

# Performance Evaluation and Vibration Analysis of Nylon-6 and FDM Moulded Coupling Gear and Sleeves

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**Abstract:** Gear couplings are commonly used in industry; the plastic moulded couplings are now industrial mainstay. Today they transfer torque and motion in various products ranging from missiles, cars, sewing machines, building controls, and watches. With the ground they've gained their evolution is still continuing as they are used in more demanding gear applications. Plastic gear couplings are serious alternatives to traditional metal gear coupling in a wide variety of applications. The use of plastic gear coupling has grown from low-power and precision transmission to more demanding power transmission applications. Conventional method of manufacturing is the plastic moulding for sleeves whereas the gears are made of plain carbon steel, but this is only for a substantial batch quantity. In present day situation many a times it is required to produce small quantity of products for which plastic moulding is not a economical solution. In such cases the method of FDM (Fused deposition modelling) can be used. But though the method is extremely fast and economical for small batch quantity, the performance of parts produced by this method is yet to be proven for strength and durability. The paper attempts to design develop and manufacture the coupling gear and sleeves in Nylon-6 and by FDM process. Project work will include design of the parts using Unigraphics Nx 8, Analysis using Ansys Work bench 16.0 and experimentally investigate the vibration performance of the coupling using vibrometer set up.

**Keywords:** Gear Coupling, FDM process, Nylon-6, Vibrometer

## 1. Introduction

Gear couplings are similar to shaft couplings that perform the basic function of torque transmission and compensate for misalignment. Gear couplings are still the king of the coupling types. While each type of coupling has its drawback, gear couplings are more power intensive, can be modified and are available in wider size, torque and bore range compared to others.

Gear couplings also work at extremely high speed. As referred by the name, gear couplings use the meshing of gear teeth to transmit the torque and to compensate for misalignment. Gear couplings can do things that many other couplings cannot do or can only do with difficulty or with expensive modifications and de-rating. Other couplings don't offer various advantages which gear couplings offer. They offer axial slide capability, low speed high torque capability, shifter capability and spindle capability not found in other couplings. They are easily modified to shear pin service, floating shaft type, vertical type, insulated type, limited end float, and can have a brake drum or disc features added. While some of those offer some features but are usually easier and less costly to modify the gear couplings.

Gear couplings means more torque transmitted per coupling weight and per cubic inch of space consumed; hence they are more power intensive. This allows space and weight for attachments without having the coupling grow to unusable proportions. Power intensity and space savings mean the

OEM can fit-in the coupling in small places. Hence the OEM will be using with the confidence that the coupling will not fail. The gear coupling has more torque capability than the shaft can transmit. The gear coupling eventually wears without having a spectacular failure. Gear couplings have been likened to a one-to-one gear box, that is, torque transfers from hub teeth to sleeve teeth and across the shaft gap with no change in RPM.

## 2. Literature Review

FRICION BETWEEN HIGH SPEED GEAR COUPLING TEETH by J. Mech. Des 103(1), 54-58 (Jan 01, 1981) (5 pages)doi:10.1115/1.3254878History:Received January 01, 1980; Online November 17, 2009.

Under misalignment, the teeth of a coupling hub and sleeve slide over each other axially. This motion and the torque transmission generate friction forces. Although laboratory measurements indicated that the friction coefficients are very low, many a thrust bearing failure was blamed on coupling "lock-up". This paper discusses the results obtained from an exhaustive test program in which the friction forces were measured as a function of many variables, including torque, axial velocity, misalignment and lubrication. Friction coefficients as large as .16 were computed when the coupling operated under adverse conditions. Lubrication proved to have the largest influence on the magnitude of the friction coefficients.

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**COUPLING CREDIBLE FAILURE MODES AND OWNER OPTIONS TO INTERVENE** by Stephen R. Locke Principal Consultant, Rotating Machinery DuPont Old Hickory, TN, USA, Proceedings of the Forty-Second Turbomachinery Symposium. September 30 – October 3, 2013, Houston, Texas.

While all machine component failures can impact reliability, cost and production, some like coupling failures may have safety risks for personnel. Intervention requires us to build appropriate steps into our machine and system designs as well as our coupling design, operation and maintenance practices. Vibration instrumentation alone can leave us vulnerable for some failure modes.

In this paper, a user's and an OEM's views are presented of the most common coupling failure modes with examples showing details in the final stages of deterioration and identifies options to enable owners to intervene in sufficient time to prevent catastrophic failure.

**THE APPLICATION OF FLEXIBLE COUPLINGS FOR TURBOMACHINERY** by Jon R. Mancuso, C. B. (Barney) Gibbons Robert E. Munyon.

Flexible couplings are too often thought of as a piece of hardware rather than a vital parts of power transmission systems. Virtually every user has a story about a piece of equipment with a coupling problem. Sometimes the coupling is the villain and just will not perform as needed, but often the coupling is only reacting to a concealed problem and shoulders the blame for the real culprit. The basics of coupling design and operation will be presented. This presentation is intended to help the equipment user and OEM better understand the purpose of a coupling, how it accomplishes those tasks, how to best specify and utilize flexible couplings, and how to locate the real causes of coupling problems. Some of the issues discussed will be why use a flexible coupling, basic principles and terms, the differences between gear and flexible element couplings, selecting couplings for new applications, retrofitting gear couplings, flexible element couplings and API Standard 671

**WHAT CAUSES WEAR IN GEAR-TYPE COUPLINGS** by M. M. Calistrat, Koppers Co., Inc., Baltimore.

Speed has a significant influence on coupling Wear: high speeds reduce the wear-rate; while low speeds can, with some lubricants, causes the coupling's failure. We can only conclude that increased rotating speed helps in improving the lubrication conditions. Worm tracks are caused by very localized welding and, as such, the sliding velocity alone cannot be blamed for this type of failure, It is likely that tracks are caused by a combination of unfavorable torques, misalignments and sliding velocities. Very little can be done about the torque, and because the alignment often cannot be controlled, the best way to avoid recurrence of worm tracks is to improve the lubrication. This can be done either by supplying a larger oil flow to the coupling or by using a better grade of oil.

### 3. Problem Area

Plastic gear couplings are serious alternatives to traditional metal gear coupling in various applications. The use of plastic gear coupling has expanded from low-power and precision motion transmission to more demanding power transmission applications. Conventional method of manufacturing is used for plastic moulding of sleeves and the gears are made of plain carbon steel, limitation with this is that it can be used only for a substantial batch quantity. In current situations many times it is required to produce small quantity of products for which plastic moulding is not an economical solution. In such cases the method of FDM (Fused deposition modelling) can be used. Even if the method is extremely fast and economical for small batch quantity, the performance of parts produced by this method is yet to be proven for strength and durability.

Processors face many challenges in creating gear geometries that maximize power while minimizing transmission error and noise. Such gear couplings call for great precision in molding concentricity, tooth geometry, and other properties. Some gear coupling involve complex movements of molds to complete the finished product, while others need precision cored teeth in extra thick sections to compensate for shrinkage. Even if the latest polymers, equipment, and tooling put the next generation of plastic gear coupling within reach of most molders, the true challenge most of the processor faces is in adapting this complete operation for such high-precision work.

Tolerances needed for precision gear coupling generally go well beyond those defined as "fine" by The Society of the Plastics Industry (see graph below). Even if the current molding machines with the latest process has provision to control the accuracy to hold mold temperature, injection pressure, and other variables within a tight enough window to allow most processors to mold precision gear coupling. Some gear molders go a step further and place pressure and temperature sensors in mold cavities to improve consistency and repeatability. Manufacturers of precision gear coupling also need specialized measuring equipment to verify gear quality, such as double-flank roll checkers for quality control and computer-controlled inspection to evaluate gear teeth and other features.

The process of plastic moulding is now a proven for tight tolerances and accuracy but the investment requirements are high and also requires more process time; hence it is uneconomical for small batch quantities.

### 4. Solution to Problem

Fused deposition modeling (FDM) is a technology commonly used for modeling, prototyping, and production applications. One of its application is 3D printing. FDM works on a Fused deposition modeling (FDM) is a technology commonly used for modeling, prototyping, and production applications. One of its applications is 3D printing. FDM works on an "additive" principle by laying down material in layers; a plastic filament is unwound from a coil and supplies material

to produce the part. The technology was developed by S. Scott Crump in the late 1980s and was commercialized in 1990. The term fused deposition modeling and its abbreviation to FDM are trademarked by Stratasy Inc. The exactly equivalent term, fused filament fabrication (FFF), was coined by the members of the RepRap project to give a phrase that would be legally unconstrained in its use. It is also sometimes called Plastic Jet Printing (PJP). FDM, a prominent form of rapid prototyping, is used for prototyping and rapid manufacturing. Rapid prototyping facilitates iterative testing, and for very short runs, rapid manufacturing can be a relatively inexpensive alternative. FDM uses the thermoplastics ABS, ABSi, polyphenylsulfone (PPSF), polycarbonate (PC), and Ultem 9085, among others. These materials are used for their heat resistance properties.

But though the method is extremely fast and economical for small batch quantity, the performances of parts produced by this method are yet to be proven for strength and durability.

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## 5. Mechanical Design

Mechanical design phase is very important from the view of designer .as whole success of the project depends on the correct design analysis of the problem.

Designer should have adequate knowledge above physical properties of material, loads stresses, deformation, failure. Theories and wear analysis Mechanical design phase is very important from the view of designer .as whole success of the project depends on the correct design analysis of the problem.

Designer should have adequate knowledge above physical properties of material, loads stresses, deformation, failure. Theories and wear analysis, He should identify the external and internal forces acting on the machine parts,

These forces may be classified as;

1. Dead weight forces
2. Friction forces
3. Inertia forces
4. Centrifugal forces
5. Forces generated during power transmission etc

Designer should estimate these forces very accurately by using design equations .If he does not have sufficient information to estimate them he should make certain practical assumptions based on similar conditions which will almost satisfy the functional needs. Assumptions must always be on the safer side.

Selection of factors of safety to find working or design stress is another important step in design of working dimensions of machine elements. The correction theoretical stress values are to be made as per the kind of loads, shape of parts & application requirements.

Selection of material should be made according to the condition of loading shapes of products environment conditions & desirable properties of material. Provision should be made to minimize adopting proper lubricating methods.

In mechanical design the components are listed down & stored on the basis of their procurement in two categories

- Design parts
- Parts to be purchased

For design parts a detailed design is done & designation obtain are compared to the next highest dimension which is readily available in market. This simplifies the assembly as well as post production service work. The various tolerance on the work are specified. The process charts are prepared & passed on to the work are specified.

The parts to be readily available hence are purchased directly are selected from catalogues & specification so that it can be purchased from the retail shop with the given specifications.

### 5.1 Motor Selection

Single Phase Induction Motor

Make: Godrej -boyce

230V, 50 Hz,

Power = 0.25Hp (0.185 Kw )

Speed = 1440 rpm (Synchronous)

Frame Size =70

Current = 1.70 AMP

Torque = 0.17 Kg . M



**TORQUE ANALYSIS:**

Torque at spindle is given by;

$$P = \frac{2\pi NT}{60} \quad (1)$$

Where:

T = Torque at spindle (Nm)

P = POWER (Kw)

N = Speed (rpm)

$$T = \frac{185 \times 60}{2\pi \times 1440} \quad (2)$$

T = 0.79 Nm

Considering 100 % overload;

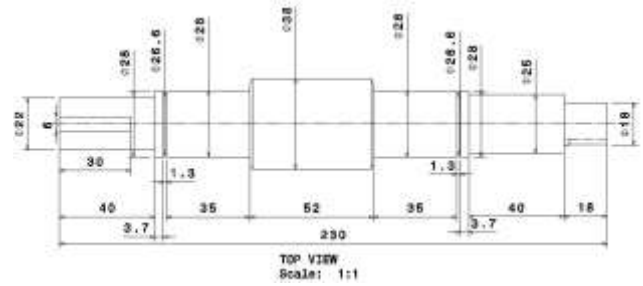
T<sub>design</sub> = 2 T

= 1.56 N-m

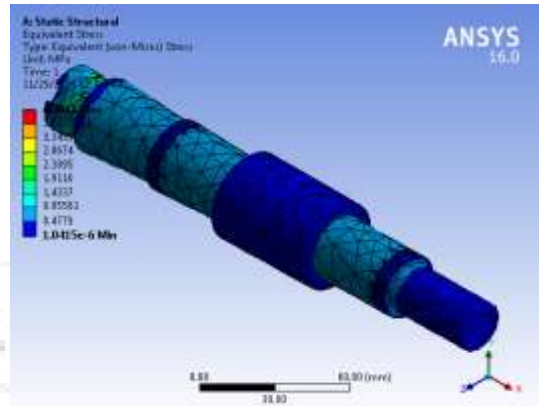
T<sub>design</sub> = 1.56 Nm



**Figure 1: Motor selection**



**Figure 2: Design of Shaft**



**Figure 3: Stresses in Shaft**

As the maximum equivalent Von-mises stress (4.381 Mpa) < Allowable stress (148.5Mpa), the shaft is safe.

**5.2 Design of Main Shaft**

T<sub>design</sub> = 1.56 Nm

Selection of main shaft material

Designation	Ultimate Tensile Strength (N/mm <sup>2</sup> )	Yield strength (N/mm <sup>2</sup> )
EN 24 (40Ni;2cr;1Mo28)	1100	880

Using ASME code of Design;

Allowable shear stress;

F<sub>sall</sub> is given stress;

$$F_{sall} = 0.30 \text{ syt} = 0.30 \times 880$$

$$= 264 \text{ N/mm}^2$$

$$F_{sall} = 0.18 \times \text{Sult} = 0.18 \times 1100$$

$$= 198 \text{ N/mm}^2$$

Considering minimum of the above values;

$$F_{sall} = 198 \text{ N/mm}^2$$

As shaft is provided with key way considering 25% reduction in strength.

$$F_{sall} = 198 \times 0.75 = 148.5 \text{ N/mm}^2$$

Considering pure torsional load;

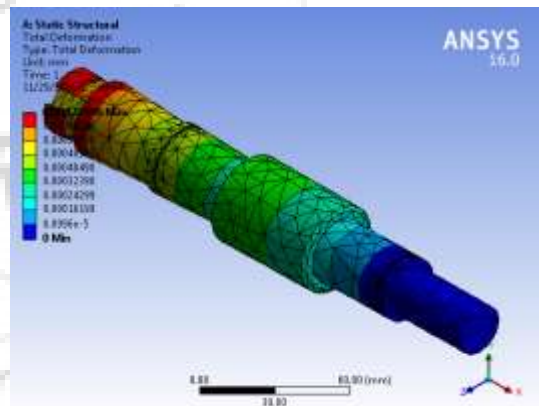
$$T_{design} = \frac{\pi * F_{sact} * d^3}{16} \quad (3)$$

$$F_{sact} = \frac{16 \times 1.56 \times 10^3}{\pi} \quad (4)$$

F<sub>s act</sub> = 1.36 mm

As; f<sub>s act</sub> < f<sub>s all</sub>

⇒ Shaft is safe under torsional load.



**Figure 4: Deformation in Shaft**

As the maximum deformation in Shaft is 0.00072 mm the Shaft is safe.

**5.3 Design of Dynamometer Pulley**

Outside diameter of hub = 40mm

Inside diameter of hub = 22 mm

Lovejoy Coupling L-095 can be considered to be a hollow shaft subjected to torsional load

Material selection:

Designation	Ultimate Tensile strength (N/mm <sup>2</sup> )	Yield strength (N/mm <sup>2</sup> )
Aluminium	400	320

As Per ASME Code;

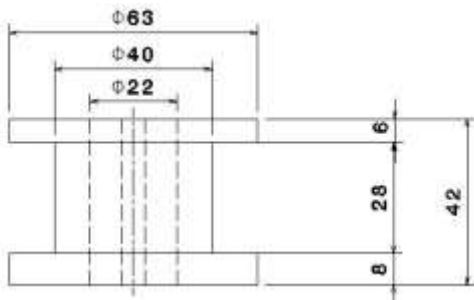
⇒ f<sub>s max</sub> = 100 N/mm

$$T = \left( \frac{\Pi * F_{sact}}{16} \right) x \left( \frac{D_o^4 - D_i^4}{D_o} \right) \quad (5)$$

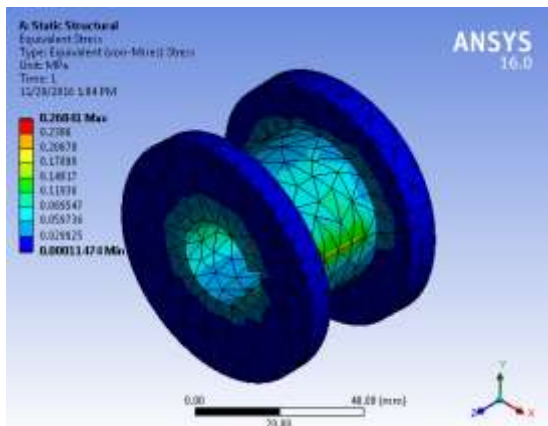
$f_{s act} = 0.1366/\text{mm}^2$

As;  $f_{s act} < f_s$  all

Pulley is safe under torsional load.

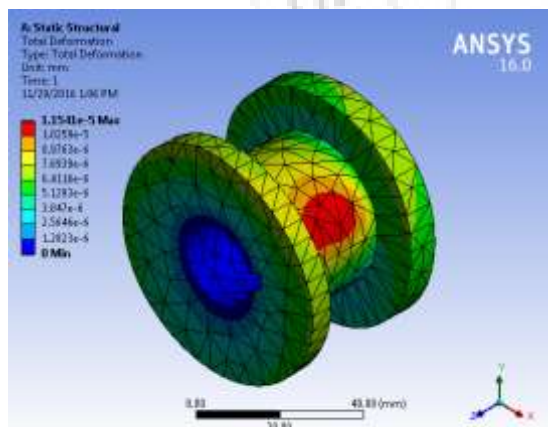


**Figure 5: Design of Pulley**



**Figure 6: Stresses in Pulley**

As the maximum equivalent Von-mises stress (0.268 Mpa) < Allowable stress (100Mpa), the Pulley is safe.



**Figure 7: Deformation in Pulley**

As the maximum deformation is 1.15e-5 mm the pulley is safe.

### 5.4 Coupling Sizing

One key component of sizing and selecting nearly every coupling is calculating the Nominal Torque as well as the Design Torque. Using inch (imperial) units of measurement.

Nominal Torque = Horse Power x 63025 / RPM = Application Torque

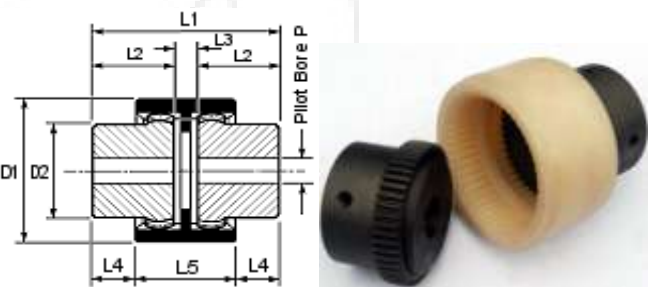
While system nominal/application torque is important to know and understand, it is imperative that this NOT be the torque used to select the coupling. According to the application of use the application torque must be multiplied by a suitable service factor to ensure the coupling is robust enough to handle the challenges of that specific application.

Design Torque = Application Torque x Service Factor = Coupling Sizing Torque

Service factors are available and listed in each manufacturer's PDF product catalog as per the application and it is this service factor that should be used when selecting your coupling. Different manufacturers do rate their couplings differently (i.e. - some companies like publishing/marketing high catalog performance values... and will compensate for their higher catalog values by insisting on higher service factors), so it is important that you use the manufacturer's published rating and not a rating found elsewhere.

Coupling Selected:

Hub Only Order Code	Sleeve Only Order Code	Complete Coupling Order Code	Size	D1	D2	L1 (I)	L2 (I)	L3 (I)	L4	L5	P	Number of Teeth	Max Bore Diameter H7 with Keyway (I)	Max Bore Diameter H7 without Keyway
120-28066	121-28066	125-28066	28-66	66	44	84	36	12	19	46	6.17	34	34	28



**Figure 8: Nylon Sleeve Gear Coupling**

### 5.5 Material for FDM gears & sleeves

The material used for Fused deposition modeling (FDM) is ABS Polymer.

Designation	Ultimate Tensile Strength N/mm <sup>2</sup>	Yield Strength N/mm <sup>2</sup>
ABS Polymer	60	42

### 5.6 Analysis of ABS Polymer gear & sleeves

The sizing of coupling was selected; the analysis is done for same design with ABS Polymer as material.

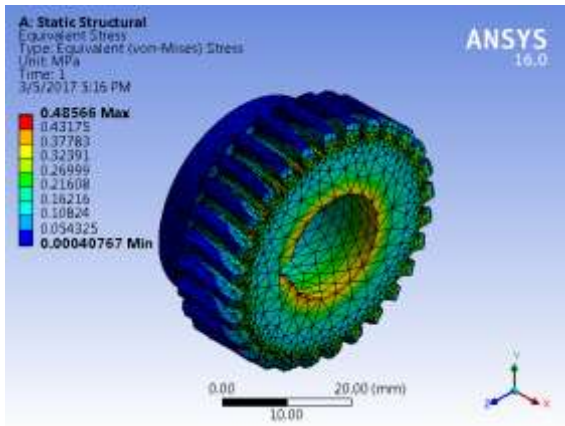


Figure 9: Stresses in Gear

As the maximum equivalent Von-mises stress (0.485 Mpa) < Allowable stress (30 Mpa) the gear is safe.

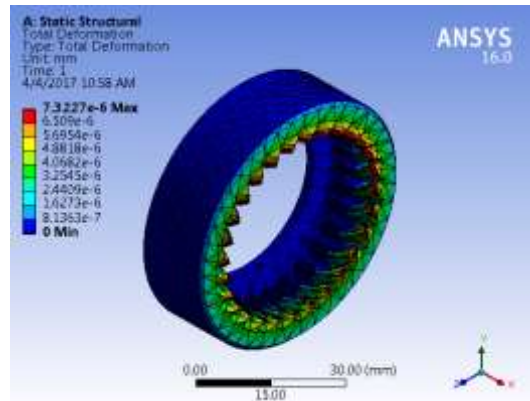


Figure 12: Deformation in Sleeve

As the maximum deformation is  $7.32 \times 10^{-6}$  mm the sleeve is safe

### 6. Manufacturing by FDM Method

Fused deposition modelling (FDM) is an additive manufacturing technology commonly used for modelling, prototyping, and production applications. FDM works on an "additive" principle by laying down material in layers; a plastic filament or metal wire is unwound from a coil and supplies material to produce a part. The gear and sleeves are manufactured by Fused Deposition Modelling of ABS Polymer. The filament of ABS Polymer is guided to the nozzle wherein the filament is heated on or above the melting point of ABS Polymer. The Nozzle is stationary at one position whereas the platform moves in the vertical direction according to the required height of the specimen. Once the height of the platform is achieved, the nozzle starts to inject the melted polymer. The desired shape of the object is achieved as the platform moves in the horizontal plane along the X& Y axis, after completion of one layer the platform readjust the height with respect to the nozzle. Below is the gear and sleeve samples produced by Fused Deposition Modelling Method.

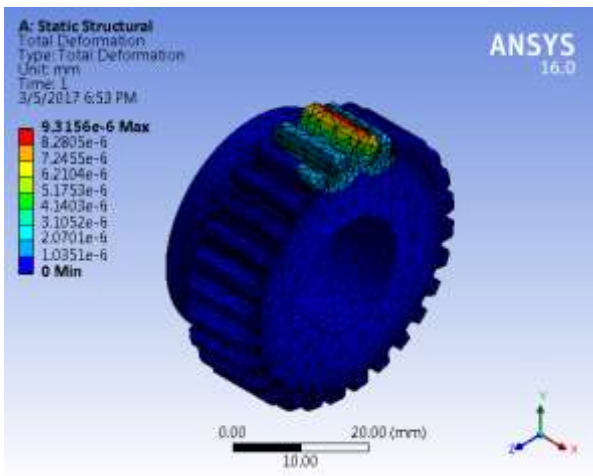


Figure 10: Deformation in Gear

As the maximum deformation is  $9.315 \times 10^{-6}$  mm the gear is safe.

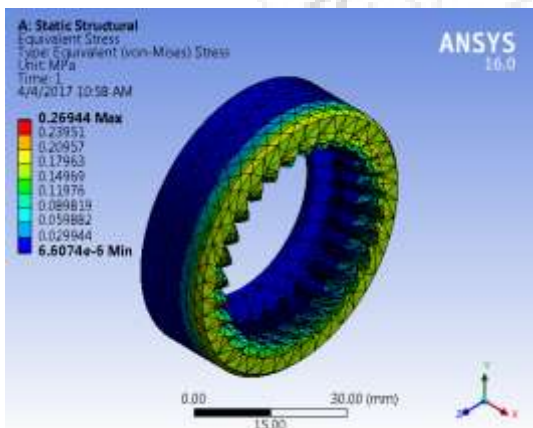


Figure 11: Stresses in Sleeve

As the maximum equivalent Von-mises stress (0.269 Mpa) < Allowable stress (30 Mpa) the sleeve is safe.



Figure 13: Gear Coupling Manufactured by FDM Process



## 7. Experimental Setup

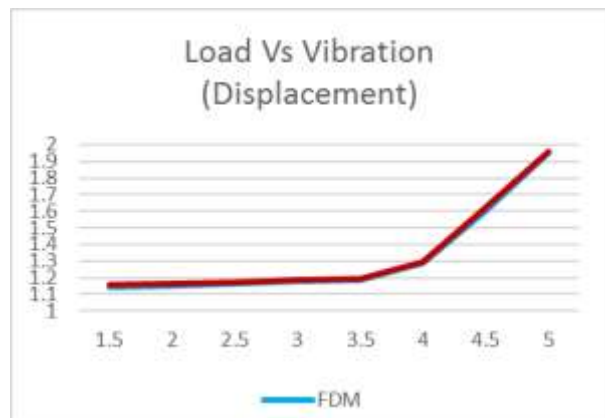
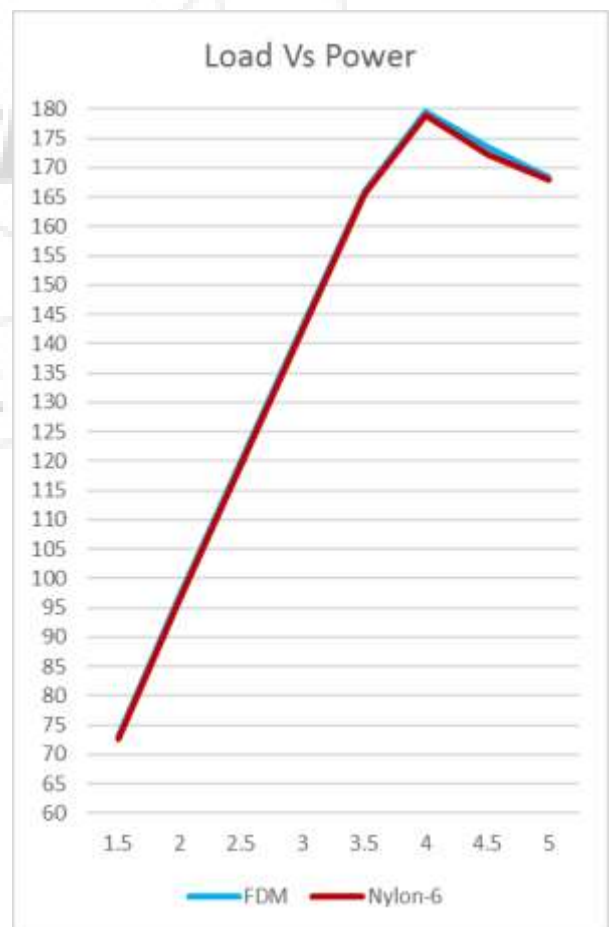
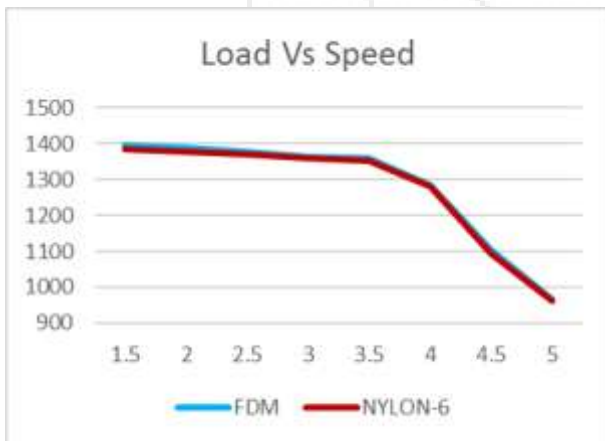
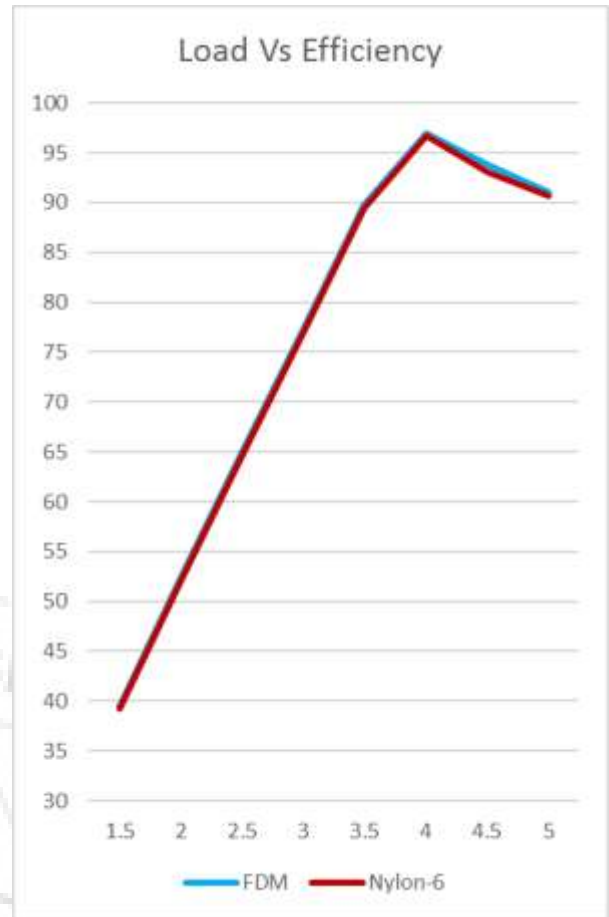
The experiment is carried to investigate if the gear couplings manufactured through FDM process are equally capable of transmitting the torque and speed to the dynamo meter pulley. We will compare the variation in speed vs load & vibration in the two types of gear couplings i.e. the standard Nylon-6 gear coupling & the ABS Polymer manufactured through the FDM process.



Figure 14: Experimental Setup

## 8. Comparison of Results ABS Polymer (FDM Method) Coupling with Nylon-6 Coupling

The Nylon-6 gear couplings were used for the first time, the load was gradually increased from zero to five kg.s on the dynamo meter pulley, the same experiment was carried with FDM (ABS Polymer) gear coupling. The comparison of the results are shown in below graphs.



## 9. Conclusion

The comparison of the results shows comparable results of ABS polymer gear coupling manufactured by FDM process and conventional Nylon-6 gear coupling. The power and efficiency of both the couplings were similar. As all the parameters i.e. load carrying capacity, power, efficiency and vibrations of gear couplings manufactured by FDM process were comparable to that of conventional gear coupling we can conclude that with the given novel process of manufacturing the gear coupling manufactured by Fused Deposition Modelling truly fits into the realm of an emerging new technology.

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- [3] THE APPLICATION OF FLEXIBLE COUPLINGS FOR TURBOMACHINERY by Jon R. Mancuso , C. B. (Barney) Gibbons Robert E. Munyon
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