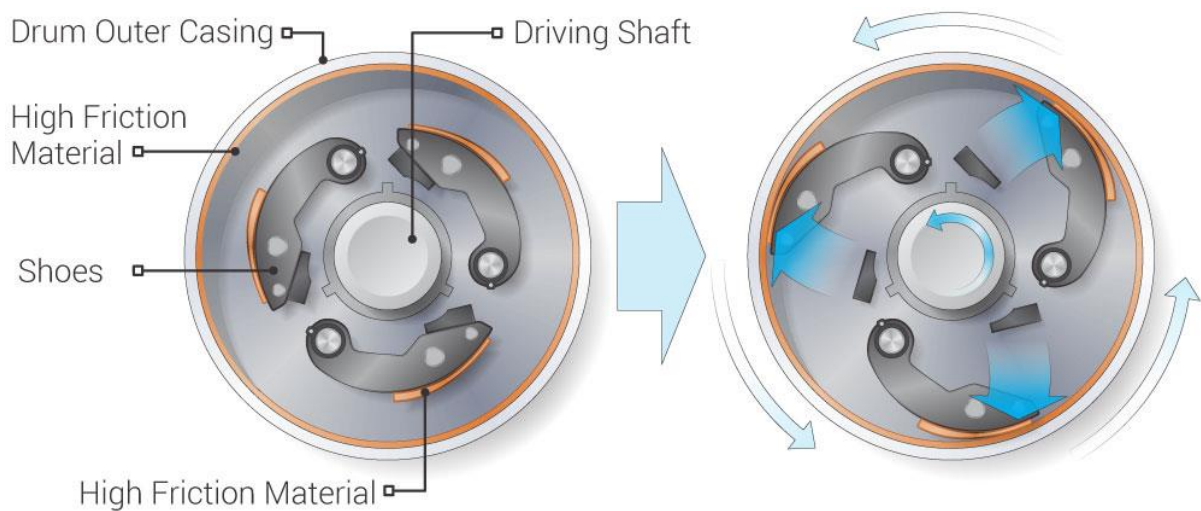


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ACMA5010 Stress Analysis and Dynamics

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Contents

1	List of figures.....	1
2	Abstract.....	2
3	Introduction	3
3.1	Task A.....	3
3.2	Task B.....	3
4	Development of Centrifugal clutches.	4
4.1	History of the centrifugal clutch.	4
4.2	Types and application of centrifugal clutches.	4
4.3	Mechanics and materials of centrifugal friction clutch	4
4.3.1	Friction pads/lining.....	5
4.3.2	Drum.....	6
4.3.3	Tension spring	7
4.4	Applications of centrifugal clutch	7
4.5	Advantages and disadvantages	7
4.5.1	Advantages.....	7
4.5.2	Disadvantages	8
5	Electromagnetic clutch.	9
5.1	Application.....	9
5.2	Advantages	10
5.3	Disadvantages.....	10
6	Task B	11
6.1	Question 1- What is the outer diameter of the drum?	12
6.2	Question 2- Determine the engagement speed of the centrifugal clutch in (RPM) revolutions per minute.	12
6.3	Question 3- Calculate the radial force acting on the clutch face when the driving shaft is rotating at a speed of 550 RPM.	13
6.4	Question 4- At the driving shaft speed of 550 RPM, what will be the value of torque transmitted to the driven shaft?.....	14

6.5	Calculate and plot on a suitable graph the transmitted torque at the driven shaft against driving shaft speed, from 450 RPM to 700 RPM in increments of 25 RPM.....	15
6.6	Question 6- Undertake the same analysis as in point 5 above but adopt a coefficient of friction of 0.3 and 0.4. Discuss the effect of changing the coefficient of friction of the shoe material on the torque transmitted when comparing the three values of coefficient of friction. ..	16
6.7	Question 7- For the maximum possible transmitted torque determined from either point 5 or 6 above, and given that the mass of the drum is 750 grams and can be considered as a solid disc, what is the angular acceleration of the drum to achieve the maximum possible torque?	17
6.8	If the driven shaft had a diameter of 17.5 mm and a constant tangential braking force of 500 N was applied to the driven shaft, determine the maximum possible angular acceleration for the drum as given in point 7 above	18
7	Conclusion.....	19
8	References	20

1 List of figures

Figure 1-Centrifugal clutch (Yousef, 2024)	5
Figure 2-(a) Normal friction liner and (b) grooved friction liner (Panchal, et al., 2023).....	6
Figure 3- Centrifugal clutch engaged and disengaged clutch (Toulas, 2018).	6
Figure 4-Electromagnetic clutch schematic (EMWorks, 2024).....	9
Figure 5-Schematic of Electromagnetic clutch found in industrial robot (Sepac, 2024).	10
Figure 6- Centrifugal clutch (Kholi, et al., 2019)	11
Figure 7- Microsoft Excel graph showing the torque T at the driven shaft and the driving shaft (RPM) with the Friction coefficient (μ) = 0.35 (Purnell-Whitehead, 2024).....	15
Figure 8-Microsoft Excel graph showing three centrifugal clutch shoes with varying values of friction coefficients and their relationship between Torque and RPM (Purnell-Whitehead, 2024).....	16

2 Abstract

This paper examined the centrifugal clutch, a vital component in automated torque transmission, particularly in small engine, industrial equipment and recreational equipment. Centrifugal clutches automatically engage and disengage based on engine speed by utilizing centrifugal force on rotating shoes, which upon reaching the threshold speed, contact is made with the drum to transmit torque to drive the component. Developments in the early 20th century centrifugal clutches provided simple, low maintenance and smooth torque transfer.

The analysis includes a discussion on clutch design, materials and mechanics, specifically focusing on frictional interactions and the roles of springs in controlling clutch engagement. Utilizing finite element analysis.

Additionally, the paper explores the electromagnetic clutch as a contemporary alternative in automation applications.

An applied engineering analysis is conducted, calculating engagement speeds, torque transmission and the effects of varying friction coefficients on clutch performance.

3 Introduction

3.1 Task A

A centrifugal clutch is a type of automatic clutch mechanism that engages or disengages power transmission in a mechanical system based on centrifugal force. It used rotating weights or clutch shoes that move outward due to the centrifugal force as the rotational speed increases, engaging with the clutch drum or outer casing. This engagement transmits torque from the driving component, For example an engine to the driven component such as a chain or gear. When rotational force decreases, causing the clutch shoe to retract the clutch will disengage and stop the torque transmission. The role of a centrifugal clutch is primarily to provide an automatic means of engaging and disengaging power transmission depending on the changes in rotational speed.

The principles behind the centrifugal clutch emerged in the late 19th century. Engineers were exploring mechanisms using centrifugal force for automated engagement, especially where manual operation was impractical. Early patents for centrifugal clutch designs date back to the early 20th century. During a period of rapid industrialization where machines like steam engines and early internal combustion engines required new forms of torque management. Design using the same principles can be found today in other applications such as motorbikes, lawn mowers and go-karts (Toulas, 2018).

The purpose of this paper is to examine the development, materials, applications and the advantages of centrifugal clutches and discuss the role of electromagnetic clutches in current automation technologies.

3.2 Task B

The aim of Task B is to answer all 8 questions on the centrifugal clutch with the information given in the brief.

4 Development of Centrifugal clutches.

4.1 History of the centrifugal clutch.

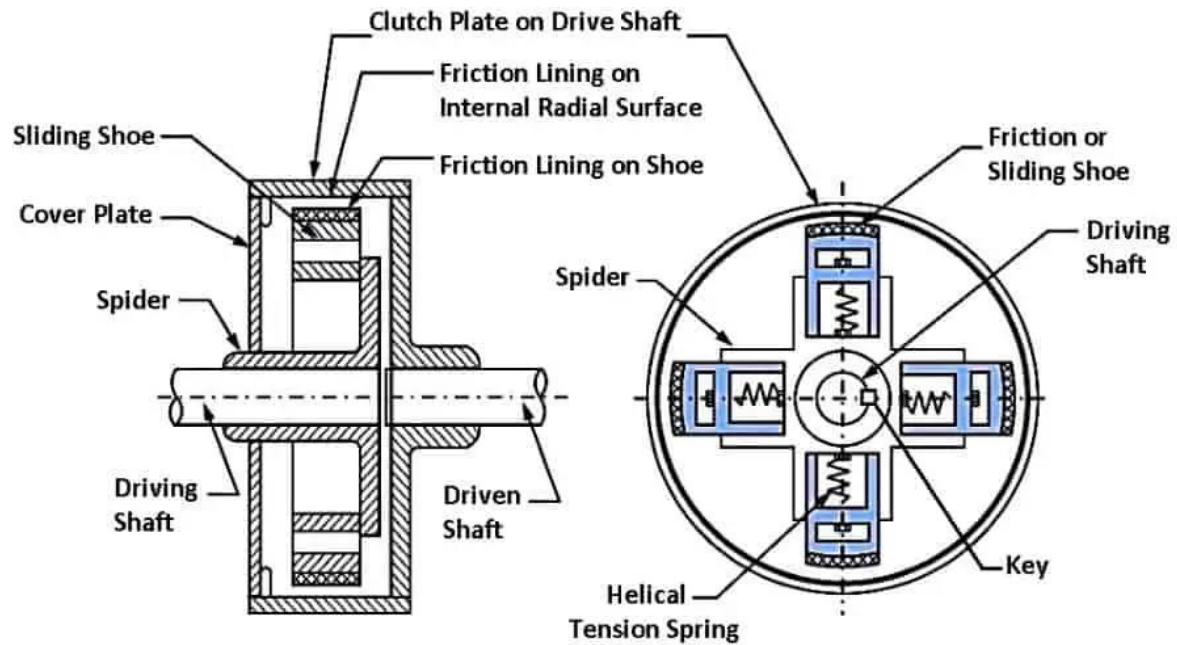
The centrifugal clutch is closely linked to advancements in automatic transmission and automotive engineering. It was widely used as a launch mechanism in various automotive applications particularly from the mid-1950s to the mid-1960, it was at this time several European manufacturers introduced the clutch free options (Just-Auto, 2017).

4.2 Types and application of centrifugal clutches.

One type of centrifugal clutch known as a pivoted or expanding shoe clutch, typically used in industrial applications but has also been adapted for use in the automotive sector. This design can work alongside hydrokinetic couplings to improve and minimise slippage after the drive is engaged. Dry plate clutches are also known for their ability to engage automatically while still allowing disengagement during gear shifts irrespective of the rotational speed (Tridgell, 1969). You will also find centrifugal clutches in other specialized applications such as sprag clutches, where they utilize the centrifugal force to eliminate premature wear. This allows for higher operation speeds and longer lasting durability (Rusnack & Tyson, 1982).

4.3 Mechanics and materials of centrifugal friction clutch

The centrifugal clutch is a mechanical component that uses centrifugal force to link two concentric shafts. As the engine speed increase, the clutch shoes, held by extension springs, move outward, allowing the shoe to engage with the drums inner surface through friction linings. Understanding the contact behaviours between these lining is essential for clutch design. If unwanted contact conditions arise, it can lead to judder, a torsional vibration issues within the clutch system, which is typically analysed by examining the relationship between friction coefficients in sliding speeds. Additionally, contact pressure ratio and temperature play key roles in explaining judder occurrences. The friction coefficient in sliding contact is influenced by contact pressure and relative sliding speed. Finite element analysis (FEA) is a widely used numerical method for designing clutches, though it can be time-consuming, especially for dynamic issues involving deformable contact or impact.



Parts of Centrifugal Clutch

Figure 1-Centrifugal clutch (Yousef, 2024)

Figure 1 show the components that make up the centrifugal clutch.

4.3.1 Friction pads/lining

Typically made with asbestos material, which is harmful to the environment and human health. Non-asbestos material offers a safer multi-material design that will deliver the performance properties. (Kholi, et al., 2019). Operates with the same logic as a clutch friction plate found in manual transmission vehicles. Attached to the outer section of the shoe (Yousef, 2024).

When choosing a friction material understanding that slippage within the clutch causes heat. Therefore, the friction material chosen should be able to perform whilst hot and still maintain its function. (Kholil, et al., 2021) . Kholils study looks at the use of wood powder, coconut fibre and green mussel shell composite for motorcycle centrifugal clutch pads.

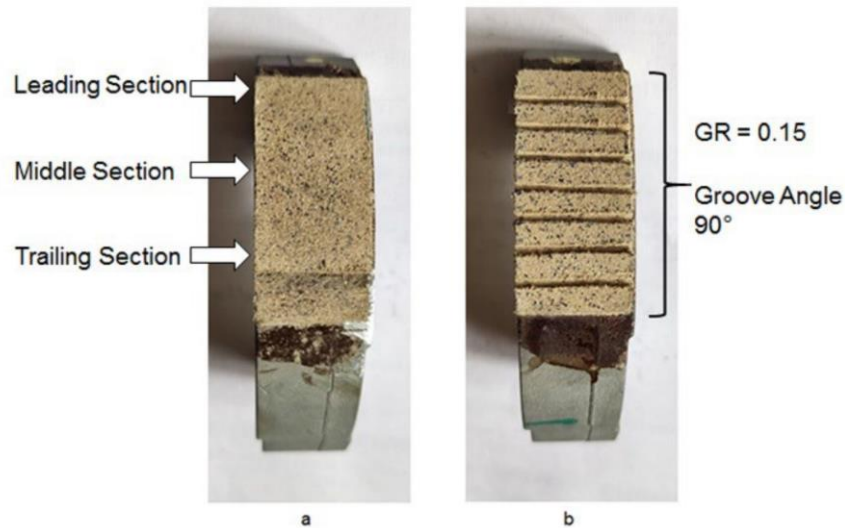


Figure 2-(a) Normal friction liner and (b) grooved friction liner (Panchal, et al., 2023)

4.3.2 Drum

The Drum is generally manufactured from steel is the component that encloses all the components of the clutch. It is the outer part of the clutch that rotates in conjunction with the crankshaft of the engine. As the engine RPM increases so does the centrifugal force, forcing the shoes containing the friction pad to contact in the inner surface of the drum. The surface of the drum is also made of high friction material. It is at this point the transfer of drive from the engine to the transmission takes place. This is shown in figure 3 (Toulas, 2018)

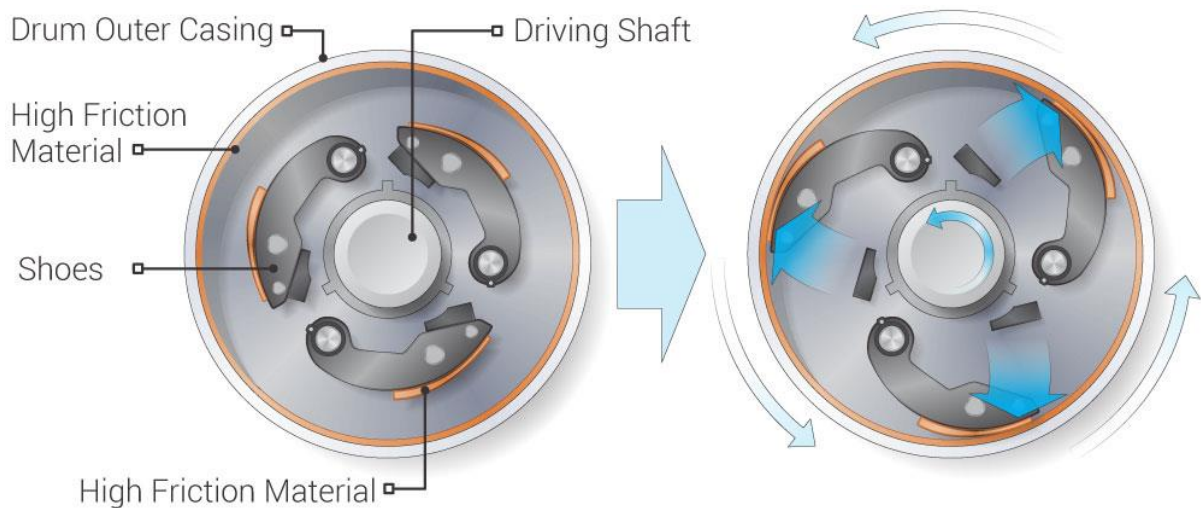


Figure 3- Centrifugal clutch engaged and disengaged clutch (Toulas, 2018).

4.3.3 Tension spring

The spring is used to limit the contact between the pad lining and the inner surface of the drum. The centrifugal force generated would need to overcome that of the spring to be able to engage drive.

Springs can be changed and/or modified as required to alter the desired force required to engage and disengage the drive. Depending on the integrity of the spring will determine the point of contact. Typically made from steel alloy that provides the necessary strength and fatigue resistance to retract the shoes at low speeds.

4.4 Applications of centrifugal clutch

Centrifugal clutches are widely used in small, motor driven equipment when automatic engagement is required. Applications include:

- **Small engine equipment:** lawn mowers, disc cutters and chainsaws as well as other garden tools where minimal input from the user is required as only engine speed is required to control operation.
- **Recreational vehicles:** Scooter, Go-kart and mini-bikes and other low power vehicles use centrifugal clutches. Advantageous for easy operation for example children's minibikes where a manual transmission is not required.
- **Industrial machinery:** Industrial equipment that requires simplified controls and consistent RPM benefit from this system.

4.5 Advantages and disadvantages

4.5.1 Advantages

There are many advantages of the centrifugal friction clutch such as:

- **Automatic engagement**-as previously mentioned in the applications. Where minimal user input is required in operation.
- **Simplicity and a low maintenance**- A straight forward system with relatively few moving parts, this minimises the likelihood of mechanical failure and reduces cost of maintenance.
- **Smooth power transfer**- As the shoes progressively contact the drum, a smooth engagement occurs and reduces the amount of judder and jerking from sudden power transfer.
- **Overload protection**-When the RPM falls below a certain threshold the clutch disengages. For example, when an excessive load is applied, and the vehicle slows down the clutch will disengage preventing any damage or engine stall.

4.5.2 Disadvantages

The system does however have drawbacks:

- **Limited torque capacity and power range**-Should its application require a high torque the system would be limited and unsuitable for high load capabilities. Given the applications mentioned in the advantages. The low power range could also be considered as a benefit. A child's minibike could benefit as it would limit power and thus be safer for children.
- **Heat generation and wear**-As the system uses friction. Heat is generated. Excessive amount of heat can lead to premature wear.
- **Lack of manual control**-As the transmission is automatically controlled, the user is limited. Should a load be applied and the need for a manual downshift be required to overcome the load, this function is unavailable.

5 Electromagnetic clutch.

5.1 Application

Electromagnetic clutches operate in way of remote activation without mechanical linkage, making the suitable for printing machines, conveyor systems, copiers and factory automation. They are also used in modern vehicles in air condition compressors (EMWorks, 2024). This is advantages as it allows the clutch to be engaged and disengaged at any desired time even while engine is running and not relying on a required RPM to be able to function.

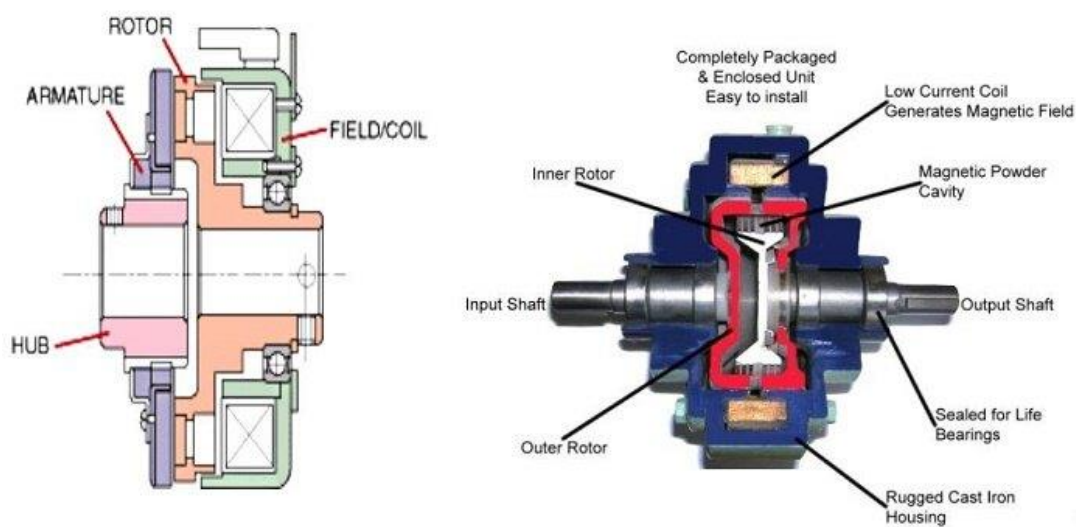


Figure 4-Electromagnetic clutch schematic (EMWorks, 2024)

An electromagnetic clutch transfers power from the primary drive shaft to a second on through electrical activation. Typically containing three main parts. The fixed drive shaft to which a stationary electromagnet is attached. A rotor mounted shaft and an armature that link the clutch hub to the secondary shaft which is often connected by a belt. When a voltage is applied a magnetic field is formed, engaging the rotor and armature connecting the primary and secondary shafts.

Applications of electromagnetic clutches:

Conveyor systems- used in factory production line conveyor systems, allowing progression of production in a timed and controlled manner.

Industrial robots- Robotic play a vital role in the manufacturing industry. Electromagnetic clutches play a vital part in control these robots.

Used in lathes, mills, and other machining equipment to control spindle rotation and tool engagement.

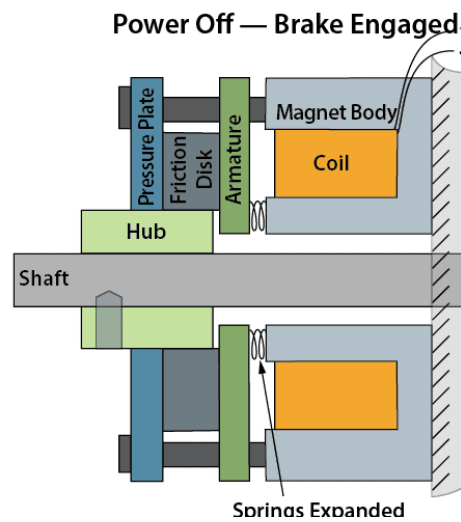


Figure 5-Schematic of Electromagnetic clutch found in industrial robot (Sepac, 2024).

5.2 Advantages

- Enables rapid engagement and disengagement, allowing quick response time.
- Smooth gradual engagement to reduce shock and wear.
- Precise control overpowering transmission
- Can be remotely operated.
- Fewer moving parts leading to reduced maintenance.
- Only consumes power when engaged.

5.3 Disadvantages

- Dependant on electrical power, making the susceptible to power interruptions or failures
- Efficiency may drop at high rotational speeds due to other electromagnetic fields
- Potential to electromagnetic interference to other nearby devices
- Limited durability under sudden or excessive loads

6 Task B

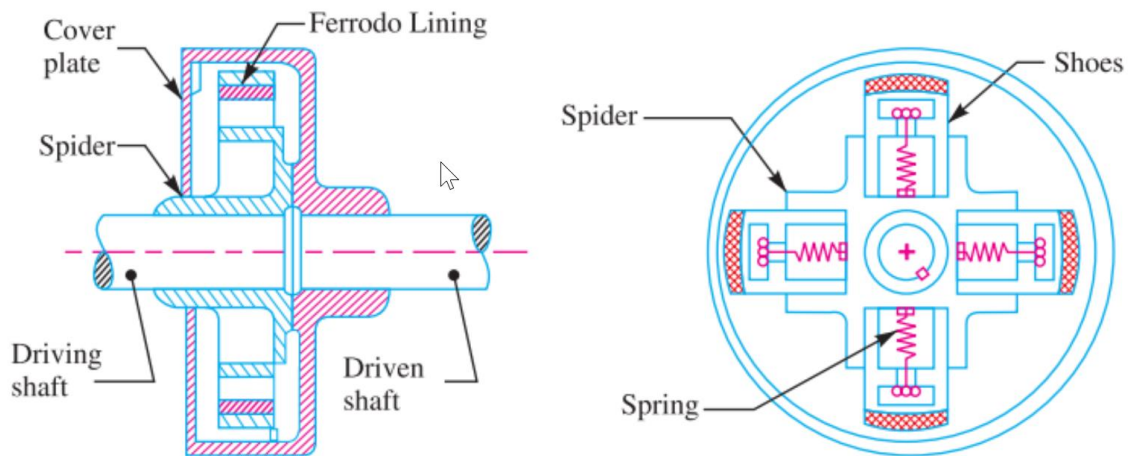


Figure 6- Centrifugal clutch (Kholi, et al., 2019)

Information given by brief.

“Consider the centrifugal clutch above that comprises of four ‘shoes’ symmetrically attached to the ‘spider’. Each shoe with its friction lining has a mass of 275 grams and is attached by means of a linear mechanical spring with a stiffness value of 7.5 kN/m. The coefficient of friction of the material attached to the shoes is 0.35. The centre of mass of each of the shoes is at a radius of 95 mm from the shaft centres in the rest position shown above, i.e. can be considered as the distance to ‘edge’ of shoes and have a clearance distance of 9 mm to the outer drum. The outer drum has a wall thickness of 4 mm.”

6.1 Question 1- What is the outer diameter of the drum?

Given the following:

The centre of mass of each shoe is 95mm from the centres in rest position.

- 9mm gap between the shoe and inner drum.
- The outer drum has a wall thickness of 4mm.

Therefore

$$\text{Radius}(r^1) = 95\text{mm} + 9\text{mm} = 104\text{mm}$$

$$\text{Diameter}(d) = r \times 2 = 104\text{mm} \times 2$$

$$\text{Diameter}(d) = 208\text{mm}$$

$$\text{Outer radius}(r^2) = 95 + 9 + 4 = 108\text{mm}$$

$$\text{Total outer diameter}(d^{\text{total}}) = 108\text{mm} \times 2 = 216\text{mm}$$

6.2 Question 2- Determine the engagement speed of the centrifugal clutch in (RPM) revolutions per minute.

Given the following (converted to SI units throughout).

- Stiffness value = 7.5 kN/m = 7500N
- Distance to engagement = 9mm = 0.009m

Therefore

$$\text{Hooke's law} = F_s = -kx$$

F = spring force. k = spring constant x = spring stretch or compression

$$F = 7500 \times 0.009 = -67.5\text{N}$$

The spring force (F) in tension is -67.5N at 9mm of extension.

For the shoe to be able to contact the lining of the drum a centrifugal force greater or equivalent to spring force is required.

$$\text{Using the centripetal force formula} = F = m \omega^2 r$$

$$\text{Force } (F) = -67.5\text{N}$$

$$\text{Mass } (m) = 0.275kg$$

$$\text{Radius } (r) = 0.104m$$

Re-arranging the centripetal force equation to make ω^2 the subject.

$$F = m \omega^2 r$$

$$\omega^2 = \frac{F}{m \times r}$$

$$\omega^2 = \frac{67.5}{0.275 \times 0.104}$$

$$\omega^2 = \frac{67.5}{0.286}$$

$$\omega^2 = 2360.14$$

$$\omega = \sqrt{2360.14}$$

$$\omega = 48.851 \text{ rad/s}$$

Coverting rad/s to RPM by multiplying by 9.549297

$$\omega = 466 \text{ RPM}$$

6.3 Question 3- Calculate the radial force acting on the clutch face when the driving shaft is rotating at a speed of 550 RPM.

Using the centripetal force formula= $F = m \omega^2 r$

Given the following (converted to SI units throughout)

$$\text{Mass } (m) \text{ of single clutch shoe} = 275g = 0.275kg$$

$$\text{Angular velocity } (\omega) = 550 \text{ RPM} = 57.596 \text{ rad/s}$$

$$\text{Radius of the drum } (r) = 104mm = 0.104m$$

$$F = m \times \omega^2 \times r$$

$$F = 0.275 \times 57.596^2 \times 0.104$$

$$F = 94.875N$$

Given that the spring force= $-67.5N$ at the radius (r)

The force(F) must overcome the spring force.

Therefore:

$$F = 94.875N - 67.5N$$

$$F = 27.375N$$

Due to there being 4 shoes acting upon the drum surface there will 4 times the amount of force (F)

$$F_{Total} = 27.375 \times 4$$

$$F_{Total} = 109.5N$$

6.4 Question 4- At the driving shaft speed of 550 RPM, what will be the value of torque transmitted to the driven shaft?

Given the following:

$$\text{Force}(F) = 109.5N$$

$$\text{External radius}(r) = 0.104m$$

$$\text{Friction coefficient } (\mu) = 0.35$$

To calculate torque(T):

$$T = F \times r \times \mu \times \text{number of shoes}$$

$$T = (109.5 - 67.5) \times 0.104 \times 0.35 \times 4$$

$$T = 6.11N/m$$

- 6.5 Calculate and plot on a suitable graph the transmitted torque at the driven shaft against driving shaft speed, from 450 RPM to 700 RPM in increments of 25 RPM.

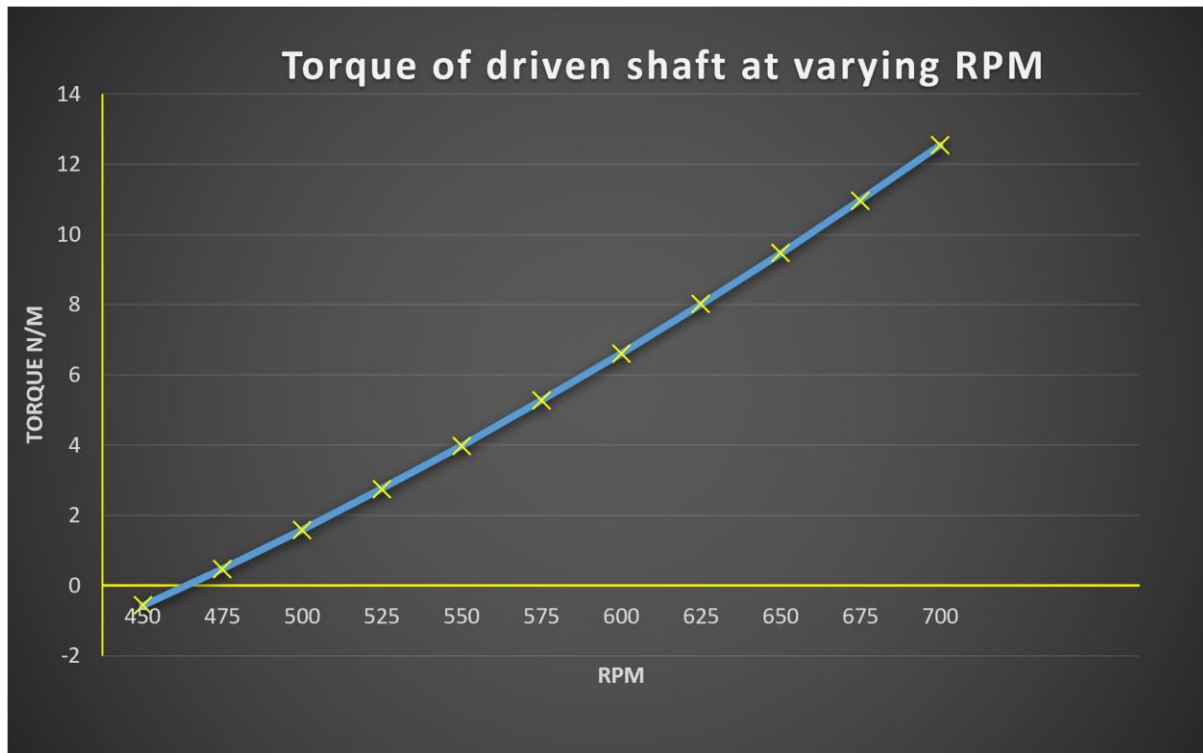


Figure 7- Microsoft Excel graph showing the torque (T) at the driven shaft and the driving shaft (RPM) with the Friction coefficient (μ) = 0.35 (Purnell-Whitehead, 2024)

In Figure 5 at 450 RPM shows a negative value, this shows that the springs centripetal force is greater than that of the centrifugal force.

Using the graph, it can be said that between 450N/M and 475N/M a zero value of torque can be seen. Up until this point it can be said that the springs have begun to compress until reaching what can be described as the point of equilibrium between the springs force and centrifugal force. From here as the RPM increases it can be assumed that this is the point of contacted between the friction pads and the inner walls of the drum thus creating a positive value in torque(T)

6.6 Question 6- Undertake the same analysis as in point 5 above but adopt a coefficient of friction of 0.3 and 0.4. Discuss the effect of changing the coefficient of friction of the shoe material on the torque transmitted when comparing the three values of coefficient of friction.

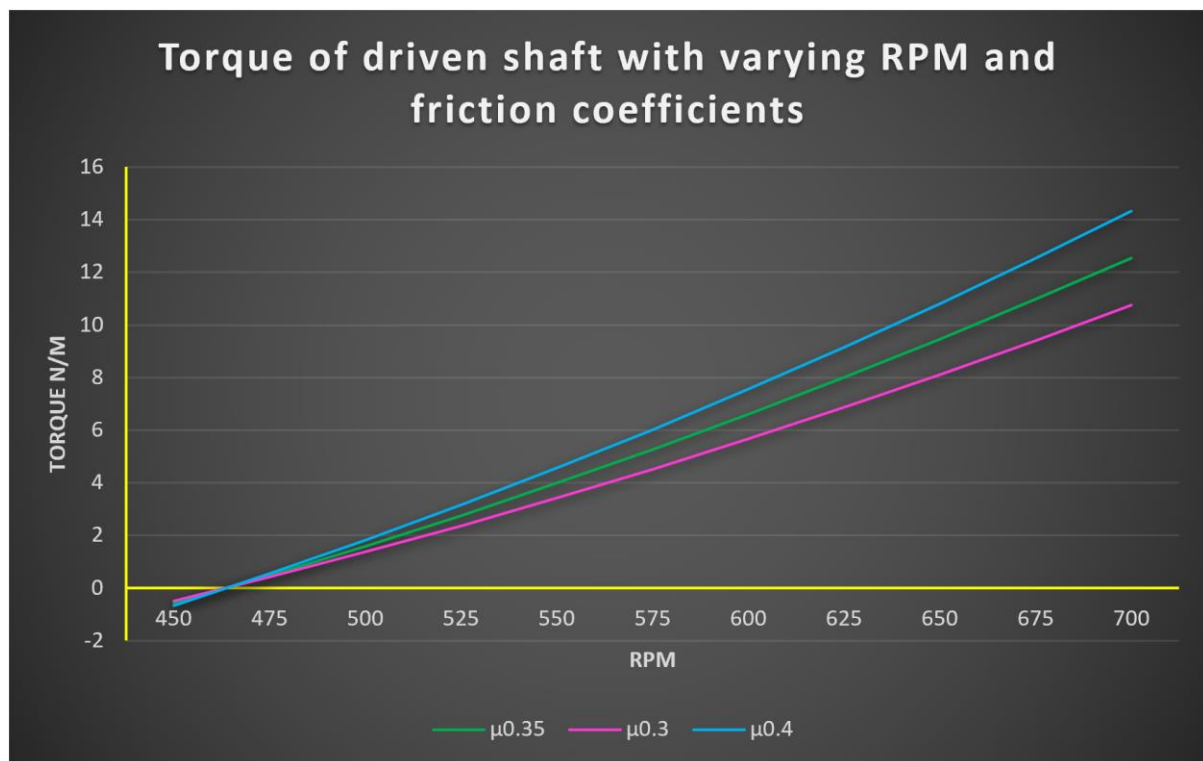


Figure 8-Microsoft Excel graph showing three centrifugal clutch shoes with varying values of friction coefficients and their relationship between Torque and RPM (Purnell-Whitehead, 2024)

Figure 6 illustrates the impact of varying the friction coefficient of the shoe friction material on the torque that is transmitted from the drive shaft. An increase in friction coefficient increases the grip of the shoe material, meaning less slippage. This effect is clear at 700RPM, the shoes with a friction coefficient of $\mu=0.4$ achieves a drive shaft torque of approximately 14.3N/m while the lower value shoe with the friction coefficient of $\mu=0.3$ results in a torque of 10.75N/m. The results shown in graph assume that there are no other external influences that could affect the results.

6.7 Question 7- For the maximum possible transmitted torque determined from either point 5 or 6 above, and given that the mass of the drum is 750 grams and can be considered as a solid disc, what is the angular acceleration of the drum to achieve the maximum possible torque?

To calculate angular acceleration needed to achieve the maximum torque. For this we need to use the Torque equation: $T = \alpha \cdot I$

Known are:

From question 5 we know that $(T) = 12.54N/m$

Mass(m) = 0.75kg

Outer radius(r) = 0.108m

Unknowns are:

Inertia(I)=?

Angular acceleration (α)=?

To find (I) we can use the following formula as we are considering a solid disc:

$$I = \frac{1}{2}mr^2$$

$$I = \frac{1}{2} \times 0.75 \times 0.108^2$$

$$I = 0.004374 \text{ Kg/m}^2$$

Using our Torque equation:

$$T = \alpha \cdot I$$

Re-arrange to make angular acceleration the subject.

$$\alpha = \frac{T}{I}$$

$$\alpha = \frac{12.54}{0.004374}$$

$$\alpha = 2866.9 \text{ rad/s}^2$$

or

$$\alpha = 2866.9 \times 9.549297 = 27376 \text{ RPM}$$

6.8 If the driven shaft had a diameter of 17.5 mm and a constant tangential braking force of 500 N was applied to the driven shaft, determine the maximum possible angular acceleration for the drum as given in point 7 above

Known are (in SI units):

$$\text{Diameter}(d) = 0.175m$$

$$\text{Radius}(r) = \frac{d}{2} = \frac{0.175}{2} = 0.00875m$$

$$\text{Braking force}(F) = 500N$$

$$\text{Moment of inertia } (I) = 0.004374kg/m^2$$

To calculate torque(T):

$$T = F \times r$$

$$T = 500 \times 0.00875$$

$$T = 4.375Nm$$

Using torque equation:

$$T = \alpha I$$

$$\alpha = \frac{T}{I}$$

$$\alpha = \frac{4.375}{0.004374}$$

$$\alpha = 100.23 \text{ rad/s}^2$$

7 Conclusion

Given the role of centrifugal force in the clutch's function, the choice of material is crucial to ensure that the force generated within the clutch is effectively transmitted to the drive shaft. Consideration should be given to the force required to overcome the tension spring and the coefficient of friction of the friction plates when designing a component.

Assuming ideal operating conditions, Part B of this report provided an opportunity to analyse both analytically and graphically, the behaviour of centrifugal clutch at various rotational speeds supporting the theoretical insights discussed in Task A.

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