© 2019 IJSRSET | Volume 6 | Issue 5 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section : Engineering and Technology
DOI : https://doi.org/10.32628/IJSRSET19658

Design and Analysis of Fully-automatic Electromechanical Single Plate Clutch for Autonomous Agriculture Vehicle

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ABSTRACT

Agriculture vehicles and farming equipment like tractors and Tillers, Sprayers etc., also use a similar automobile transmission. With the shortage in labor and also increase in labor expenses there is a trend to automate the farming equipment to save time and labor cost. The major challenges in automation is the clutch control which is presently manual, and the automatic clutch control in the high end vehicles cannot be used due to the high cost, complexity of design. Hence in order to carry out the automatic clutch control a special electro mechanical clutch is needed.

The fully- automatic electromechanical Single plate clutch for autonomous agriculture spray vehicle is our attempt to design develop and apply the clutch to agriculture automation. The Clutch development includes the theoretical design as to the Power and torque transmission of the engine power and also design of an innovation clutch engagement-disengagement arrangement with quick-response, low cost, easy serviceability and compact space.

The paper presents a brief overview of the clutch, design and analysis of the critical components like the flywheel, clutch plate and pressure plate, The components have been developed using Unigraphic Nx8 and the structural analysis has being done using Ansys Workbench 16.0 . The testing was carried out on the clutch using a test rig to determine the performance characteristic of the clutch.

Keywords : Single Plate Clutch, Electromechanical, Autonomous Agriculture Vehicle.

I. INTRODUCTION

Friction clutch is widely used in manual mechanical transmission. While in the automatic transmission, it is complex to control for it need the additional servomechanism to control clutch. Hydraulic torque converter has problems of complex structure, high price, and low transmission efficiency and so on, so it is not suitable for small cars [1].The magnetic powder clutch for the vehicle is a new type power transmission member. It has the advantages of smooth clutch engagement, easy to control, torque transmission wide range and fast response and so on. And it adapted to the working characteristics of vehicle driveline, which ensure the vehicle to operate with high efficiency and imagine the vehicle with conventional transmission system and manual five speed gearbox, when required to be moved from stationary condition to the top gear the driver will have to perform in all thirteen operations. The operations are first dis engagement of clutch, shifting the gear, then re engagement of clutch, thus three operations per gear, in all fifteen operations, the first and last operation being common in cycle of operations, hence total thirteen operations are required to be performed. This becomes an extremely tiresome activity in dense traffic areas. It is important to note that majority of the operations performed are cutch related. Hence the need of a semi-automatic or automatic transmission system that makes the driving of vehicle easier without many hassles

Objectives:

Design development and analysis of automatic clutch components through suitable theoretical and analytical procedure.

II. LITERATURE REVIEW

A. The contribution of Transmission to vehicle fuel economy by D Simmer, [2] shows the importance of power transmission towards fuel efficiency. This research highlights how transmission plays an important role for the fuel economy which is the prime factor can be influenced by transmission system in four ways and not just transmission efficiency alone.

1. Parasitic losses in transmission i.e. Oil churning, seal and bearing drag.
2. Power proportional losses at chain, gear or belt mesh.
3. The weight and rotational inertia of transmission and driveline components.

The complete approach to minimize fuel usage with acceptable emissions for wide range of operating situations encountered by the vehicle.

B. Zero shift Automated Manual Transmission (AMT) by R. P. G. Heath and A. J. Child, [3] shows that Zero shift technology allows a manual transmission to change gear in zero seconds. This technology is patented new design for a transmission. The technology is easy to manufacture and allows a cost effective alternative to the traditional torque converter based automatic transmission. Zero shift provides potential fuel economy improvements from driveline efficiency and the best possible vehicle acceleration. Compared to an existing AMT, Zero shift offers an uninterrupted torque path from the engine to vehicle which allows for a seamless gearshift.

C. Electric Hydraulic Accelerator Control Device in AMT by Yinong Zhaoaa and Jiabao Chena, [4] shows that to regulate the fuel injection quantity for non-electronic- controlled engine during the process of automatic shifting, independent accelerator auxiliary control device needs to be designed .The accelerator control device should not only meet servo requirements in normal driving but also to regulate the fuel injection quantity automatic in the process of automatic shifting. This puts forward a new accelerator auxiliary control device for automatic shift control system with non-electronic controlled engine. This new device can Control injection quantity automatic during the process of automatic shift, not reducing the quality of controlling the engine. And it can solve the problems such as reliability, safety, the complex nature of control method for common linear accelerator scheme driven by motor.

D. Modeling of an Automatic Manual Transmission system by Gianluca Lucente, Marcello Montanari and Carlo Rossi, [5] shows that vehicles having Automated Manual Transmissions (AMT) system for gear shift control offer so many advantages in terms of reduction of fuel consumption and improvement of driving comfort along with gear shifting quality. Complexity, nonlinearity and high-order dynamics of the automated driveline, combined with strict requirements for high performance gear shifts, demand the development of driveline models, which include a detailed description of the actuators. These models can be useful for different purposes

1. During system development, to evaluate the achievable performance and its dependency on system properties as simulation tools for gear shift control algorithm design .In this topic, physically-based detailed nonlinear models of the electro-hydraulic actuated gearbox and of the dry clutch electro-hydraulic actuator of an automated manual transmission are developed as shown in Fig. To analyze their behaviour and impact on the drive train during gear shifting, actuator models are also integrated with a simplified transmission shafts dynamics

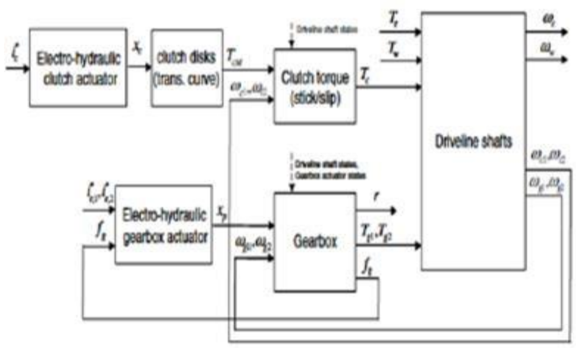


Fig 1 : Driveline layout with model

E. Development of an Automated Manual Transmission based on Robust Design by Yoshinori Taguchi, Yoshitaka Soga, Akira Mineno and Hideki Kuzuya, [6] showed use of three actuators for automation of gear shifting and clutch actuation process. Convention transmission system along with actuator was used for AMT. Two more actuators were used for shift and select actuation. To improve the control, stability and robustness of system these control devices was developed. The result gives a way forward for cost effective solution for AMT. The automatic clutch is constituted by a standard dry clutch controlled by an electro- hydraulic servo. The clutch actuator is constituted by disks between the flywheel and the clutch plate, whose surfaces are covered with high-friction materials. Electro hydraulic clutch actuator, which is driven with a three-way spool servo valve applies pressure to control the displacement of the clutch piston, which pushes on the release bearing. The transmitted torque can be called as stick slip friction, while the maximum transmissible torque (related with static friction) is modulated by normal force applied to clutch disks. In a clutch actuator model focusing on the hydraulic part and involving the release bearing position as output variable has been developed. The model is refined with considering the relation in-between the force applied to release bearing and the transmitted clutch torque. When there is no external force is applied, flywheel and clutch disks are pressed together by Bellville and pre-load springs and hence engine torque can be transmitted. In order to release the clutch, the hydraulic piston pushes the release bearing The Bellville spring, acting as a lever, reduces the normal force applied to the clutch plates, thus separating friction disks. The Bellville spring acts both as a spring and a lever with variable coupling ratio. Hence the steady state piston force is related to the force applied to the clutch plate by a nonlinear relation dependent on the clutch piston displacement.

F. Analysis and simulation of a torque assist Automated Manual Transmission by E. Galvagno, M. Velardocchia and Vigliani, [7] presents the kinematic and dynamic analysis of a power-shift Automated Manual Transmission (AMT) characterized by a wet clutch, called assist clutch (ACL), replacing the fifth gear synchronizer. This torque assist mechanism becomes a torque transfer path during gearshifts, in order to overcome a typical dynamic problem of the AMT that is the driving force interruption. The mean power contributions during gear shifting are computed for different engine and ACL interventions, thus allowing drawing considerations useful for developing the control algorithms. The simulation results shows the advantages in terms of gear shifting quality and ride comfort of the analysed transmission. From the analysis of the AMT, ACL transmission it is possible to state that a assist clutch proves useful during up shifts, downshifts (Kick Down) and motoring mode.

DESIGNATION	ULTIMATE TENSILE STRENGTH N/mm^2	YEILD STRENGTH N/mm^2
EN24	800	680

III.DESIGN AND ANALYSIS

A. Design & Analysis Input Shaft

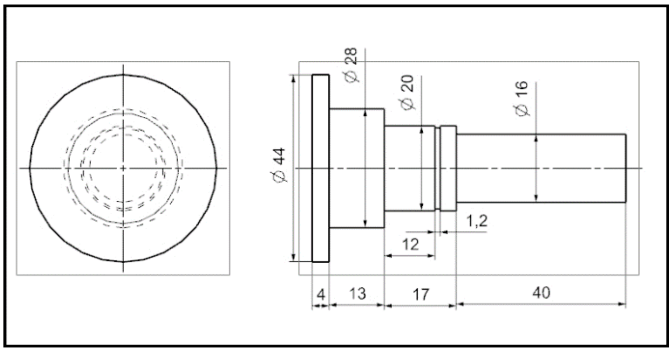


Fig 2 : Drawing of Input Shaft

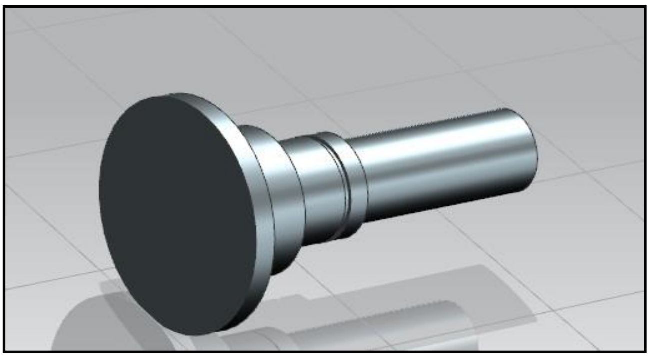


Fig 3:3D Model of Input Shaft

Material : En24

Material Selection: -Ref :- PSG (1.10 & 1.12) + (1.17)

$\Rightarrow$ fs_{max} = uts/fos = 800/2 = 400 N/mm^2

This is the allowable value of shear stress that can be induced in the shaft material for safe operation.

Now let's have a check for torsional shear failure of input shaft.

$$Te = \frac{\Pi}{16} fs\, d^3$$

fb_{act} = $0.313 N/mm^2$

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

Input shaft is safe under torsional load.

The following figures shows the analysis of input/output shaft using ANSYS,

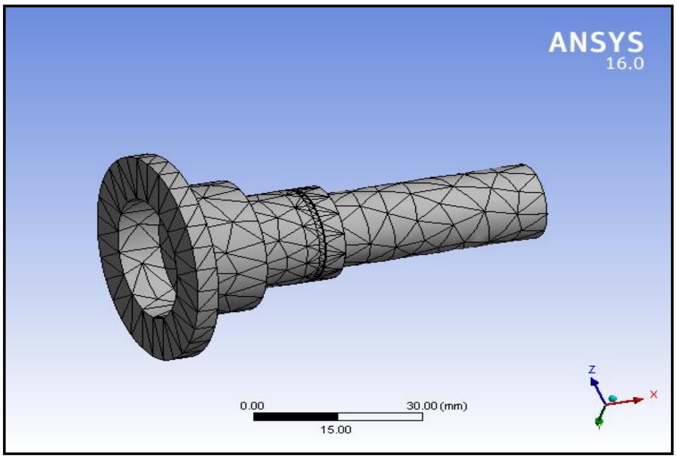


Fig 4: Meshing of input shaft in Ansys

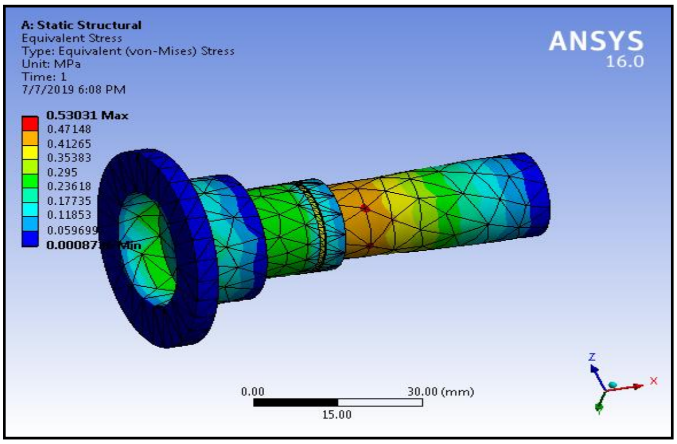


Fig 5 : Stress distribution in input shaft

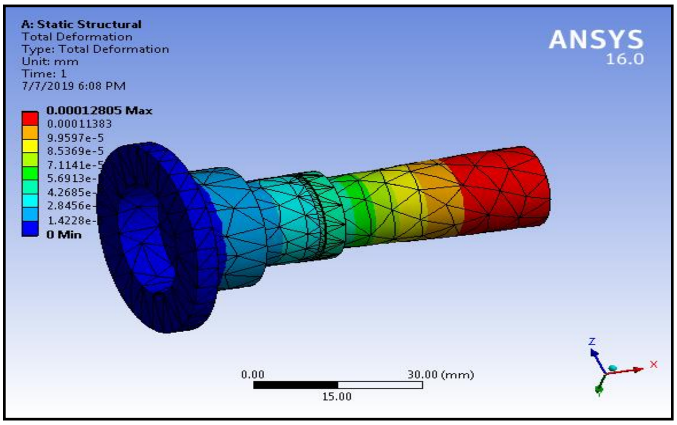


Fig 6 : Total deformation in input shaft

Part Name	Maximum theoretical stress (MPa)	Von-mises stress (MPa)	Result
Input Shaft	0.313	0.5303	safe

IV. RESULT AND DISCUSSION

Conclusion:

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

A. Design & Analysis Output Shaft

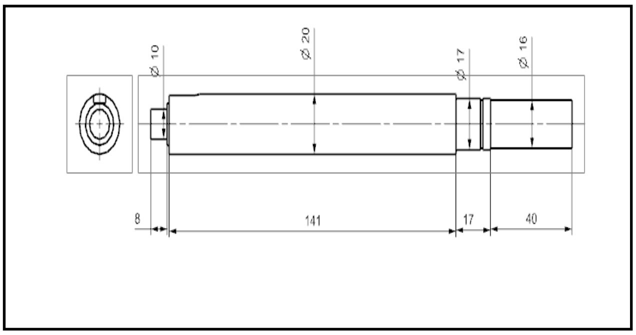


Fig 7 : Drawing of Output Shaft

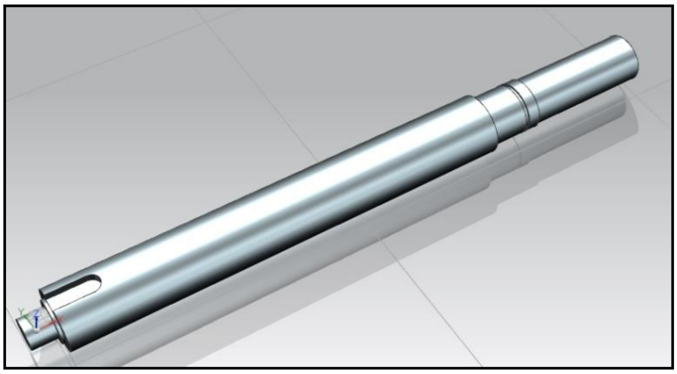


Fig 8 : 3D Model of Output shaft

Material : EN24

Material Selection : -Ref :- PSG (1.10 & 1.12) + (1.17)

DESIGNATION	ULTIMATE TENSILE STRENGTHN/mm²	YEILD STRENGTH N/mm²
EN24	800	680

Part Name	Maximum theoretical stress (MPa)	Von-mises stress (MPa)	Result
FLYWHEEL SHAFT	1.283	0.5109	safe

⇒ $fs_{max} = uts/fos = 800/2 = 400\ N/mm^2$

This is the allowable value of shear stress that can be induced in the shaft material for safe operation.

Check for torsional shear failure of shaft

$$Te = \frac{\Pi}{16} fs\, d^3$$

$fb_{act} = 1.283\ N/mm^2$

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

Output shaft is safe under torsional load.

Analysis of Output shaft

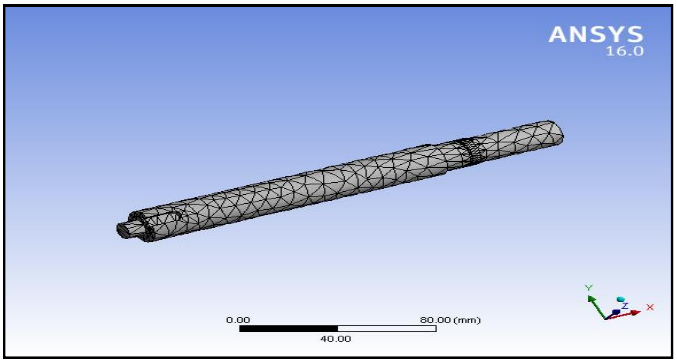


Fig 9: Meshing of Output shat in Ansys

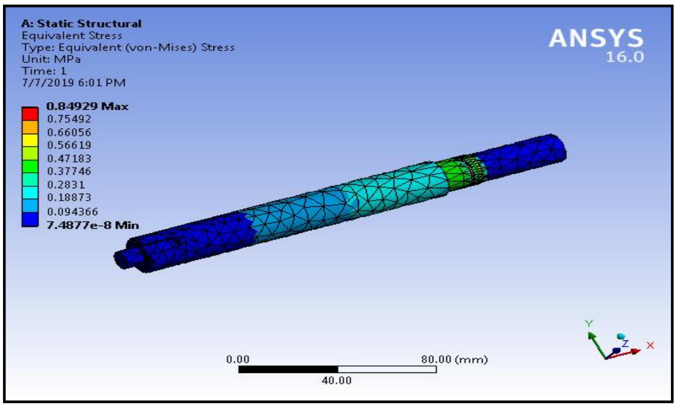


Fig 10: Stress distribution in Output Shaft

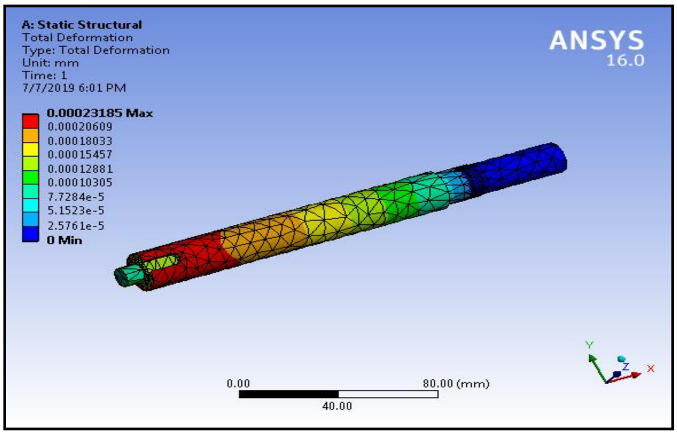


Fig 11: Total Deformation in Output Shaft

Conclusion:

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

B. Design & Analysis Screw

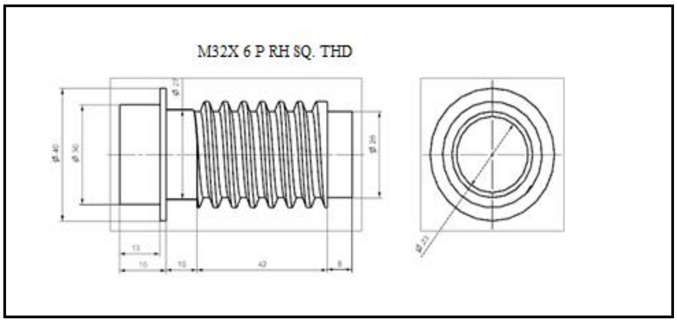


Fig 12: Drawing of Screw

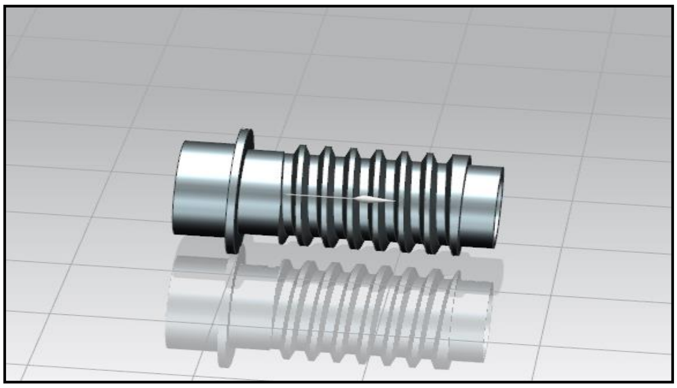


Fig 13: 3D model of Screw

Material :En24

Material Selection : -Ref :- PSG (1.10 & 1.12) + (1.17)

DESIGNATION	ULTIMATE TENSILE STRENGTHN/mm²	YEILD STRENGTH N/mm²
EN24	800	680

$\Rightarrow$ fs_{max} = uts/fos = 800/2 = 400 N/mm²

This is the allowable value of shear stress that can be induced in the shaft material for safe operation.

Check for torsional shear failure of Screw considering that the maximum torque exerted by the retraction motor is 2 N-m

$Td = \Pi/16 \times fs_{act} \times (D^4 - d^4)/D$

$2000 = \Pi/16 \times fs_{act} \times (26^4 - 23^4)/26$

$\Rightarrow$ $\underline{fs_{act}}$ = 14.7579191 MPa

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

Screw is safe under torsional load

Analysis of Screw :

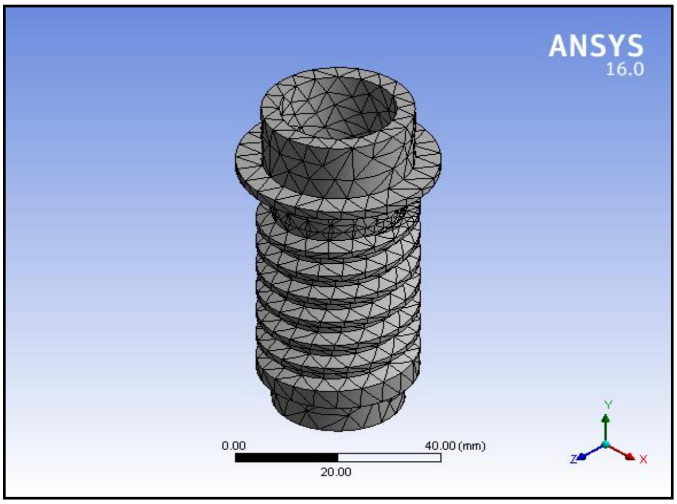


Fig 14 : Meshing of Screw in Ansys

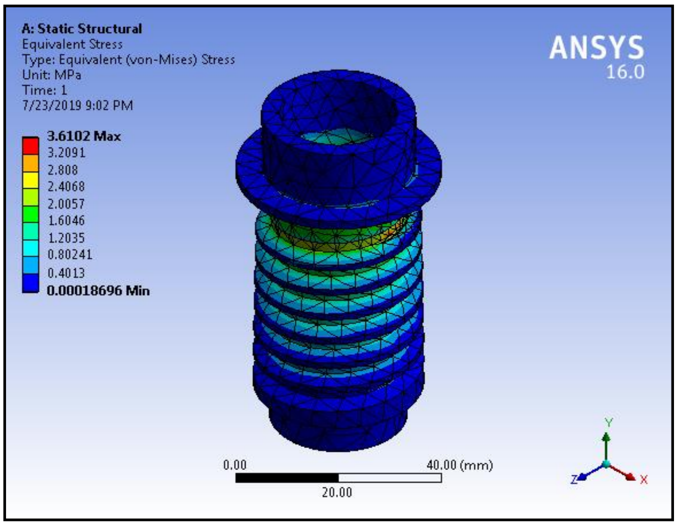


Fig 15: Stress distribution in Screw

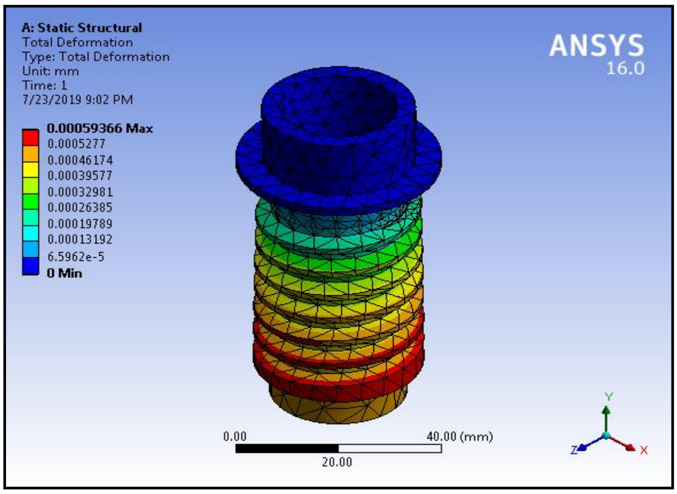


Fig 16: Total Deformation in Screw

Part Name	Maximum theoretical stress (MPa)	Von-mises stress (MPa)	Result
FLYWHEEL SHAFT	14.75	3.610	safe

Conclusion:

1. Maximum stress by theoretical method and Von-mises stress are well below the allowable limit, hence the Screw is safe.
2. Screw shows negligible deformation under the action of system of forces

V. EXPERIMENTAL VALIDATION

Test & Trial

In this part, trial test will be conducted for electromechanical single plate clutch designed in earlier chapters. The main objective for this trial test would be to study the characteristics of Load vs Speed, Torque vs speed, power vs Speed and efficiency vs speed. These characteristics will help to conclude the efficiency & effectiveness of the electromechanical single plate clutch.

In order to conduct test trial, a dyno brake pulley cord, weight pan are provided on the output shaft as in the trial run load need to be applied on output shaft.

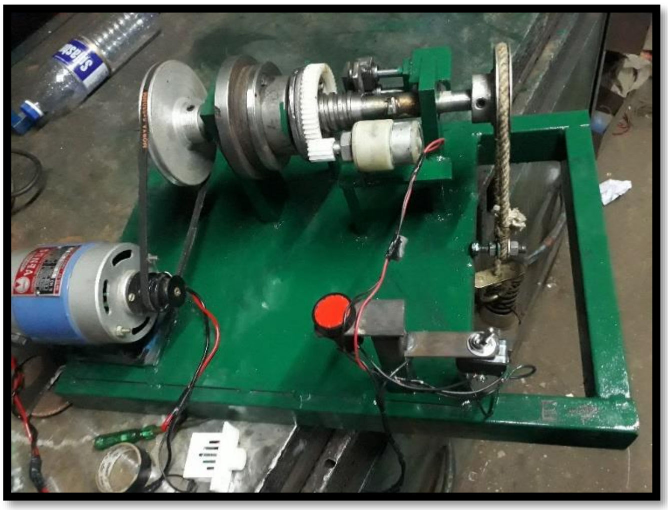
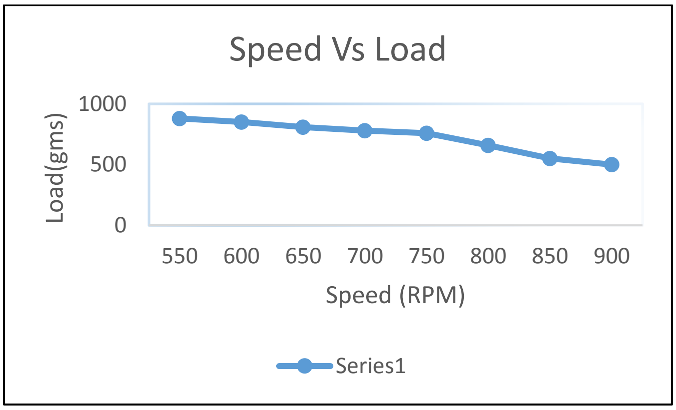


Fig 17: Experimental setup of Automatic clutch test rig

Result Table:

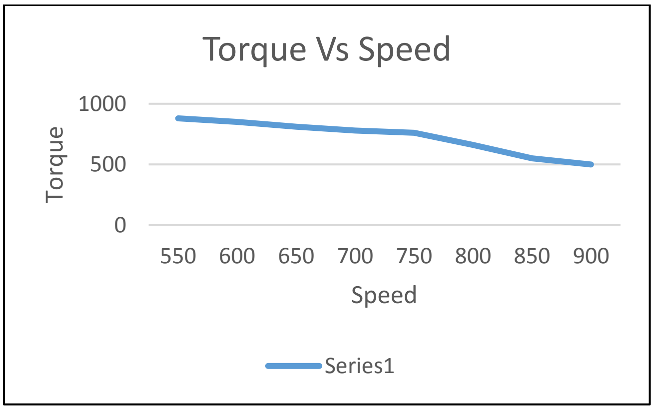
Graphs : Speed Vs Load



Graph 1: Speed vs Load

The graph plotted between Speed & load shows speed drops with increase In load

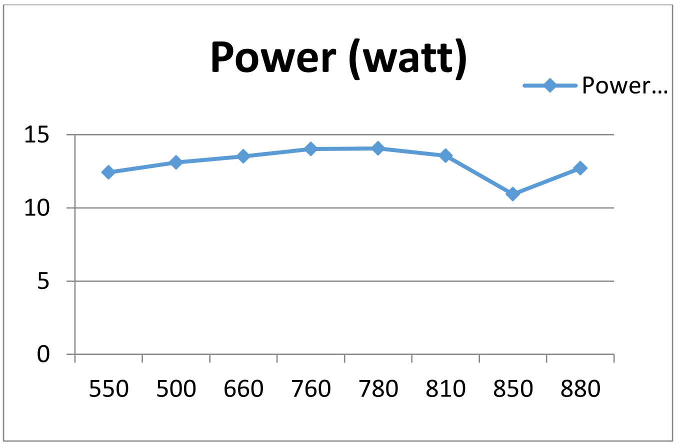
Torque Vs Speed



Graph 2: Torque vs Speed

The torque increases with decrease in speed

Power Vs Speed

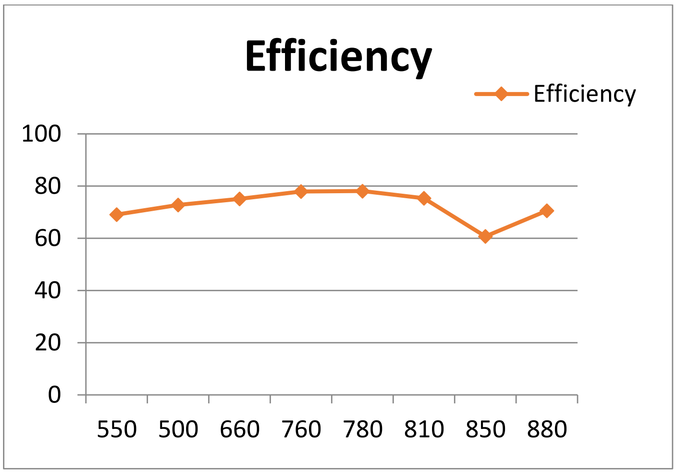


Graph 4: Power vs Speed

SR.No	Load (gms)	Speed (rpm)	Torque (N-m)	Power (watt)	Efficiency
1.	550	880	0.134875	12.42	69.05556
2.	600	850	0.14715	13.1	72.77778
3.	650	810	0.159412	13.52	75.11111
4.	700	780	0.171674	14.02	77.88889
5.	750	760	0.17658	14.06	78.11111
6.	800	660	0.1962	13.56	75.33333
7.	850	550	0.208642	10.93	60.72222
8.	900	500	0.220724	12.71	70.61111

The power output of clutch is seen to be maximum at 750 rpm

Efficiency Vs Speed



Graph 5: Efficiency vs Speed

The clutch is seen to have maximum efficiency at 750 rpm

VI. CONCLUSION

The design of the Flywheel shows that the maximum stress induced calculated using theoretical method as well as the analytical method is well below the allowable stress in the material of the part hence it is safe, so also deformation is negligible.

The design of the Pressure Plate shows that the maximum stress induced calculated using theoretical method as well as the analytical method is well below the allowable stress in the material of the part hence it is safe, so also deformation is negligible.

The design of the Clutch plate shows that the maximum stress induced calculated using theoretical method as well as the analytical method is well below the allowable stress in the material of the part hence it is safe, so also deformation is negligible.

Design of Input & Output shaft also shows that the maximum stress induced calculated using theoretical method as well as the analytical method is well below the allowable stress in the material of the part hence it is safe, so also deformation is negligible.

Design for auto clutch actuation parts are also found safe as maximum stresses induced are less than that of maximum stresses.

Testing revealed that

- ✓ Automatic clutch was developed with speed dependent engagement.
- ✓ The automatic disengagement was achieved through the application of solenoid
- ✓ The Speed of the clutch drops with increase in load
- ✓ The torque drops with in speed and the rise in torque is observed when speed drops
- ✓ The clutch offers maximum Power at 750 rpm
- ✓ The clutch offers maximum efficiency at 750 rpm

1. The design of the Flywheel shows that the maximum stress induced calculated using theoretical method as well as the analytical method is well below the allowable stress in the material of the part hence it is safe, so also deformation is negligible.
2. The design of the Pressure Plate shows that the maximum stress induced calculated using theoretical method as well as the analytical method is well below the allowable stress in the material of the part hence it is safe, so also deformation is negligible.
3. The design of the Clutch plate shows that the maximum stress induced calculated using theoretical method as well as the analytical method is well below the allowable stress in the material of the part hence it is safe, so also deformation is negligible.

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Cite this article as :

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