flexibility of set-up should be considered to operated set-up with equal ease in both conditions
- Design and geometrical derivations of the input and output shafts
- Design and development of gear train.
- Selection and design of loading arrangement.
- Selection and geometrical profile of phasing mechanism on input and output shaft.
- Selection of motor drive transmission for testing purpose under various speed conditions
- Selection loading arrangement in the form of dyno-brake with suitable load indicator.
- Design of the various components of test-rig for strength considerations using theoretical formulae method.
- Validation of theoretical strength calculations for critical components like input shaft, output shaft , using ANSYS

3.2 Experimental analysis:

- Testing of gears in the phasing conditions to determine vibration in input housing side and output housing side.
- Determination of Vibration reduction factors. (Displacement, acceleration) will be measured using Vibrometer.
- Interpretation of results will be done to suggest the modifications to improve the design of input – output shaft arrangements for application of gearing in phasing conditions.

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 phasing using Nylon-6 and the integral gears in phasing condition produced using FDM Process using ABS polymer

3.3 Different parts of Test rig

A) Input shaft: The input shaft is made of high grade steel EN24 material, it holds one pair off the spur gears. The Input shaft is held in ball bearings 6004 ZZ at either ends.

B) Output shaft: The output shaft is made of high grade steel EN24 material, it holds one pair off the spur gears. The Output shaft is held in ball bearings 6004 ZZ at either ends.

C) Bearings: Four ball bearings are used in the project. Single row deep groove ball bearing 6004zz is used at each end of shaft. Bearings are held in the bearing housings which are fitted on to the bearing housing holders.

D) LH/RH bearing housings: These are round members of the system that support the above two shafts in ball bearings, the bearings on the output shaft are appropriately locked, they are mounted on housing plates.
E) Base plate: The base plate is the base member that houses the entire assembly of system. The housings are bolted to the base plate.

F) Dynamometer Pulley: The dynamometer pulley is fastened to the output shaft of the system. The rope is wound on the pulley with its one end fixed to the drum whereas the other free end carries the load.

G) Motor: The drive motor is 230 volt motor that drives an open belt drive with ratio 1:5 reduction
Specifications of motor are Power 50 watt, Speed = 0 to 6000 rpm, TORQUE = 0.08 N-m

H) Base Frame: Base frame comprises of the base plate and base frame structure both made from mild steel. Square pipe of (20x20) mm cross-section and 1.6 mm thickness is used for frame structure.

I) FDM Phased Gear: FDM phased gears are prepared from ABS polymer and the process used for manufacture is fused deposition method

J) Spur Gears (Nylon 6): The concept of gear phasing is in the position of teeth while in mesh, a phase shift of 6.43 degree in position of the keyway on the gear which enable to get a phase shift in assembly on the shaft. The gears are made of Nylon 6, 2 module and 28 teeth. Gers have been prepared by injection moulding process.

3.4 Analysis of Input & Output Shaft

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 are as below

Statistics	
Nodes	10148
Elements	5779
Mesh Metric	None

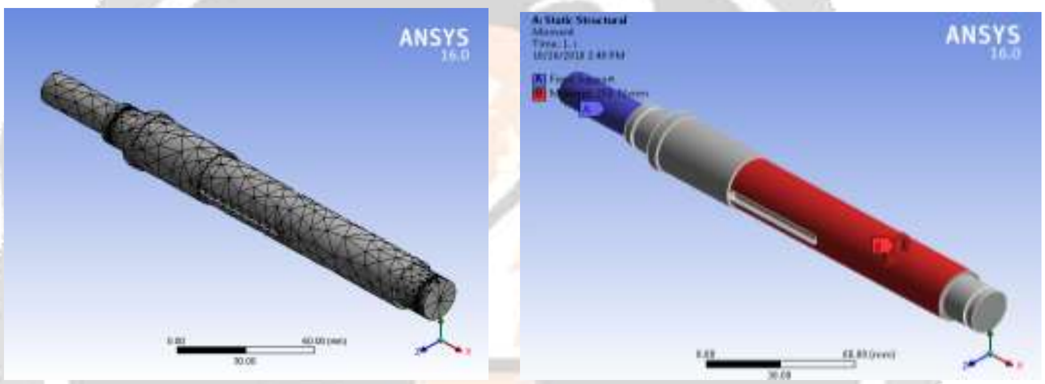


Fig -3 Meshing & Boundary conditions of Input shaft in Ansys.

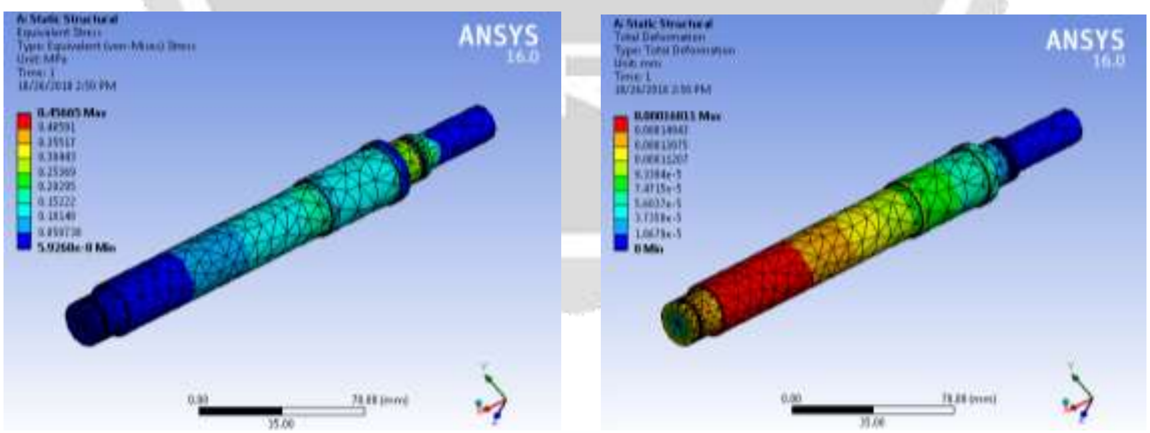


Fig -4 Maximum Stress induced & Maximum deformation in Input shaft

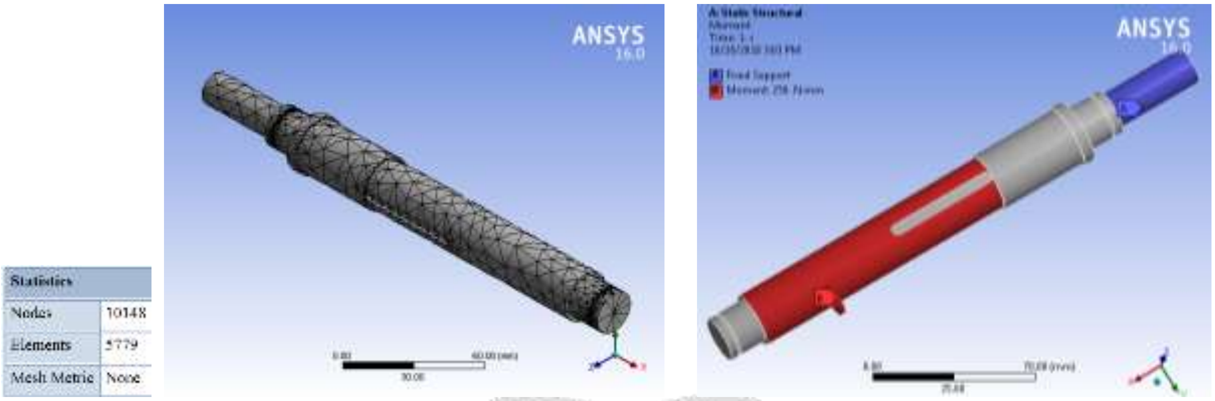


Fig -5 Meshing & Boundary conditions of Output shaft in Ansys.

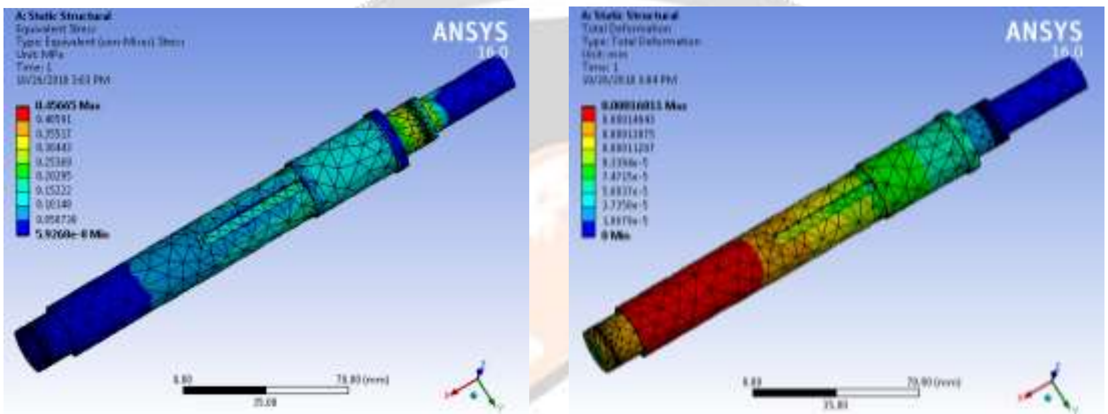


Fig -6 Maximum Stress induced & Maximum deformation in Output shaft

Table -1: Result of analysis

Part Name	Maximum theoretical stress N/mm2	Von-mises stress N/mm2	Maximum deformation mm	Result
Input/Output Shaft	0.310	0.456	0.00016	safe

- Maximum stress by theoretical method and Von-mises stress are well below the allowable limit, hence the input shaft & output shaft is safe.
- Input shaft & output shaft shows negligible deformation under the action of system of forces.

3.5 Selection of bearing Input & Output shaft RH/LH end

The Input & Output shaft is held in two ball bearings that equally share the radial load on the shaft. Single Row deep groove ball bearing as follows.

Table -2: Selection of Bearing

IsI No	Bearing of basic design No (SKF)	d	D1	D	D2	B	Basic capacity	
2AC04	6004	20	23	42	36	12	4500	7350

As the required dynamic capacity of bearing is less than the rated dynamic capacity of bearing, bearing is safe.

3.6 Design of Plastic Gear (NYLON-6)

Drive as GEAR and pinion arrangement
-Maximum load =Maximum torque / Radius of gear
-Maximum torque = 0.25N-m
-No of teeth on pinion= 28
-No of teeth on gear = 28
-Module = 2.14 mm
-Radius of gear by geometry = (28 x 2.14) /2= 29.96mm
-Maximum load = T/r = 0.25x 103 /29.96 =8.34N
-b = 10 m
-Material of spur gear and pinion = NYLON6

Selecting standard module = 2.14 mm for ease of construction as we go for single stage gear box, making size compact & achieving maximum strength and proper mesh.
Hence gear pair dimensions are as Pinion: 28 teeth. 2.14 module integral with input shaft

3.7 ABS polymer Gear in phased condition: ABS Technical Specifications & Properties

-Pyrolysis Thermal Degradation: 201°c
-Flexural Strength: 75.84 MPa(11,000 psi)
-Heat Resistance: 110°c
-Melting Temperature: 200°c (392°f)
-Tensile Strenth: 44.81 MPa (Available)
-Elongation at Break: 3-75%
-Standard Tolerance: 0.1% with a Minimum of ± 200 µ
-Wall Thickness: 1mm-2.5mm
-Density: 1.01-1.21ρ(Mg/m3)
-Shrinkage: 8%

Integrated ABS Phased gear is produced using 3D printing machine as shown in fig. 7

Fig -7 Integrated Phased ABS Gear

3.8 Experimental Setup

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

Fig -8 Experimental Setup

4. RESULT & DISCUSSION

4.1 Readings for FDM Gears with phasing integral gears

Table -3: Readings for FDM Gears with phasing integral gears

Sr. No	load(kg)	Speed (rpm)	Torque ((N-m)	Vibration(disp) mm	Vibration(acc) mm/sec2
1	1.5	1400	0.50031	1.021	4.183
2	2	1384	0.66708	1.082	4.223
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	1.126	3.867
6	4	1296	1.33416	1.146	3.642
7	4.5	1120	1.50093	1.126	2.861
8	5	1080	1.6677	1.142	2.322

4.2 Readings for Nylon Gears with Phasing:

Table -4: Readings for Nylon Gears with 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

Chart -1 Load Vs Speed (Nylon)

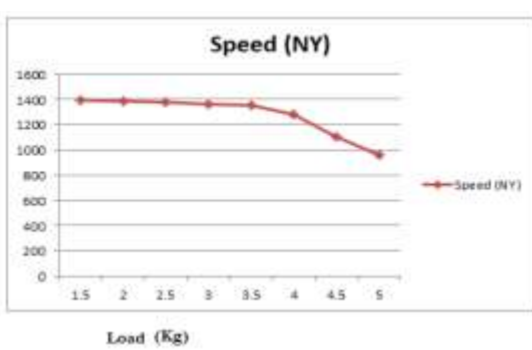


Chart -2 Torque Vs Speed (Nylon)

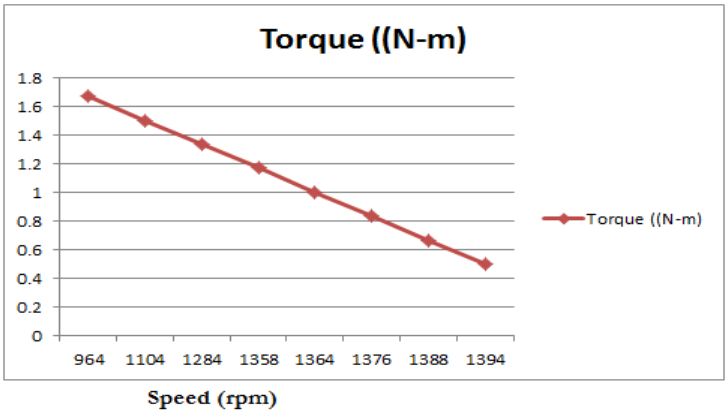


Chart -3 Displacement Vs Speed (Nylon)

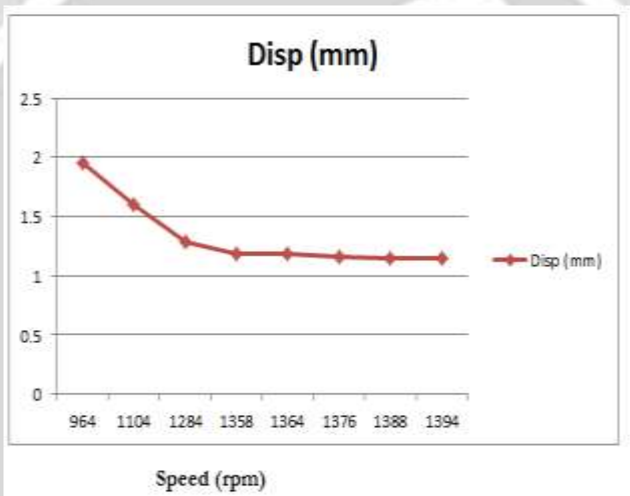
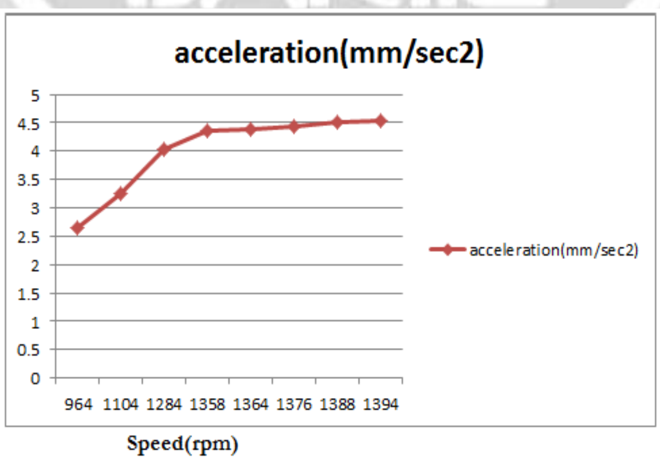


Chart -4 Acceleration Vs Speed (Nylon)



4.3 Readings for FDM Gears with phasing non integral gears

Table -4: Readings for FDM Gears with phasing non integral gears

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

Chart -5 Load Vs Speed (ABS nonintegrated)

Chart -6 Torque Vs Speed (ABS nonintegrated)

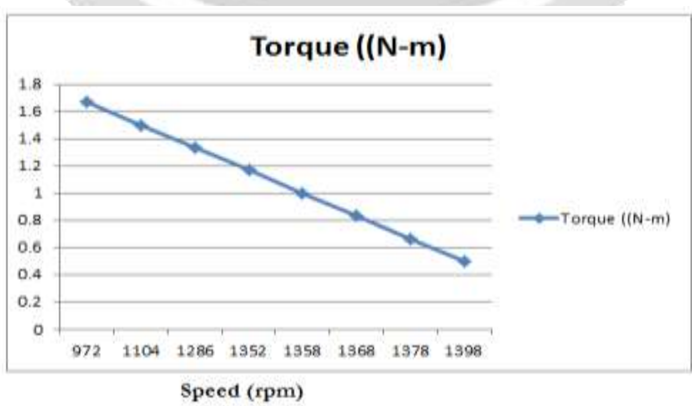


Chart -7 Displacement Vs Speed (ABS nonintegrated)

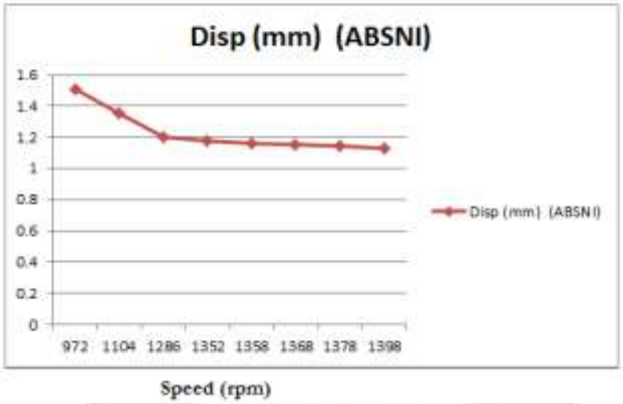
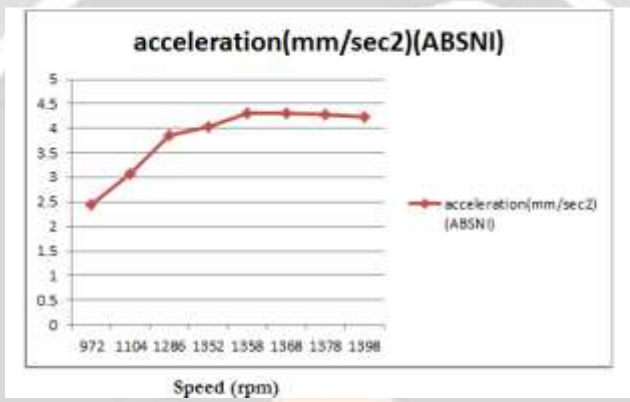


Chart -8 Acceleration Vs Speed (ABS nonintegrated)



- The speed drops with the increase in load
- The value of torque is seen to increase with the drop in speed.
- The displacement value is stable over the range of 1100 to 1400 rpm, at the lowered speed value due to increased load the displacement is slightly higher**.**

4.4 Comparison of Nylon Gears and ABS gear – nonintegrated

Chart -9 Displacement Vs Speed (Comparison)

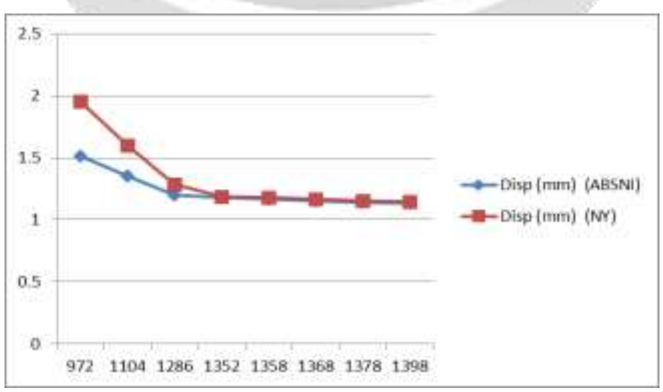
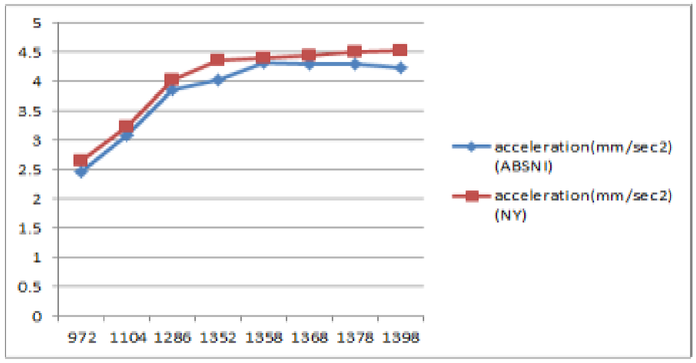


Chart -10 Acceleration Vs Speed (Comparison)



- The comparison of the Nylon Gears with the ABS –non integrated gears shows that the ABS gears show lower displaced at higher load (reduced speed) thereby showing better performance than the nylon gears.
- The comparison of the Nylon Gears with the ABS –non integrated gears shows that the ABS gears show lower acceleration at all loads thereby showing better performance than the nylon gears.

5. CONCLUSION

The main objective of this study was to prepare the experimental set-up to find out the vibrations in nylon & ABS (integrated & non integrated) spur gear pair with phasing arrangement using Vibrometer. The variation in mesh stiffness is greatly reduced, which is a principal source of internal excitation in gear systems. The experimental results obtained during experimentation showed the meshing of gear pair with phasing method reduces the vibrations in meshed gear pair.

6. REFERENCES

[1] "Experimental Investigations of Noise Control in Planetary Gear Set by Phasing", S. H. Gawande, S. N. Shaikh, Hindawi Publishing Corporation, Journal of Engineering, Volume 2014, Article ID 857462

[2] "Experimental Investigations of Vibration Reduction in Spur Gear Pair by Method of Phasing", S. H. Gawande, and D. K. Kokare, Journal of Vibration Engineering & Technology, Vol. 5, No. 6, December 2017.

[3] "Noise Level Reduction in Planetary Gear Set", S.H. Gawande, S.N. Shaikh, R. N. Yerrawar, K.A. Mahajan, Journal of Mechanical Design and Vibration, 2014 2 (3), pp 60-62.

[4] "Numerical study on reducing the vibration of spur gear pairs with phasing", Cheon, Gill-Jeong, Journal of Sound and Vibration, Volume 329, Issue 19, p. 3915-3927, September 2014.

[5] "Vibration Measurement and Noise Control in Planetary Gear Train", A.R.Mokate, R.R.Navthar, International Journal of Innovative Research in Science Engineering and Technology, Vol. 4, Issue 8, August 2015.

[6] "Investigation of the Noise and Vibration of Planetary Gear Drives", Yong Chen, Akira Ishibashi, Gear Technology, Jan/Feb 2006.

[7] "Gearbox Noise and Vibration Prediction and Control", Jiri Tuma, International Journal of Acoustics and Vibration, Vol. 14, No. 2, 2009 (pp. 111)

[8] "Numerical Analysis of variation in mesh stiffness for Spur Gear Pair with Method of Phasing", D.K.Kokare, S.S.Patil, International Journal of Current Engineering and Technology ISSN 2277 – 4106

[9] "Methodology of increasing accuracy of gear models manufactured using additive FDM method", Grzegorz Budzik, Advances in Manufacturing science and technology, Vol. 39, No. 4, 2015 DOI: 10.2478/amst-2015-0021

[10] "Friction Induced Wear of Rapid Prototyping Generated Materials: A Review", A. Tsouknidas, Hindawi Publishing Corporation Advances in Tribology Volume 2011, Article ID 746270, 7 pages doi:10.1155/2011/746270

[11] "Factors Affecting Dimensional Precision of Consumer 3D Printing", David D. Hernandez, International Journal of Aviation, Aeronautics, and Aerospace, Volume 2, Issue 4, Article 2, 2015.

[12] “Modelling and Testing of Spur Gear made of Different 3D Printed Materials”, Tanmay Kotkar, Prashant Masure, Pundalik Modake, Chirag Lad, Basanagouda Patil © 2018 IJSRSET, Volume 4, Issue 4, Print ISSN: 2395-1990, Online ISSN : 2394-4099 Themed Section : Engineering and Technology.
[13] “Profile Modification for Increasing the Tooth Strength in Spur Gear Using CAD”, Shanmugasundaram Sankar, Maasanamuthu Sundar Raj, Muthusamy Nataraj, Engineering, 2010, 2, 740-749