ISSN 2395-1621

Design, Analysis and Performance Evaluation of Torque Limiter using FDM process

Amit Rajendra Tayade

amit.tayade1@gmail.com.

Mechanical Engineering Department, D.Y.P.C.O.E Akurdi
Pune, Maharastra

ABSTRACT

Generally, Power is transmitted from power source to output shaft without any interference i.e no excessive load acts on the machine. But problem arises when excessive load acts on the machine's output shaft resulting in overloading of engine which can lead to burnout of motor and ultimately making it to come stand still it can also lead to breakage of drive elements and clutch. To avoid such extreme scenarios and damage during overload it is essential to disconnect or isolate input and output shafts of the transmission. These issues can be minimizes by using Torque limiters consisting of overload slipping ball clutch. The Torque limiter acts as safety device and disconnects the input and output member in case of overload. In the project the Torque limiter elements are manufactured using FDM technology due to its easy and quick manufacturing advantage compared to conventional methods, also the torque transmitting capacity of the assembly based on the position of locking nut is analyzed for its performance evaluation.

Keywords— FDM, Gear coupling, Overload slipping Spring Ball Clutch, Safety clutch overload protection, Torque Limiter.

ARTICLE INFO

Article History

Received:30th December 2020

Received in revised form :

30th December 2020

Accepted: 1st January 2021

Published online :

2nd January 2021

I. INTRODUCTION

In any industry there is always a need of more rapid, rigid and precise equipment to increase capacity and productivity. Such requirement demands various mechanisms like gearing arrangements, high-capacity motors and shaft drive mechanism, torque transmitters. The output load on driving member exceeds in some cases like centrifugal pumps, grinders, ship propellers etc. Thus, when machine gets overloaded it results in failure of components such as shafts, burning of motor, gear teeth rupture and ultimately breakdown of system [1]. In order to avoid such overloading some preventive mechanism needs to be incorporated between driving and driven mechanism, and the use of torque limiter is one of way to deal with such overloading. This paper describes the spring ball type torque limiter made using FDM (3D printing) method. Till now many types of torque limiters are being available and used. These come with various specifications for instance shear pin torque limiter which is designed to with stand specific shear load. But It has disadvantage as it requires replacement of shear pin after each breakage. Another type of torque limiter is permanent magnet torque limiter, but again it creates backlash problems. Another type of torque limiter consists of pawl spring torque limiter, which involves spring-loaded cam follower. But as it requires need of operator for re-engagement it is not preferred. Considering these drawbacks, we have designed this torque limiter to protect the mechanism from overload at particular torque limit of the mechanism which inherits following features,

i. Variable torque limits using various lock nut positions
ii. Automatically re-engaged when the load limit drops
iii. No-manual reengaging required
iv. No part worn-out
v. Low cost of replacement parts in case of failure
vi. Quick manufacturing

In conventional flying ball type spring clutch torque is transmitted from input to output shaft using balls which are constantly held by a spring in the assembly and when overload occurs the balls slip and will come out of the assembly thus disconnecting input and output shafts and eventually saving part failures. In this paper the spring ball clutch is designed in a way that the balls will not come out of assembly in case of overload and stays in the slotted grooves. There will be just slipping of the balls when the torque exceeds. One more advantage is that the clutch can be preset to a particular torque limit without removing it from assembly by using an adjustable locknut and this will save considerable amount of downtime as compared to the conventional clutch. The following features must characterize the torque limiter [1]:

- Reliable and safe in operation.
- Limitation accuracy, to a certain required value of the transmitted torque;
- Ability to adjust transmitted torque.
- Automatic re-engagement of clutch, after the overload stops.

The use of safety clutch is recommended in the following situations:

- In machines transmissions where constant shocks occur of varying degree, as a result of the impossibility to have precise determination of overloads;
- For the transmissions systems of the machines that process inhomogeneous mediums (dredger for clearing dry earth, farm implements, and so on);
- In case of automatic machines transmissions, as there is lack of a permanent control of their working;
- In case of kinematically linked chains with more machine tools, due to the inability of the transmission protection by the electric motor;
- In case of all the transmissions systems where the over measure cost for overloads resistance is higher than the cost of a safety clutch. (1)

Disadvantages of Current System of Overload Protection

To protect the system from failure, currently Flying ball clutch is available which transmits torque from input to output shaft using balls held by a spring in assembly, when overload occurs the balls will come out of assembly completely –thus disconnecting input and output thereby saving part failure But

- Rating of clutch is 1N-m, 5 N-m, 20 N-m etc. i.e., fixed value so if o/p torque change we have to replace clutch for an application.
- Every time ball slips or comes out of assembly we have to remove the clutch to replace ball this increases down time of machine and is tedious.
- In case the clutch made from conventional material fails we need to replace whole part which adds to cost, but in case of parts made of FDM they are cheap and quick to manufacture.
- Drive always remains coupled there is no flexible arrangement like automobile clutch i.e., possibility to disengage at will.
- If temporary overload occurs in the system the clutch will slip and remain disengaged until it is preset even though the overload is now removed this leads to process down time. Whereas in our case it gets engaged as soon as torque value decreases.

Advantages of Overload Torque Limiter made of FDM.

The overload slipping ball clutch has the following advantages.

- Overload slipping ball clutch prevents the burnout or damage to the electric drive motor due to sudden over load since it disengages the drive when overload is detected**.**
- Over load slipping ball clutch can easily be preset after disengagement.
- Overload slipping ball clutch is capable of transmitting a wide range of torque which can be precisely preset on the drive itself with the help of locknut.
- Low cost of manufacturing due to FDM.
- Compact size as it consists of gear coupling integrated with torque limiter in a single assembly.
- If temporary overload occurs the clutch will slip and remain disengaged only till the overload is removed thus if the overload is removed while in running condition the clutch shall automatically engage and start transmitting power.
- Instantaneous response.

II. LITERATURE REVIEW

In this we study various configuration of Overload Torque limiters, from various Handbooks, United State Patent documents, Technical research papers, etc.

Tobias wolf et al.

He identified that for those are involved in the design of motion control and automation systems, there is need elimination of excess mass and inertia important. Energy savings, higher throughout rates, and reduced downtime, all this without compromising quality or accuracy, is the need. To solve this problem, R+W has developed a new torque limiter called SL Series, which has half the inertia and less than half the mass, allowing for a rapid and recovery from maximum torque overload in most advanced drive technology. It consists of spring-loaded ball, along with a previously patented preload for zero backlash operation.[1]

Nicolae eftimie

In his paper naming “Dynamic Simulation of The Safety Clutches With Balls” he discovered that the torque limiter are used in machine buildings, and with correct selection of these depends on the safe and long working of the machine [2].

M jackel1 et al.

In his paper named “The MRF-ball-clutch design – a MRF-safety-clutch for high torque applications” it consists of design of torque limiter with magneto rheological fluids (MRF) for the transmission of torque.[3]

Mark S Landquist

He designed radial ball torque limiter which had a element with an annular wall slot with rows of internal teeth extending circumferentially outwards along the interior of the annular wall, and an input shaft extending into the cavity along with several caged ball assemblies surrounding the input shaft with each was having row of balls held circumferentially to engage in the groove between adjustment teeth and the cage.[4]

S.Shelke et al.
In this paper "Design development, testing and analysis of torque limiter for overload protection" he concluded that safety clutch can be easily adjustable to transit a range of torque values.[5]

Aitavade et al.
In his paper on Spring Loaded Torque Limiter conclude that clutch (torque limiter) ensures that, the variation of the transmitted moment can take over technological and assembling deviations.[6]

Chandrakant Labade et al.
In his paper on Torque Limiter for Overload Shaft found that the enclosed design of the mechanical torque limiter enables it to operate in a wide variety of industrial environments to withstand even more adverse conditions [7]

Guy James Burlington et al.
In his paper he presented that clutch mechanism consists of clutch members in engaged position, in which torque generated by a drive is transmitted to output, and another disengaged position, in which there is no any transmission of torque. The clutch is able to slip in order to avoid damage caused by overload conditions. [8]

William j silver et al.
He found out that torque limiter consists an outer cylindrical housing having semicircular grooves in the interior surface and a inner cylindrical housing arranged inside the outer cylindrical housing. The torque value cannot be changed once the torque limiter is installed. That value helps determines what spring is used during the assembly. To change the torque value the torque limiter needs to be disassembled and the springs is changed to achieve the new torque value. Also, these torque limiters can b configured for different torque values for different rotational directions.[9]

III. PROBLEM STATEMENT

Whenever a sudden overload occurs in any shaft drive mechanism there are three possibilities:
a) Shaft / coupling/ belt drive fill fail or break
b) Application i.e., machine shaft will fail or break
c) Motor will be overloaded resulting into electric burn
In any case it is damage leading to machine part replacement Down time of machine and increased part replacement and maintenance cost.

IV. SCOPE OF WORK

- In many cases pump shaft drives either electrical or engine drives are normally furnished with the overload slipping ball clutch to avoid the breakage or damages arising due to pump clogging or blockage Compressor drives, especially in many mining applications are equipped with the over load slipping ball clutch.
- Compact size: The size of the Torque limiter gear coupling is very compact; which makes it low weight and occupies less space in any drive.
- Easy engagement and disengagement depending on the torque applied
- Ease of operation: The changing of torques gradual one hence no calculations of speed ratio required for change torque, merely by rotating adjuster lock nut torque can be changed.
- In case of Machine tool slides are driven by electrical drives via lead screw. The over load slipping ball clutch isolates the electrical drive from the output when there is overload.
- Ease of replacement: Even if the torque limiter gets damaged, the parts made by ABS polymer using 3d printing are very cheap and quick to manufacture

V. OBJECTIVES

- Design of ball detent 3 ball set overload torque limiter with adjustable torque limit.
- To design a Test rig, plunger, base flange output shaft which easily avoid the excess load acting on the system.
- To prevent the Motor from burning due to overloading on output shaft by doing static structural analysis.
- Design and geometrical derivations of the groove profile in input base flange.
- Design and geometrical derivations of spring plunger profile
- Selection of geometrical profile of ball holder clutch body.
- Selection and design of torque control lock nut arrangement.
- Mechanical design: This includes the design and development of springs selection of suitable drive motor, strength analysis of various components under the given system of forces.
- The critical components of the assembly like, Safety ball clutch, input shaft, base flange, plunger, cylindrical body, casing, output shaft etc., components will be designed using conventional theories of failure using formulae, 3-D models of the above parts will be developed using Catia V5R21 software and meshing, analysis will be done, the result of stress produced will be validate using ANSYS-Workbench 16 release.
- Testing of drive to derive performance characteristics for
  a) Load Vs Speed
  b) Torque Vs Speed
  c)Power VsSpeed
  d) Efficiency Vs Speed

VI. METHODOLOGY

Phase 1: Data collection
Data collection phase involves the collection of reference material for project concept, the idea is taken from book HMT handbook.

Phase 2: System design

The system design comprises of development of the mechanism so that the given concept can perform the desired
operation.

Phase 3: Mechanical design
The parts mentioned above in the part list will be designed for stress and strain under the given system of forces, and appropriate dimensions will be derived. The standard parts will be selected from the PSG design data handbook.

Phase 4: Production drawing preparation
Production drawings of the parts are prepared using Auto Cad, with appropriate dimensional and geometric tolerances. Raw
material sizes for parts are also determined.

Phase 5: Material procurement & process planning
Material is procured as per raw material specification and part quantity. Part process planning is done to decide the process of manufacture and appropriate machine for the same.

Phase 6: Manufacturing
Parts are produced as per the part drawings
.
Phase 7: Assembly –test & trial Assembly of device is done as per assembly drawing, and test and trial is conducted on device for evaluating performance.

Phase 8: Report preparation
Report preparation of the activities carried out during the above phases is done.

VII.CONSTRUCTION

- The adjustable torque spring ball Torque Limiter is an safety device used in the transmission line to connect the driving and driven elements such that in case of occasional overload the Torque Limiter will slip there by disconnecting the input and output members. This protects the transmission elements from any breakage or damage.

For a particular condition the Torque Limiter is preset to for slipping at a different overload, it is simply mounted on input member by means of a locknut which is adjusted in the appropriate direction, during which the balls are pressed against the grooves; thus, setting operation is simple, instantaneous, rapid and reliable.

The Torque Limiter is there connected to the output member. When the input shaft is rotation through the coupling and motor the base flange is rotated along with it the balls pressed against V- serration also rotate. This motion is transmitted through springs; plunger to the cylindrical body which then rotates the output shaft. When the load on the output shaft exceeds the preset design overload the resistance of the balls to more in direction of motion of base flange, there by balls start slipping in the "V" serrations.

- At one point the balls completely come out of the serrations into open space in base flange there by disconnecting the base flange and the cylindrical body. Thus, the input shaft keeps rotating where as the output shaft comes to stand still. To increase the overload value; move sleeve towards the base flange with the help of lock nut where as to reduce the overload; move the sleeve away from the base flange the sleeve can be locked in position by means of the lock nut.

VIII. DESIGN OF CRITICAL COMPONENTS

DESIGN AND ANALYSIS OF INPUT SIDE LEFT HAND GEAR:

MATERIAL SELECTION: -Ref :- PSG (1.10 & 1.12) + (1.17)

DESIGNATION	ULTIMATE TENSILE STRENGTH N/mm^2	YEILD STRENGHT N/mm^2
ABS POLYMER	60	42

$\Rightarrow$ τ allowable = 60/2 = 30 N/mm^2
$\Rightarrow$ T design =1272 Nmm

CHECK FOR TORSIONAL SHEAR FAILURE OF SHAFT.

$$\tau_{max} = \frac{1272 * 18}{\frac{\pi(36^4 - 19^4)}{32}}$$

τ_{max} =0.1505 N/mm^2
As $\tau_{act} < \tau_{all}$
$\Rightarrow$ Gear is safe under torsional load.
ANALYSIS OF LH INPUT GEAR FOR TURNING MOMENT APPLIED

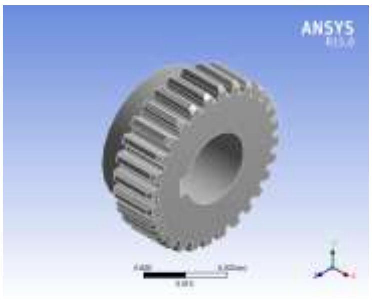


Fig 1. Model of LH Gear

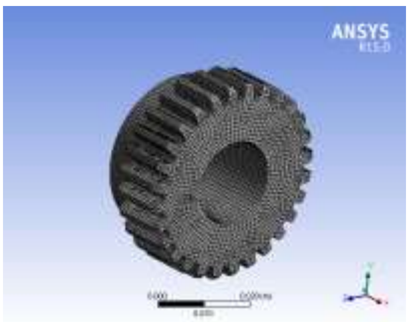


Fig 2. meshing of LH gear

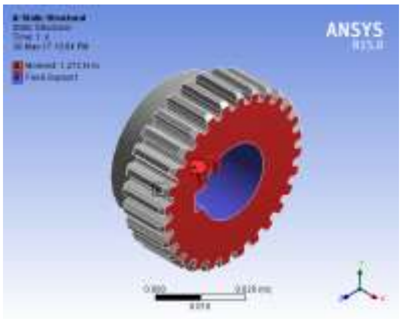


Fig 3. Moment applied on LH Gear

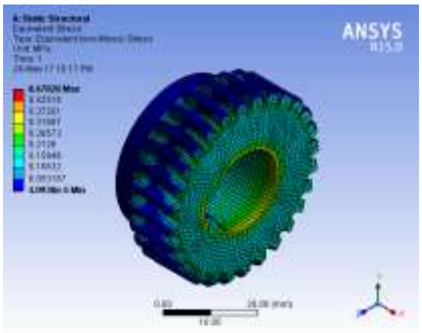


Fig 4 Streses devloped on RH Gear

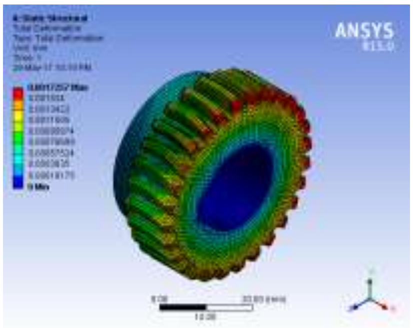


Fig 5. Deformation in LH gear

as the maximum equivalent stress induced in the gear blank is well below the allowable limit of 30 N/mm^2 the gear is safe.

ANALYSIS OF LH GEAR CONDISERING TANGENTIAL TOOTH LOAD

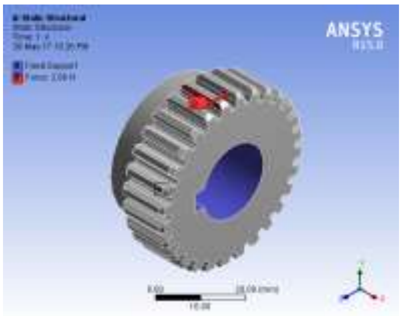


Fig 6. Boundary conditions applied on LH Gear

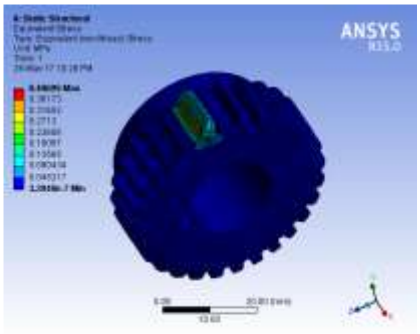


Fig 7. Streses devloped on RH Gear

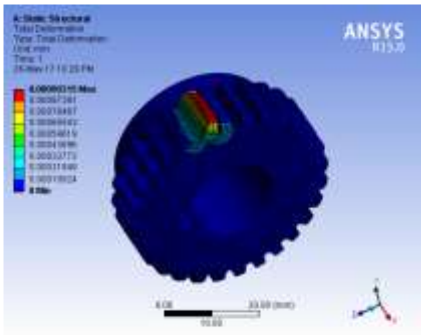


Fig 8.Deformation in RH gear

as the maximum equivalent stress induced in the gear blank is well below the allowable limit of 30 N/mm^2 the gear is safe.

DESIGN ANALYSIS OF SLEEVE :

MATERIAL SELECTION: -Ref :- PSG (1.10 & 1.12) + (1.17)

DESIGNATION	ULTIMATE TENSILE STRENGTH N/mm^2	YEILD STRENGTH N/mm^2
ABS POLYMER	60	42

$\Rightarrow$ τ allowable = 60/2 = 30 N/mm^2
$\Rightarrow$ T design =1272 Nmm

CHECK FOR TORSIONAL SHEAR FAILURE OF SLEEVE.

$$\tau_{max} = \frac{1272 * 19.5}{\frac{\pi(39^4 - 36^4)}{32}}$$

τ_{max} =0.3986 N/mm^2

As $\tau_{act} < \tau_{all}$

$\Rightarrow$Sleeve is safe under torsional load

As $fs_{act} < fs_{all}$

$\Rightarrow$ sleeve is safe under torsional load.

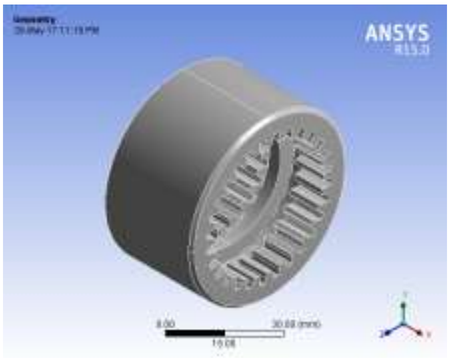


Fig 9 .Model of Sleeve

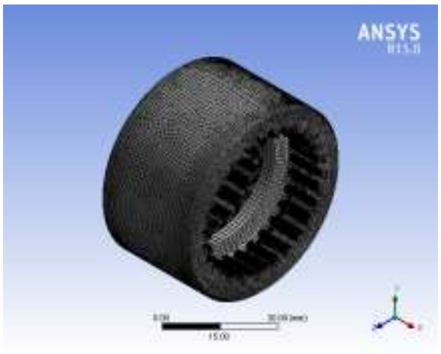


Fig. 10 Meshing of Sleeve

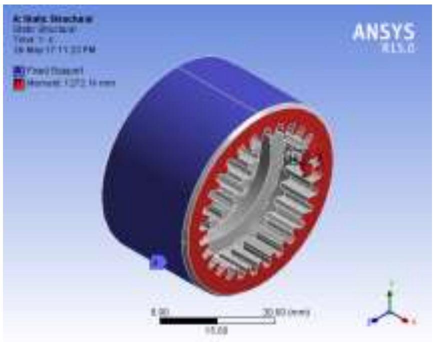


Fig 11. Boundary conditions on Sleeve

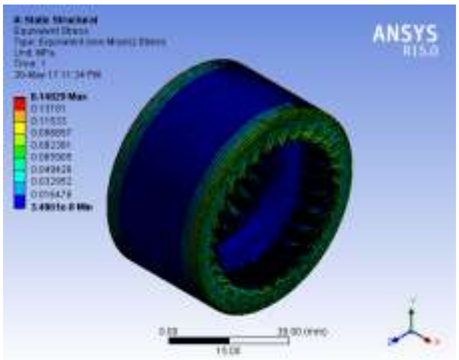


Fig 12. Stresses Developed in Sleeve

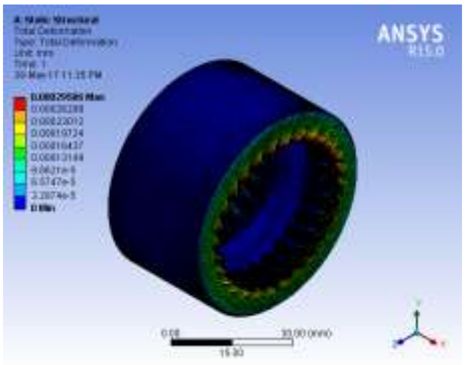


Fig 13 . Deformation in Sleeve

DESIGN AND ANALYSIS OF RH GEAR BASE FLANGE

MATERIAL SELECTION : -Ref :- PSG (1.10 & 1.12) + (1.17)

DESIGNATION	ULTIMATE TENSILE STRENGTH N/mm^2	YEILD STRENGTH N/mm^2
ABS POLYMER	60	42

$\Rightarrow$ τ allowable $= 60/2 = 30$ N/mm^2
$\Rightarrow$ T design $=1.273$ Nm

CHECK FOR TORSIONAL SHEAR FAILURE OF BASE FLANGE.

$$\tau_{max} = \frac{1272 * 18}{\frac{\pi(36^4 - 19^4)}{32}}$$

τ_{max} $=0.1505$ N/mm^2
As $\tau_{act} < \tau_{all}$
$\Rightarrow$ Base Flange is safe under torsional load.

Fig 14. Model of RH Gear base flange

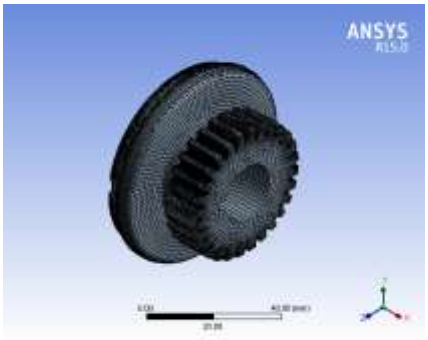


Fig15.Meshing of RH Gear flange

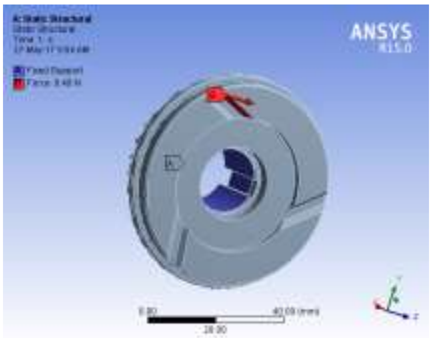


Fig16. Boundary conditions on RH Gear Base Flange

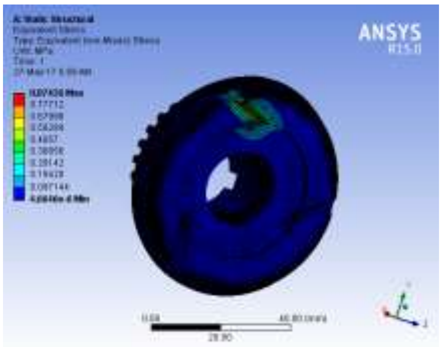


Fig17.Stresses in RH Gear Base Flange

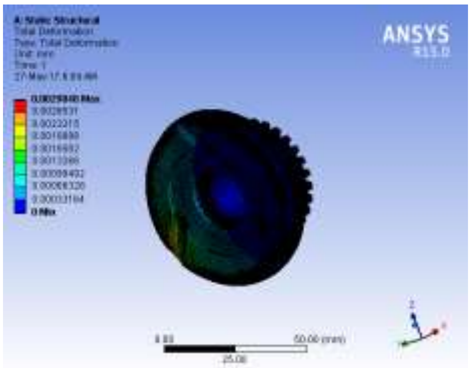


Fig 18.Deformation in RH Gear Base flange

DESIGN AND ANALYSIS OF CYLINDRICAL BODY

DESIGNATION	ULTIMATE TENSILE STRENGHT N/mm^2	YEILD STRENGHT N/mm^2
ABS POLYMER	60	42

MATERIAL SELECTION : -Ref :- PSG (1.10 & 1.12) + (1.17)

$\Rightarrow$ τ allowable = 60/2 = 30 N/mm^2

$\Rightarrow$ T design =1273 Nmm

CHECK FOR TORSIONAL SHEAR FAILURE OF CYLINDRICAL BODY.

$$\tau_{max} = \frac{1272 * 15}{\frac{\pi(30^4 - 19^4)}{32}}$$

τ_{max} =0.2859N/mm^2

As $\tau_{act} < \tau_{all}$

$\Rightarrow$ Cylindrical body is safe under torsional load.

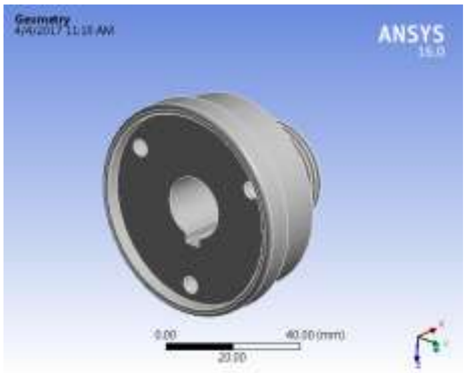


Fig 19. Model of Cylindrical body

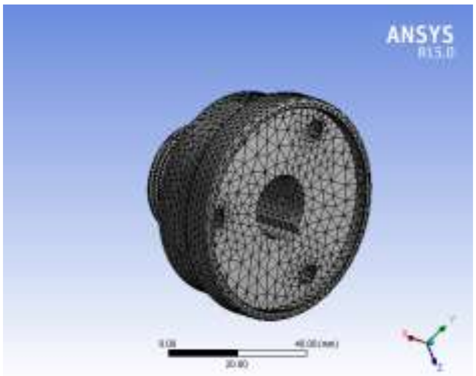


Fig 20. Meshing of Cylindrical Body

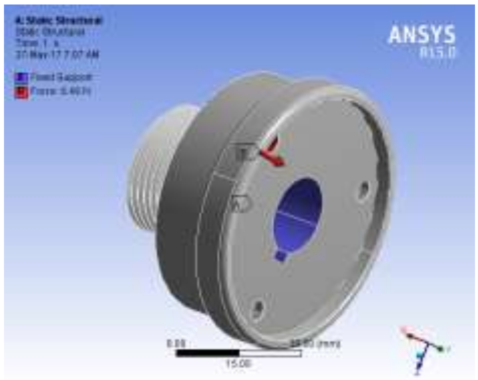


Fig 21.Boundary conditions on Cylindrical body

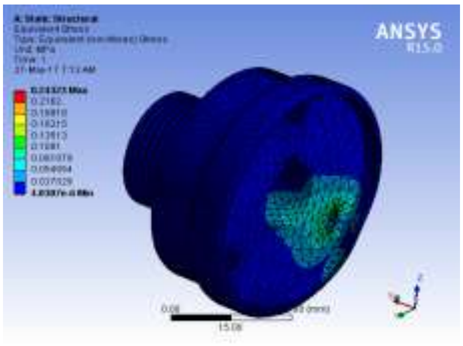


Fig 22. Stresses on Cylindrical body

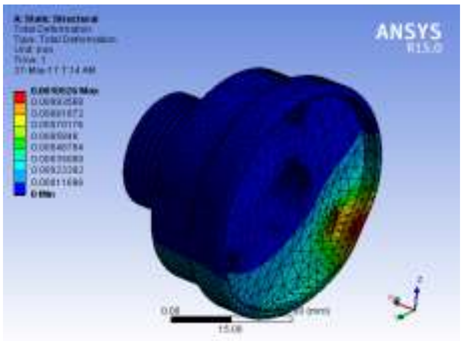


Fig 23. Deformation in Cylindrical body

IX. RESULTS AND CONCLUTION

Fig 24. Experimental Setup

Fig 25.Exploded view

Table 1. Stress comparison

Part name	Maximum allowable stress N/mm^2	Theoritical stress N/mm^2	Maximum Von Mises Stress N/mm^2	Deformation mm	Result
LH Gear	30	0.1505	0.47	0.001534	Safe
Sleeve	30	0.3986	0.1482	0.00029	Safe
Base Flange	30	0.1505	0.58	0.0023	Safe
Cylindrical Body	30	0.2859	0.17	0.0010	Safe

Maximum stress by theoretical method and Von-mises stress are well below the allowable limit, for the Input flange and cylindrical body, Here all the designs are verified with the results of ANSYS, so every design stated are safe.

Table 2 . Observation table on application of load

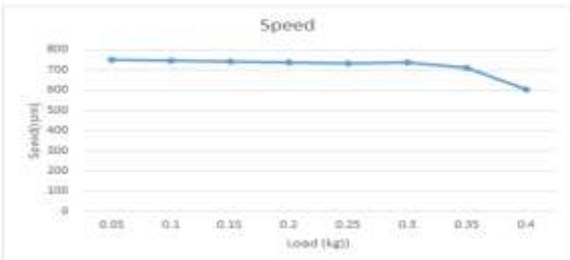
Sr. no	Load	Speed
01	0.05	750
02	0.1	746
03	0.15	742
04	0.2	738
05	0.25	732
06	0.3	738
07	0.35	710
08	0.4	602

Table 3. Result table

Sr. no	Load (KG)	Speed (rpm)	Torque (N-m)	Power watt	Efficiency
01	0.05	750	0.01962	1.5411	12.842
02	0.1	746	0.03924	3.0658	25.548
03	0.15	742	0.05886	4.5746	38.11
04	0.2	738	0.07848	6.065	50.549
05	0.25	732	0.0981	7.5208	62.673
06	0.3	738	0.11772	9.0989	75.824
07	0.35	710	0.13734	10.212	85.105
08	0.4	602	0.15696	9.8962	82.468

Graph of Load Vs speed

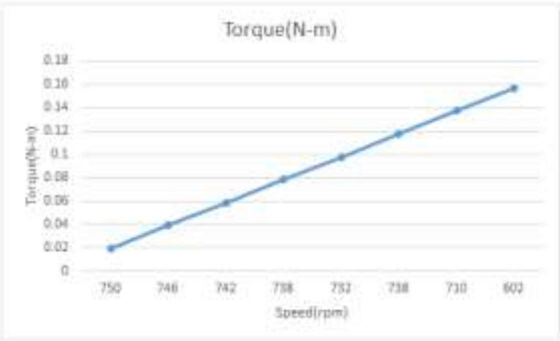
Output speed drops woth increase in load on output pulley



Graph of Load Vs speed

Graph of Torque Vs speed

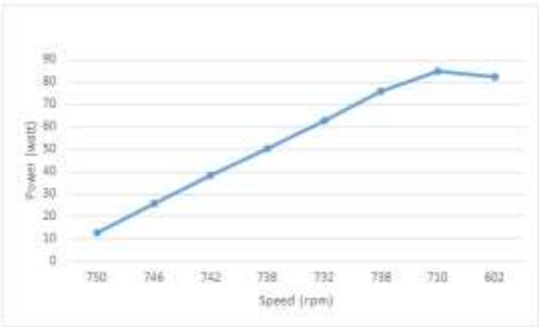
Output torque increases with drop in output speed



Graph of Torque Vs speed

Graph of Power Vs speed

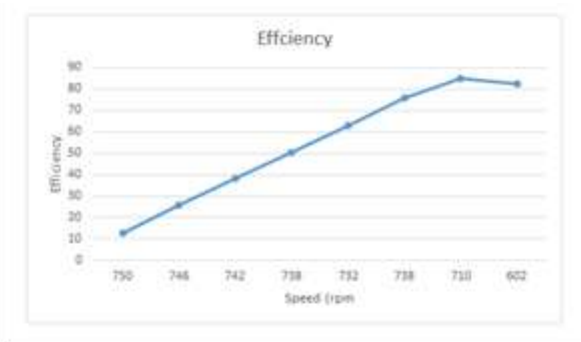
Output power is maximum at speed range of 700 rpm



Graph of Power Vs speed

Graph of Efficiency Vs Speed

Efficiency is optimal at output speed 0f 710 rpm



Graph of Efficiency Vs Speed

By designing this type of clutch it is possible to disengage the motor from the transmission automatically. These type of clutches can be used to protect motor from overload as well as we can disengage the motor from transmission at will i.e., for maintenance purpose, without stopping motor. Following characteristics are plotted,

a) Load Vs Speed

b) Torque Vs Speed

c)Power VsSpeed

d) Efficiency Vs Speed

ACKNOWLEDGMENT

I gratefully acknowledge Mechanical Engineering Department of DYPCOE, Akurdi, Pune for their technical support. I would also like to thank to Prof. Ravindra Lahane (Project guide), Dr. Panchagade (HOD, Mech Dept.), and Dr. Tapobrata Dey (PG co-ordinator) for their help and dedication toward my work. Also, I thank to my friends for their direct & indirect help, support and co-operation.

REFERENCES

[1] Tobias Wolf, Product Engineer, R+W GmbH and Andrew Lechner, Product Manager, R+W America.

[2] Nicolae Eftimie, “Dynamic Simulation Of The Safety Clutches With Balls”, facility of technical science, NOVI SAD, May 18 2007.

[3] M Jackel 1, J Kloepfer, M Matthias and B Seipel, “The novel MRF-ball-clutch design – a MRF-safety-clutch for high torque applications”, Journal of Physics: Conference Series 412 (2013) 012051.

[4] Landquist. Rock Ford University. “Radial ball torque limiter. United states patent no 4792321, dec 20 1988.

[5] Khainar S.S. and Shelke S.N., Design development, testing and analysis of torque limiter for overload protection.International Journal of innovation in engineering research and management.

[6] Kadam A. N. and Aitavade E. N., Spring Loaded Torque Limiter, IJSRD - International Journal for Scientific Research & Development Vol. 2, Issue 06, 2014

[7] Labade K.C., Torque Tender /Limiter For Overload Shaft, International Journal of Engineering Research & Technology (IJERT), Vol. 3 Issue 8, August – 2014.

[8] Gay James Burlington (Dyson technology limited) “United states patent no 7731618 B2, jun 8, 2010

[9] William j silver Holmed corporation. “United states patent no 8083596 B1, dec 27 2011.

