Design and Analysis of Compliant Centrifugal Clutch

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Abstract -- The stresses and deformations of an automotive compliant centrifugal clutch are presented in this study based on the materials used. For mechanical clutches to be durable and compact, an accurate forecast approach of maximum structural stress should be needed. The ANSYS software suite was used to do the numerical analysis. As a result, the strains and deformations that occur on the clutch during vehicle operation may be calculated. In this thesis, one of the steel alloys is investigated AISI 4140. Due to their relative flexibility, carbon content and tensile strength, steel alloys are examined. Fusion 360 software is used to develop and model a compliant centrifugal clutch. It is composed of a rigid body since revolving joints have been replaced with flexible segments. Flexible segments can be used as energy stores, further reducing revolving joints can reduce backlash and wear. In many situations, a compliant mechanism may maintain or even increase performance, and it is less costly than a traditional clutch.

Index Terms -- Clutch, stress, deformation, material, ANSYS, vehicle exploitation, static analysis, fusion 360.

I. INTRODUCTION

A clutch is a machine component that connects a driving shaft to a driven shaft, allowing the driven shaft to be started or stopped at will while the driving shaft remains unaffected. The driven shaft must stop in order to change gear or stop the vehicle, but the engine must continue to operate. As a result, the driven shaft must be disengaged from the driving shaft.

A centrifugal clutch is an automated clutch that operates by using centrifugal force. When the rotational speed is low, the output shaft is disengaged position; as the rotational speed increases, the output shaft engages with the driving shaft. It's used in mopeds, underbone, lawn mowers, go-karts, chainsaws, mini motorcycles and certain paramotors and boats to protect the engine from stalling when the output shaft is slowed or stopped abruptly, as well as to relieve load during starting and idling.

This compliant centrifugal clutch works on a principle of compliant mechanism. Compliant mechanisms rely on the deflection of its parts to achieve some or all of their motion. A single flexible link in a compliant mechanism frequently substitutes two or more rigid links in an equivalent rigid-body system. Compliant centrifugal clutches include only one plate, making them easier to produce and more cost effective than typical centrifugal clutches. It has the potential to generate greater torque than a traditional centrifugal clutch. The flexible segment, that store potential energy, may be used to replace springs and the reduction in revolute joints lowers backlash and wear. The rigid body mechanism of the compliant clutch was created using a graphical approach of dimensional synthesis. A mechanism is assessed and a specific force-deflection relationship is constructed.

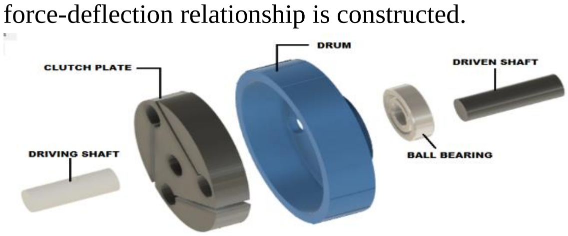

Figure 1 Parts of compliant centrifugal clutch

II. LITERATURE REVIEW

For millennia, clutches and brakes have been employed. General design formulae for clutches and brakes have been thoroughly established throughout Crane, Nathan B.[1] went through an evaluation of existing centrifugal clutch ideas. To create successful novel centrifugal clutch ideas, researchers employed the pseudo-rigid body model (PRBM), rigid-body replacement synthesis, force-deflection analysis, compliance potential evaluation and compliant concept evaluation in the previous century.

Weight, Ryan G. [2] produced high-torque, low-cost floating opposed arm clutches with important performance features. For the Hoffco-Comet, floating-opposing-arm (FOA) and floating 1 (F1) clutches, contact engagement speed and torque capacity models were developed.

Srivastava, Jay Prakash [3] Studied the construction of a go-kart that helps students learn about all of the divisions involved in vehicle design, such as chassis, steering, gearbox, and brakes. In every vehicle, including go karts, the engine dictates the vehicle's speed and power.

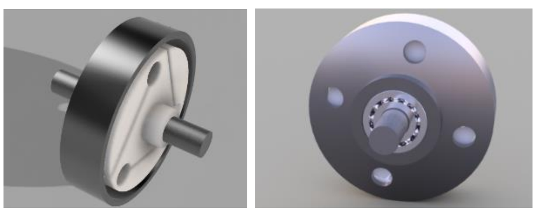

Figure 2 Compliant centrifugal clutch

III. PROBLEM STATEMENT AND OBJECTIVES

3.1 Problem statement

After reading several research papers, blogs, and books, the concept of a compliant centrifugal clutch was developed, as well as its design, to address the issues with traditional centrifugal clutches. Because in traditional centrifugal clutches several pieces are involved and due to which the mass producing them is relatively difficult. The torque transmitted by a traditional centrifugal clutch is modest. Clutches are less likely to endure as long due to backlash and wear.

3.2 Objectives

The material used in the compliant centrifugal clutch is a high strength deformable material that does not have many pieces. It just has a single plate that deforms to interact with the outer drum. Because the compliant centrifugal clutch has just one plate, it is simple to make and delivers higher torque. It is also more cost effective than typical centrifugal clutches. Using this style of clutch eliminates the problem of backlash and wear.

3.3 Justification

This concept will be significant for the industry since its purpose is to provide cost-effective power transmission. It is also easy to manufacture. The clutch deforms elastically and engages with the drum successfully. All of the design and simulation were completed using FEA software.

IV. METHODOLOGY

A research project's methodology is the manner through which it is carried out. The corpus of techniques and concepts linked with a topic matter are the focus of this form of examination. A study must be designed in such a manner that the results are valid and trustworthy and match with the study's aims and objectives. Many strategies are used in the right design of a compliant centrifugal clutch in order to get the required clutch. The following were the approaches used in this study:

4.1 Material selection

For a successful engineering design process, material selection is critical. Materials must be chosen for their technical performance as well as their user-centered attributes in order for goods to be successful. Here the materials are selected on the basis of relative flexibility, ultimate tensile strength, conductivity, density and carbon %.

4.2 Modelling

Modeling creates a visual representation of the system to be built. The representation of a model, as well as its creation and functioning, are all part of this process. Following the selection of the material, a model is generated in the Autodesk Fusion 360 programme, which provides a 3D perspective and aids in the comprehension of the clutch design.

4.3 Simulation

Models are used in simulations to mimic the operation of real-world processes or systems. The simulation depicts how the model changes over time under various situations. During this step, the 3-D model is analyzed for total deformation, stress, temperature, and other factors.

4.4 Fabrication

Fabrication is the process of integrating usually standardized pieces with one or more separate procedures to create products. A 3-D print model of a compliant centrifugal clutch is created as a prototype in this project, with the clutch plate made of ABS and drum is made up of PLA material.

V. DESIGN

The compliant mechanism, i.e. the flexible link, is used to construct the compliant centrifugal clutch in this project. Fusion 360 software is used to create the 3-D model of the compliant centrifugal clutch. The compliant centrifugal clutch was designed using the design and specifications of the Moosun centrifugal clutch, which is used in Go-karts and Mini bikes[3]. Around 2,000 rpm, this clutch begins to engage and will lock up around 2,600 rpm. So, when designing the clutch, many criteria were taken into account, such as the diameter of the drum, the diameter of the clutch plate, the thickness, and this clutch should also engage with the drum at 275 rad/s.

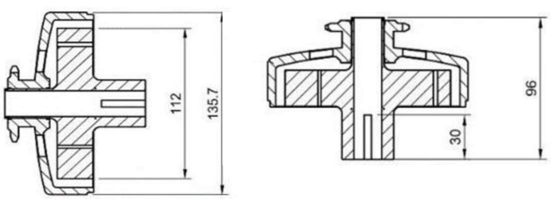

Figure 3 Specifications of compliant centrifugal clutch

5.1 Technical specifications and values

Symbols	Properties	Values
D	Diameter of the Drum	13.5 cm
D_1	Diameter of the clutch	11.2 cm
F	Centrifugal Force produced	4605.56 N
M	Mass of the clutch	2.1004 Kg
T	Thickness of the clutch	1.22 cm
D2	Diameter of each slot	2.16 cm
W	Width of the slot	1 cm
D3	Diameter of centre hole	2 cm

Table 1 Technical specifications and values of compliant centrifugal clutch

VI. MATERIAL SELECTION

A good engineering design process requires careful material selection. The component must be strong and dependable in order to function under extreme circumstances. The safety aspects should be addressed while designing any component. As a result of poor material selection, any component might fail catastrophically. As a result, when building the Compliant centrifugal clutch, safety is the primary consideration. Material selection is a very vital step in the process of machine design.

For compliant centrifugal clutch the main three factors which are mainly considered are:

- The Relative Flexibility of a material should be more which is the ratio of yield stress to modulus of elasticity.
- The carbon content should be less so that material should be less brittle and more ductile.
- The strength of material should be good for bearing stresses and stay long.

Following are the five specimen of steel alloys that are being selected for our study:

Steel alloys

1. AISI 5160
2. AISI 316L
3. AISI 304
4. ASTM A815
5. AISI 4140

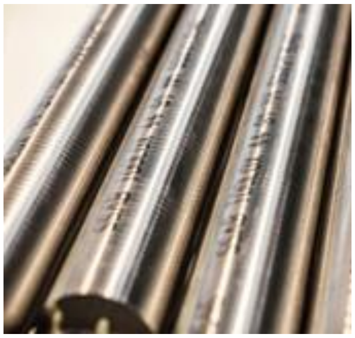
Figure AISI 5160[4]


Figure ASTM A815[5]


Figure AISI 4140[6]


Figure AISI 304[7]

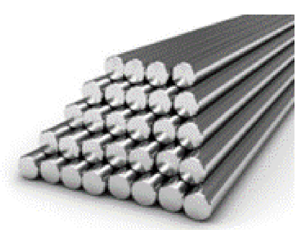
Figure AISI 316L [8]

Figure 4 Different specimens of steel alloys

STEEL ALLOYS	YIELD STRESS (Mpa)	MODULUS OF ELASTICITY (Gpa)	ULTIMATE TENSILE STRENGTH (Mpa)
AISI 5160	275	195	724
AISI 304	190	193	600
ASTM A815	205	415	415
AISI 316L	205	193	530
AISI 4140	415	210	655

Table 2 Yield stress, modulus of elasticity and ultimate tensile strength of different specimens of steel alloys

STEEL ALLOYS	DENSITY (g/cm3)	CONDUCTIVITY (W/mK)	CARBON %
AISI 5160	7.85	46.6	0.6
AISI 304	8.0	16.2	0.7
ASTM A815	7.6	15	0.5
AISI 316L	8.0	15	0.8
AISI 4140	7.85	42.6	0.38

Table 3 Density, conductivity and carbon% of different specimen of steel alloys

After comparing all these five steel alloys on the basis of their relative flexibility, ultimate tensile strength, carbon content, density and conductivity the steel alloy which is selected or used for making clutch plate is AISI 4140. Basically, the AISI 4140 has more relative flexibility and ultimate tensile strength which makes it high strength deformable material and due to less carbon content, it is flexible in nature.

In this project, the selection of materials is based upon only on few parameters. Material selection is a completely different and vast scope, choosing a perfect material for the clutch plate will divert the main scope of the project and also changing the material will surely change the analysis and calculation of the project.

VII. COMPONENTS OF CLUTCH

The Compliant centrifugal clutch comprises of five parts:

- DRIVING SHAFT
- CLUTCH PLATE
- DRUM
- BALL BEARING
- DRIVEN SHAFT

However, with respect to design analysis of clutch, the following parts are important:

- CLUTCH PLATE
- DRUM

7.1 CLUTCH PLATE

The friction material is linked to the spinning element of the clutch, called the clutch disc or clutch plate. The friction of the friction material pads on each side of the clutch disc generates clutch torque. Equal pressure on both sides of the clutch disc disengages the clutch, enabling the torque converter to function normally. Under clamping pressure, the clutch sandwiches the clutch disc between two frictional, matched surfaces.

Figure 5 3-D and 2-D model of clutch plate

7.2 DRUM

An automatic transmission's transmission drum is an important component. It links the center or sun gear of the gearbox to the clutch pack's external half. Because manually driven gears glide along shafts to engage or disengage, manual gearboxes do not require transmission drums. Because automatic transmission gears do not move except to spin, a distinct technique of engaging and disengaging transmission gears is utilized.

Figure 6 3-D and 2-D model of drum

VIII. SIMULATION AND ANALYSIS

8.1 STRUCTURAL ANALYSIS

In this project the structural analysis of Compliant centrifugal clutch is performed by giving rotation velocity as load to the clutch plate and cylindrical support to the shaft with proper contact definition between the parts and structured mesh. This analysis results show the total deformation, equivalent stress and some contact tools like status, gap, frictional stress and penetration.

8.1.1 Boundary conditions

Contact- When the clutch plate gets engaged with the drum, there is a contact between the clutch plate and the drum which is a frictional contact whose friction coefficient is 0.2.

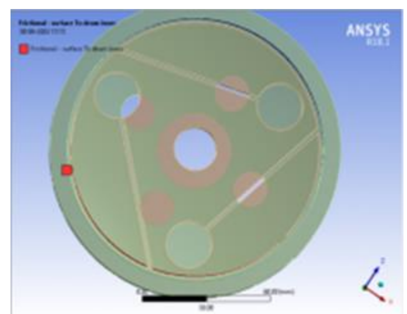

Figure 7 Frictional contact between the clutch plate and the drum

Mesh- The meshing of Compliant Centrifugal clutch is homogeneous with no. of elements as 22737 and no. of nodes as 112902.

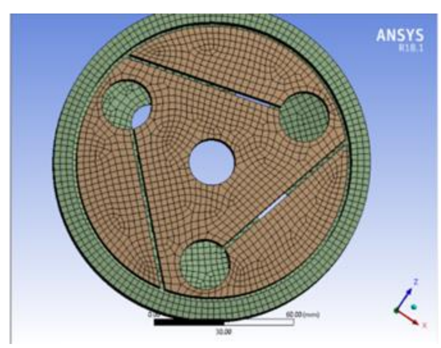

Figure 8 Meshing of Compliant centrifugal clutch

MESH QUALITY- Generally the quality of meshing is checked by skewness or element quality.

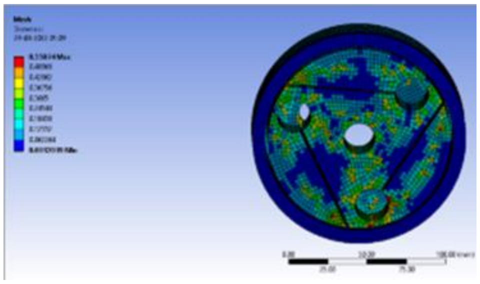

Figure 9 Skewness (0.55074)

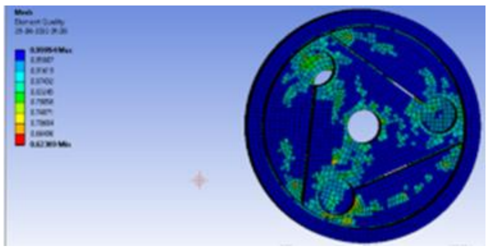

Figure 10 Element quality (0.99994)

Load- In this analysis, a load is acting on the body in the form of centrifugal force due to the rotational velocity given to the clutch plate as 275 rad/s in the form of tabular data.

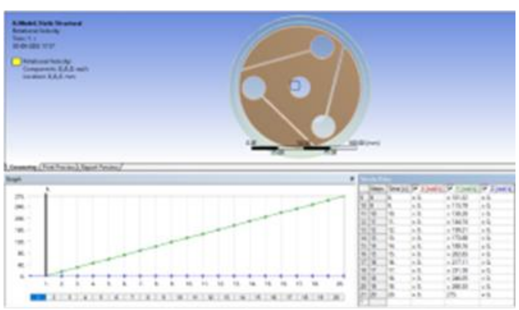

Figure 11 Rotational velocity given to clutch plate

Support- A cylindrical support is assigned to the clutch plate and the drum where the radial and tangential motion of clutch plate and drum is allowed and axial motion is fixed.

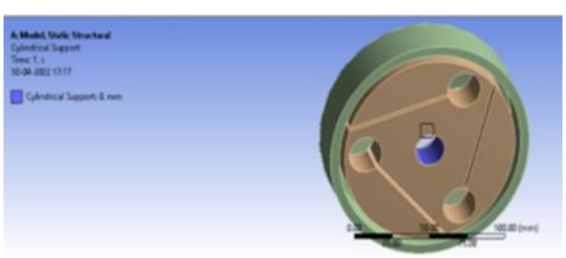

Figure 12 Cylindrical support given to the clutch plate and the drum

8.1.2 Results of structural analysis

After the simulation is completed, the first step is to check the engagement between the clutch plate and drum, there are two means, which are: the use of contact tool and; to find out the the total deformation of the clutch plate with and without drum.

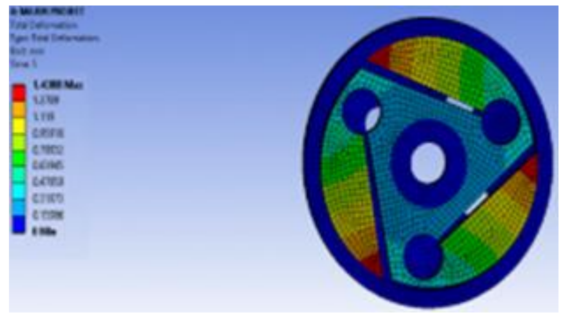

Figure 13 Deformation of clutch plate with drum(1.4388mm)

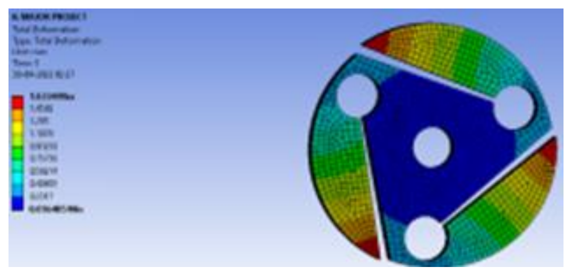

Figure 14 Deformation of clutch plate without drum(1.6334mm)

The results shows that the total deformation of clutch plate with drum is 1.4388 mm and without drum is 1.6334 mm. Here the value of total deformation in case of without drum is more as compared to with drum. And thus, the difference in both the cases is considerable, which hence prove that the clutch plate is engaged with the drum while rotating at 275 rad/s.

Status- Here, initially after giving the load which is the rotational velocity of 275 rad/s the clutch plate will first slide with the drum and then it will stick which is shown in the below figures.

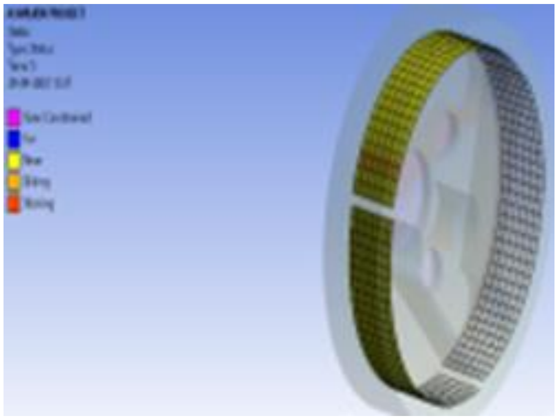

Figure 15 Sliding condition between the clutch plate and the drum

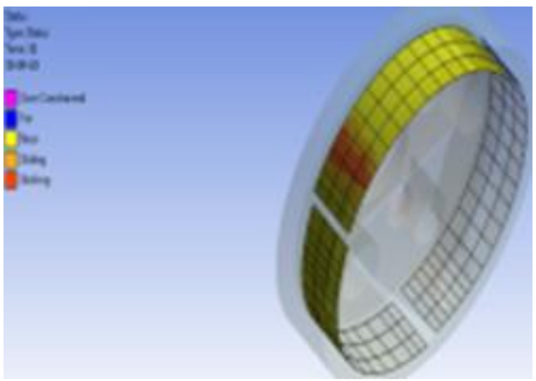

Figure 16 Sticking condition between the clutch plate and the drum

- Gap- When the clutch plate gets engaged with drum there should be no gap between the flexible links or leaf's of the clutch plate with the drum.

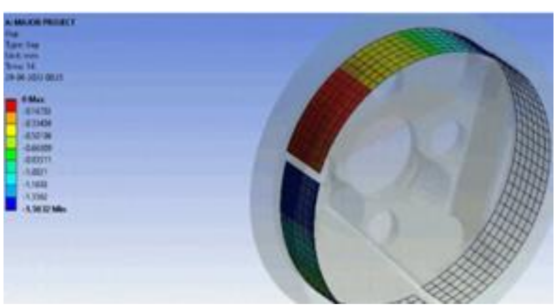

Figure 17 Gap between the clutch plate and the drum

- Penetration- There should be no penetration between the flexible links or leaf's of the clutch plate and the drum.

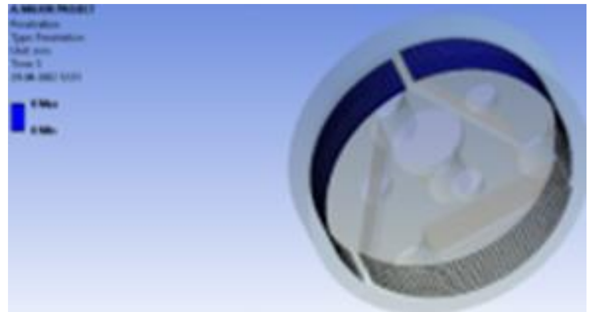

Figure 18 Penetration between the clutch plate and the drum

- Total deformation- It tells about the deflection or deformation of the flexible links of the clutch plate which is due to the centrifugal force.

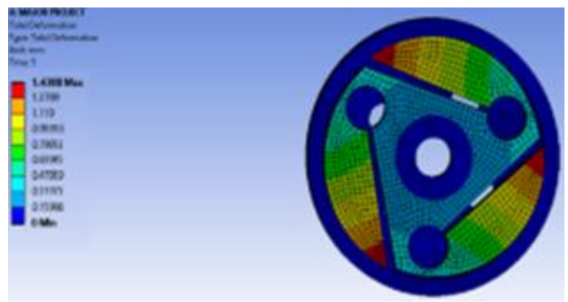

Figure 19 Total deformation in the clutch plate(1.4388mm)

- Equivalent stress- It is the stress generated on the clutch due to the centrifugal force which comes into play by the rotational velocity given to the clutch plate.

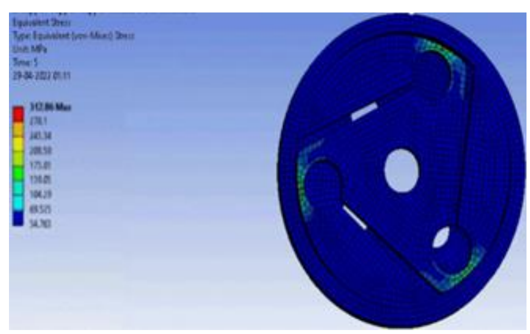

Figure 20 Equivalent stress generated on both clutch plate and drum (312.86 Mpa max)

- Frictional stress- When the clutch plate gets engaged with the drum, some friction is generated between the outer surface of clutch plate and inner surface of drum which leads to some amount of frictional stress on the clutch plate and on the drum.

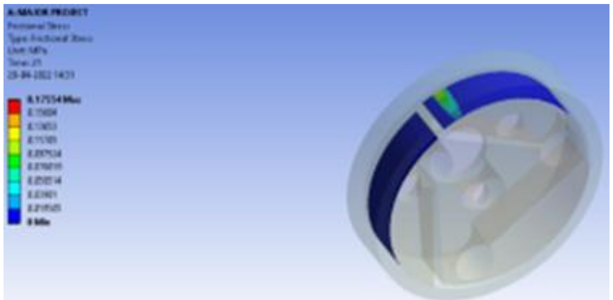

Figure 21 Frictional stress generated on the clutch plate(0.175Mpa)

8.2 CALCULATION

Consider a small element on the given diagram having centrifugal force “dF” on the element and given by the expression:

As we know that, centrifugal force acting on any mass is given by:

$\mathrm{dF} = \mathrm{m(x).dx.}\omega^2$

$\int_0^l \mathrm{dF} = \omega^2.\int_0^l \left(\frac{\mathrm{m}}{\mathrm{l}}\right).\mathrm{x.dx}$

$\mathrm{F} = (\mathrm{m.l.}\omega^2)/2$

Where,
Mass of the single leaf of clutch plate, m = 0.56 kg
Length of the leaf of clutch plate, l = 79.40mm
Angular velocity, ω = 275 rad/s
Centrifugal force, F = 4605.56 N

Assumptions:
1. Material is homogenous and isotropic.
2. Considering load distribution to be uniformly varying load (UVL).
3. Considering like a cantilever beam having UVL acting on it.
4. No damage of material takes place due to acting of load.

$\delta = \frac{11.F.l^4}{120.E.I}$ where

Young modulus of material, E= 210 Mpa

Moment of interia, I= 680.2861 cm^4

δ = 1.17 mm
Calculation of Moment of Inertia=

$$\mathbf{I} = \left(\frac{\pi.D_1^4}{64}\right) - 3 \times \left(\frac{tL^3}{12} + \frac{\pi.D_2^4}{64}\right) - \left(\frac{\pi.D_3^4}{64}\right)$$

Where values are taken from the Table 1.

8.3 Thermal analysis
In Compliant centrifugal clutch, due to slip condition some frictional stress is generated between the outer surface of clutch plate and inner surface of drum, which results in the heat generation due to wearing and friction.

8.3.1 Boundary conditions
Loads- In this analysis, convection and heat flux are the loads applied on the Compliant centrifugal clutch to find out the temperature difference between the clutch and the surroundings and directional heat flux.

Convection- For the convection heat transfer to be occur, all the surfaces of clutch plate and drum of Compliant centrifugal clutch which are in contact with surrounding temperature are selected where the film coefficient value is given as 30 W/mm^2°C & hence the convection takes place.

Figure 22 Convection given to the clutch plate and the drum

- Heat Flux- Heat flux of 1000 W/mm^2 is given to the inner rim of the drum of Compliant centrifugal clutch which occurs due to the frictional stresses between the clutch plate and the drum. Heat flux is the heat generated in the inner rim per unit area of that inner rim.

Figure 23 Heat flux given to the clutch plate and the drum

8.3.2 Results of thermal analysis

- Temperature- The temperature on the inner surface of the drum will be maximum and the temperature difference between the inner surface and outer surface of the drum is around 40°C which is sufficient for the transfer of heat from the drum to the surroundings.

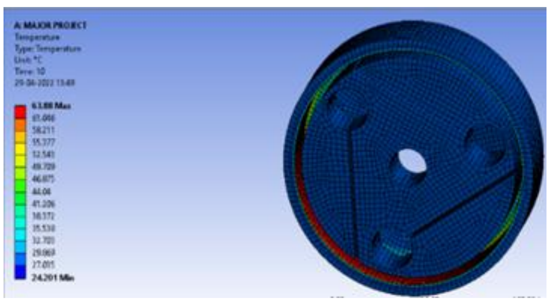

Figure 24 Temperature of the Compliant centrifugal clutch(63.88°C)

Directional heat flux- The direction of heat flux is from inner rim of the drum to its outer rim. Hence, the magnitude is also high in inner rim & decreases towards the outer rim of the drum.

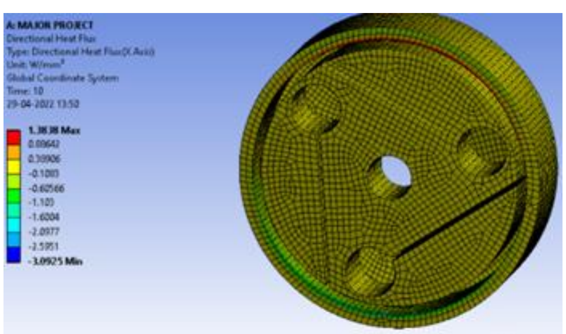

Figure 25 Directional heat flux generated in Compliant Centrifugal Clutch (1.38 W/mm^2)

IX. FABRICATION

This project uses a 3D print model as a prototype, with the clutch plate made of ABS material and the drum made of PLA material.

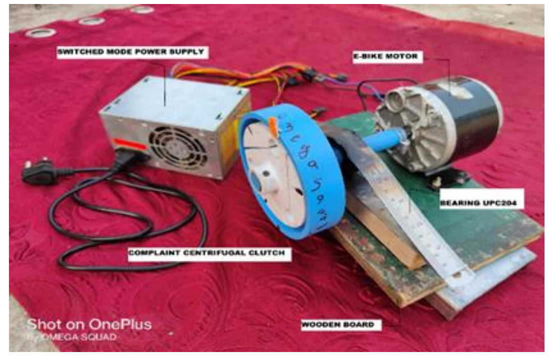

Figure 26 Experimental setup

Components-

- Compliant Centrifugal clutch.
- Ball bearing upc204.
- Ebike MY1016Z3 24V 350W
- Gear DC Motor – 324 RPM (GB)
- Switched mode power supply.
- (12 volts and 15 ampere).
- Wooden board.

Figure 27 Disengaged position

When the power is turned on, the clutch shaft starts rotating at a certain speed, which means that just the clutch plate is moving with some deflection or deformation of the flexible links, and the orange strip is utilized to see the location of the drum better. Only the clutch plate rotates with a rotational velocity less than the required rotational velocity for clutch engagement in the fig.27.

Figure 28 Engaged position

After a few seconds, when the clutch plate reaches the requisite rotational velocity or when the centrifugal force is sufficient to bend the clutch plate's flexible connections to the point where they get linked to the drum, the drum begins to rotate. Fig. 28 shows how the orange strip changes position during interaction.

X. FUTURE SCOPE

A proper experimental investigation of Compliant centrifugal clutch made up of AISI 4140 steel alloy has to be done for the accurate validation of FEA results.

CONCLUSION

Following the analysis and outcome section, the following findings were found:

1. After giving the rotational velocity to the clutch plate, the compliant centrifugal clutch at a particular rad/s gets engaged by deformation of the flexible link of the clutch plate with the drum which is the property of the compliant mechanism on which this clutch is working.
2. The results coming from the analytical method is comparable to the results got from the FEA structural analysis.
3. A 3-D print model has been made of compliant centrifugal clutch as a prototype and a rotational velocity is given to the clutch plate which engages with the drum successfully at some particular rad/s due to the deformation of the flexible links and this deformation is because of the centrifugal force produced in the clutch plate.

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