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Stress Analysis and Dynamics

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1 Introduction

This report will focus on the design and development of centrifugal clutches and will also touch on material selection, working conditions and their applications in day to day life. It will also look at its advantages and disadvantages in a range of these different applications. There will also be a highlight on the modern move to electromagnetic clutches in automated systems, which looks at how technical advancements continue to power transmission efficiency and control.

1.1 Centrifugal Clutches Overview

Centrifugal clutches are mainly common in tiny motor applications due to their ability to allow power transmission to engage and disengage smoothly and automatically. The clutch works on the basis of centrifugal force. Centrifugal force is the outward force on a mass when it is rotated. In a centrifugal clutch this outward force is used to push frictional components (shoes) outward to engage the drum. This transmits power to the connected loads as rotational speed increases (Sehgal, Pratap and Kuhar). When the speed decreases the shoes retract, disengaging the clutch. This can be seen in the image below:

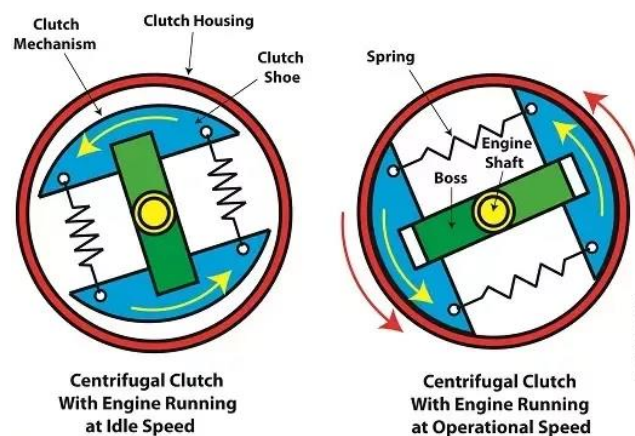


Figure 1: Image showing how Centrifugal clutch works.

Centrifugal clutches provide a straightforward and efficient way to transmit power without requiring human input as rotational speed increases. They are useful in applications that need reliability, simplicity, and low maintenance such as chainsaws and go-carts.

2 Development Of The Centrifugal Clutch

In the 20th century the need for a self-engaging clutch mechanism became more apparent as these small motors developed to become more powerful. This is where the centrifugal clutches offered an effective, low-maintenance solution for devices where manually engaging and disengaging the clutch would be inconvenient and impractical. Examples of these devices are chainsaws, lawnmowers, and small motorcycles(Lin and Lin). The design of centrifugal clutches evolved overtime to enhance performance and reliability.

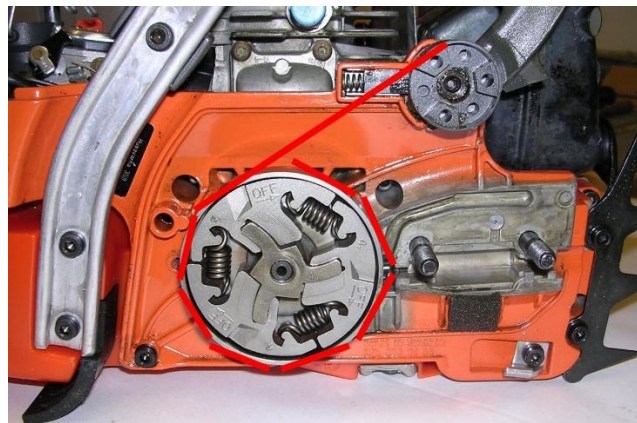


Figure 3:Image showing a Centrifugal clutch in a chainsaw.

A key development in the centrifugal clutches was the refinement of the engagement mechanism to help ensure that the operation is smooth. This is because early designs sometimes had issues from abrupt engagement which caused strain on the mechanism. The solution to this was the use of multiple shoes and springs with force distribution to ensure gradual engagement and improved control.

In the late 20th century centrifugal clutches began to be phased out in favour of fluid mechanical clutches in larger and more complex machinery. Although they started to be phased out, centrifugal clutches are still used in many applications due to their simplicity, cost, reliability(Lin and Lin). This highlights the value of centrifugal clutches as an efficient power transmission solution.

3 Design And Materials

The design of the centrifugal clutch relies on key mechanical components working together to ensure automatic engagement and disengagement based on speed. The main elements that makes up a centrifugal clutch are the clutch drum, friction shoes, springs, and hub.

These components are designed and manufactures using specific materials that can perform efficiently under various conditions.

Components, design, and materials

1. Clutch drum

The drum is the outer shell of the centrifugal clutch that houses the friction shoes. When the engines rotational speed increases, the friction shoes are pushed outward by the centrifugal force to contact the drums inner surface, transmitting torque to the output shaft.

- Design: The inside surface of the drum must be smooth and uniform to provide consistent friction and reduce the amount of wear on the shoes. It must also be able to handle high heat caused by friction.
- Material: The most common materials used to make the clutch drum are steel or cast iron. This is due to their strength, heat dissipation, and wear resistance

2. Friction shoes

The friction shoes are critical for the transferring of energy from the engine to the drum. They push outward under centrifugal force and are mounted onto the hub.

- Design: The shoes must provide high friction and withstand heat generated during operation.
- Material: The shoes are usually made from composite materials with friction lining, such as fibres that are combined with resins. These fibres are asbestos free and offer thermal resistance and durability.

3. Springs

The springs control the engagement of the clutch by resisting the outward push of the friction shoes. To prevent premature engagement at lower speeds the springs purpose is to hold the shoes in place.

- Design: The tension in the spring determines the clutch's activation speed. This makes the springs such an important part of the centrifugal clutch.
- Material: The springs are usually made from high-tensile steel alloys. This is because they provide enough elasticity and fatigue resistance.

4. Hub

The hub connects the clutch to the engine shaft and supports the friction shoes and springs.

- Design: The hub must be strong enough to handle rotational forces, but should also be lightweight.
- Material: the hub is made out of aluminium alloys or hardened steel as they are both strong and lightweight.

The material selection for these key components is very important as it ensures the durability and performance of the clutch. In modern centrifugal clutch's materials like composite friction linings and heat-treated metals are used to help reduce weight, improve heat dissipation, and to improve resistance to wear and tear (Lin and Lin; Sehgal, Pratap and Kuhar). An example of this is the use of lightweight aluminium alloys in the hub to reduce the moment of inertia, improving responsiveness. The image below shows all the components of a centrifugal clutch:

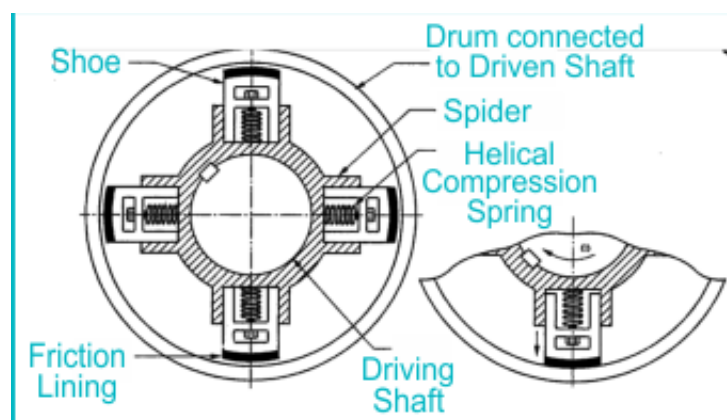


Figure 2: Image showing components of a Centrifugal clutch.

Material choice is important as it affects the clutch's ability to withstand factors such as temperature, abrasion, and fatigue.

4 Operating Conditions

Centrifugal clutches are used in many different applications where automatic operation and reliability are needed. The clutches can engage and disengage the transmission of power based on the speed of the engine making them good for small motor equipment and

machinery that operate under variable speed conditions. This chapter will look into the operating conditions they are designed to handle.

4.1 Operating conditions

- **Variable engine speeds:** The springs and shoes of the clutch need to be tuned precisely, due to the clutch having to engage smoothly at specific speeds and disengage when the engine slows down.
- **Friction and heat generation:** The engaging of the clutch produces heat due to the friction that occurs between the shoes and the drum. Materials with a high thermal resistance help prevent overheating and wear of the drum.
- **Outdoor:** These clutches are exposed to dirt, moisture, and environmental elements due to use in outdoor settings. Protective designs help protect the clutch under such conditions.
- **Intermittent load:** Centrifugal clutches are often subjected to start-stop operations.

5 Advantages Of Centrifugal Clutches

Centrifugal clutches have many benefits that help maintain its value in small motor applications and machinery. These benefits are as follows:

- **Self-engagement:** The biggest advantage of centrifugal clutches is their ability to self-engage and disengage based on engine speed. This removes the need for user innovation, making the device user friendly for people with no technical expertise.
- **Smooth power transfer:** The clutch allows for gradual power transfer to the output shaft. This reduces stress on the engine and other components, reducing wear and preventing abrupt movements.
- **Easy design and maintenance:** Due to having fewer components, centrifugal clutches are easy to manufacture and maintain. Their simplicity reduces chances of failure and makes it cost effective when having to maintain the system.
- **Compact design:** The clutch is lightweight and compact, making them well-suited for portable devices and small machines where space and weight are important factors.

6 Electromagnetic Clutches

Electromagnetic clutches play a vital role in the automation of manufacturing processes due to their ability to be versatile, engage rapidly, and precise control. They operate through electromagnetic field which is generated by a coil that activates a friction plate to engage and disengage power transmission(Chowdhary, Kumar and Singh). They vital in automation due to their ability to be controlled electronically allowing improvement in speed, accuracy, and flexibility(Ranjan *et al.*, 2017).

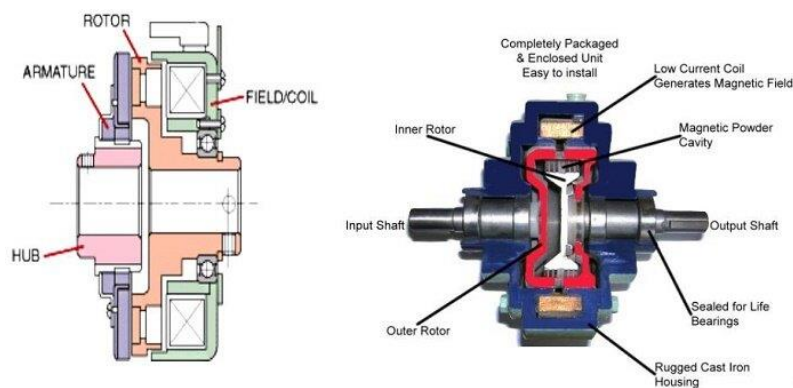


Figure 4:Image showing how an electromagnetic clutch functions.

6.1 Applications Of Electromagnetic Clutches

- **Conveyor Systems:** They are used in conveyor systems to control the movement of products on the belt. They are mainly used for start – stop operations, controlling speed, and changing directions in these conveyor systems, such as on an assembly line.
- **Textile industry:** In weaving and spinning machinery, electromagnetic clutches allow for there to be accurate control over string tension and machine control. This helps to produce consistent quality.
- **Machining tools:** In lathes, milling machines, and other machining machines the electromagnetic clutches ensure that there is accurate cutting of the work piece. They function by rapidly engaging and disengaging spindles or tool feeds, increasing efficiency and accuracy.

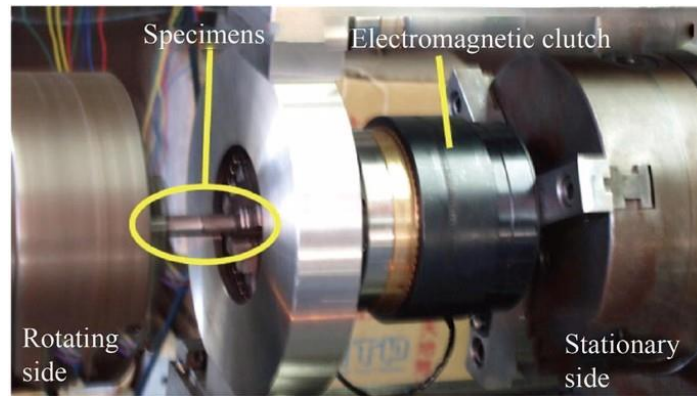


Figure 5: Image showing an electromagnetic clutch working in a clutch.

6.2 Advantages Of Electromagnetic Clutches

- **High speed and efficiency:** They operate effectively at high speeds, making them very useful for industrial applications with rapid production cycles.
- **Integration with automated systems:** Their ability to integrate with control systems brings forward their utility in smart factories where automation is crucial.
- **Accuracy:** Electromagnetic clutches have an ability to respond to electrical signals, which allows from accurate control over the processing.

7 Conclusion

Centrifugal clutches have offered simple, cost-effective and reliable solutions for automatic power transmission in small motor applications, making them a very vital component in mechanical systems. However, with the evolving nature of industries, advanced alternatives such as electromagnetic clutches have slowly replaced them (Kirchengast *et al.*, 2015).

Electromagnetic clutches have become essential in modern manufacturing due to their rapid response, accurate control, and integration with automated systems. They have provided efficiency and accuracy in the manufacturing processes, meeting the demands of automated industries. The evolution to electromagnetic clutches has helped meet the need for precision, efficiency, and automation in today's industries.

8 Task B

8.1 The Diameter of The Outer Drum

Information:

Radius at rest: $r = 95\text{mm}$

Clearance between shoes and drum: 9mm (Shoe clearance)

Drum wall thickness: 4mm (Wall thickness)

Calculations:

1. Inside drum Radius:

$$R + \text{Shoe clearance} = 95\text{mm} + 9\text{mm} = 104\text{mm} (r_{\text{inside drum}})$$

2. Outer drum Radius:

$$R_{\text{inside drum}} + \text{Wall thickness} = 104\text{mm} + 4\text{mm} = 108\text{mm} (r_{\text{outside drum}})$$

3. Diameter (D) of outer drum:

$$r_{\text{outside drum}} \times 2 = 108\text{mm} \times 2 = 216\text{mm}$$

Therefore, the diameter of the outer drum is **216mm**.

8.2 Engagement Speed of The Centrifugal Clutch

Information:

Shoe mass: $m = 275\text{g} = 275 \div 100 = 0.275\text{kg}$

Radius at rest: $r = 95\text{mm}$

Spring stiffness: $k = 7.5\text{kN/m} = 7500 \times 10^3$

Clearance between shoes and drum: $9\text{mm} = 9 \times 10^{-3}\text{m}$ (Shoe clearance)

Calculation:

1. At engagement the shoes will move out by the clearance distance, which is: 0.009m.
The symbol used to denote the spring extension: Δx .
2. Spring force: the spring force is given by Hooke's law:

$$k \cdot \Delta x = 7500 \times 0.009 = 67.5N$$

3. Centrifugal force:

$$F = m \cdot r \cdot \omega^2 \text{ where } \omega \text{ is the angular velocity.}$$

Rearrange the formula for ω :

$$\begin{aligned}\omega^2 &= \frac{F}{m \cdot r} \\ \omega^2 &= \frac{67.5}{0.275 \cdot 0.095} = 2595.9 \\ \omega &= \sqrt{2595.9} = 50.95 \text{ rad/s}\end{aligned}$$

4. Converting to RPM:

$$\text{Radians to RPM} = \frac{\omega \cdot 60}{2\pi} = \frac{50.95 \cdot 60}{2\pi} = 486.4 \text{ rpm}$$

The engagement speed of the centrifugal clutch is approximately **486rpm**.

8.3 Radial Force At 550 RPM

Information:

Mass of each shoe: $m=0.275\text{kg}$

Radius of the centre of mass: $r = 0.095\text{m}$

Rotational speed: $N = 550\text{RPM}$

Angular velocity in radians per second: $\omega = \frac{2\pi N}{60}$

Calculation:

1. Change the rotational speed to angular velocity:

$$\omega = \frac{2\pi \cdot 550}{60} = 57.6 \text{ rad/s}$$

2. Centrifugal force for one shoe:

$$F = m \cdot r \cdot \omega^2 = 0.275 \times 0.095 \times 57.6^2 = 86.6N$$

3. Total Radial force:

$$4 \times 86.6 = 346.4N$$

The total radial force that acting on the clutch face at 550RPM is **346.4N**.

8.4 Torque Transmitted at 550 RPM

Information:

Radial force: 346N

Radius: $r=0.095m$

Coefficient of force: $\mu=0.35$

Calculation:

1. Find the torque by using the following formula:

$$T = F \cdot r \cdot \mu = 346 \times 0.095 \times 0.35 = 11.51Nm$$

The torque that is transmitted to the driven shaft at 550RPM is **11.51Nm**.

8.5 Graph showing the transmitted torque at the driven shaft from 400RPM to 700RPM

Calculation:

$$T = F \cdot r \cdot \mu$$

- $F = 346.4N$
- $r = 0.095m$
- $\mu = 0.35$
- $\omega = \frac{2\pi \cdot 550}{60}$

The table below shows the calculations performed in MS Excel to find the torque at the different RPM(s) using the information and formulae given above:

Torque Calculation			
RPM	Angular Velocity	Centri Force	Torque
450	47.1238898	58.01476837	1.928991
475	49.74188368	64.63991167	2.149277
500	52.35987756	71.62317083	2.38147
525	54.97787144	78.96454584	2.625571
550	57.59586532	86.6640367	2.881579
575	60.21385919	94.72164342	3.149495
600	62.83185307	103.137366	3.429317
625	65.44984695	111.9112044	3.721048
650	68.06784083	121.0431587	4.024685
675	70.68583471	130.5332288	4.34023
700	73.30382858	140.3814148	4.667682

Table 1: Calculations performed to find the torque.

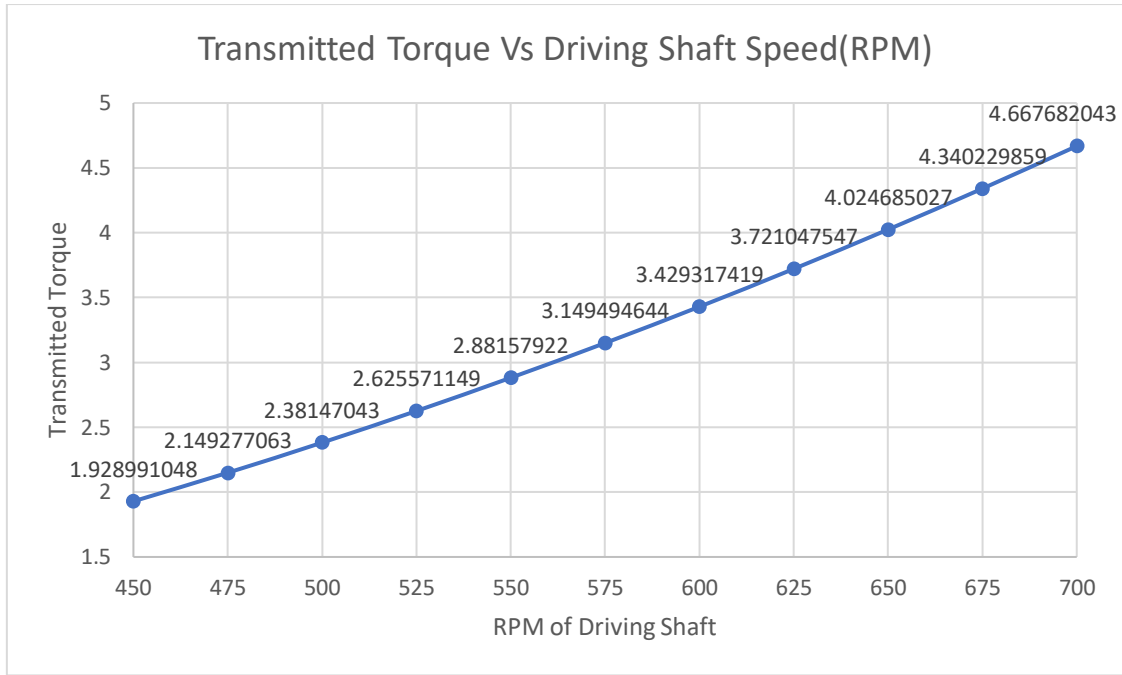


Figure 5: Shows a scatter graph of transmitted torque against RPM of drive shaft.

The above scatter chart shows that as the driving shaft speed increases, the transmitted torque also increases due to rising centrifugal force.

8.6 Graph showing the transmitted torque at the driven shaft from 400RPM to 700RPM with μ of 0.3, 0.35, and 0.4

Calculation:

$$T = F \cdot r \cdot \mu$$

- $F = 346.4N$
- $r = 0.095m$
- $\mu_1 = 0.3$
- $\mu_2 = 0.35$
- $\mu_3 = 0.4$
- $\omega = \frac{2\pi \cdot 550}{60}$

The table below shows the calculations performed in MS Excel to find the torque at the different RPM(s) and μ given above and in the previous answer:

Torque Calculation					
RPM	Angular Velocity	Centri Force	Torque 0.3	Torque 0.35	Torque 0.4
450	47.1238898	58.01476837	1.653420899	1.928991048	2.2045612
475	49.74188368	64.63991167	1.842237483	2.149277063	2.45631664
500	52.35987756	71.62317083	2.041260369	2.38147043	2.72168049
525	54.97787144	78.96454584	2.250489556	2.625571149	3.00065274
550	57.59586532	86.6640367	2.469925046	2.88157922	3.29323339
575	60.21385919	94.72164342	2.699566837	3.149494644	3.59942245
600	62.83185307	103.137366	2.939414931	3.429317419	3.91921991
625	65.44984695	111.9112044	3.189469326	3.721047547	4.25262577
650	68.06784083	121.0431587	3.449730023	4.024685027	4.59964003
675	70.68583471	130.5332288	3.720197022	4.340229859	4.9602627
700	73.30382858	140.3814148	4.000870322	4.667682043	5.33449376

Table 2: Calculations performed to find the torque.

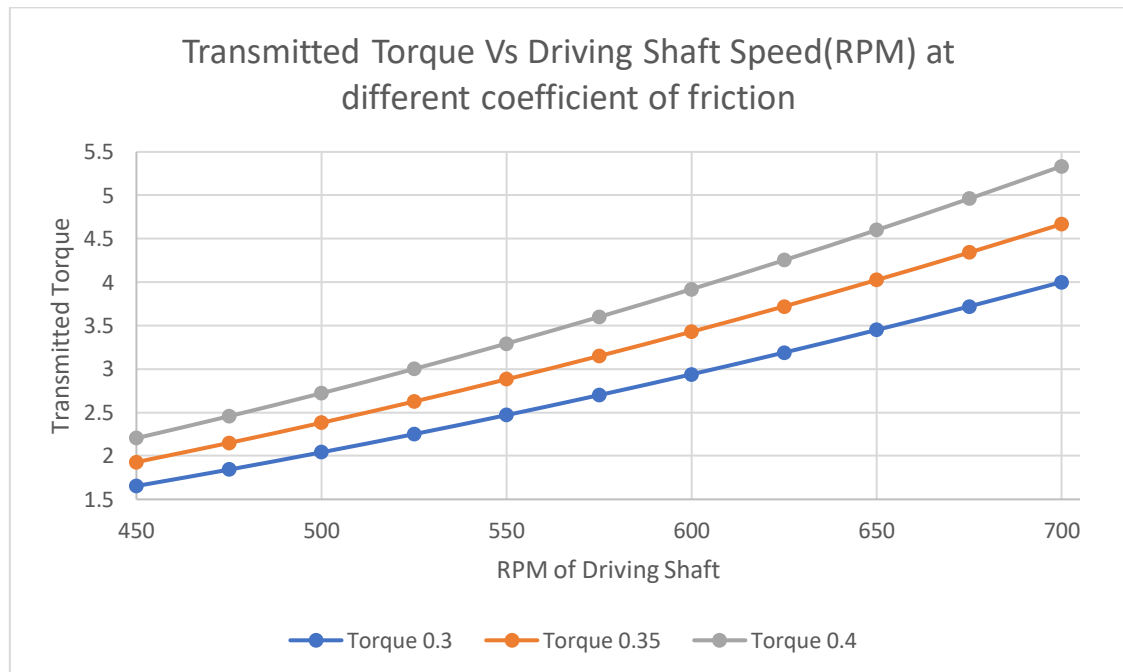


Figure 6: Shows a scatter graph of transmitted torque against RPM of drive shaft at different μ .

From the above chart it is seen that as the coefficient of friction increases, the torque at all shaft speed increases because torque is directly proportional to the coefficient of friction.

8.7 Angular acceleration (α) of the 750g drum.

$$T_{max} = I \cdot \alpha$$

Information:

Mass of drum: $750\text{g} \div 100 = 0.75\text{kg}$

Drum Radius: $r = 0.095 + 0.009 + 0.004 = 0.108\text{m}$

T_{max} : 15.13Nm (this was calculated in the previous task for $\mu = 0.4$)

Calculation:

1. Calculate the moment of inertia using the formula $I = \frac{1}{2}Mr^2$
2. Adding the values to the formula:

$$I = \frac{1}{2} \cdot 0.75 \cdot 0.108^2 = 0.004374\text{kgm}^2$$

3. Calculate α using the formula $T = I \cdot \alpha$
4. Rearrange the formula for α :

$$\alpha = \frac{T_{max}}{I}$$

5. Adding the values to the formula:

$$\alpha = \frac{15.13}{0.004374} = 3459.1\text{rad/s}^2$$

For the maximum transmitted torque α is **3459.1rad/s²**.

8.8 Maximum possible angular acceleration for the drum.

To find the angular acceleration, the braking torque needs to be considered to allow for net torque acting on the drum to be found.

Information:

To find the angular acceleration (α), the following formula will be used:

$$\alpha = \frac{T_{net}}{I}$$

The net torque is found using the following formula:

$$T_{net} = T_{max} - T_{brake}$$

Where T_{brake} is the braking torque. The braking torque is caused by tangential force applied to the driven shaft.

$$F_{brake}: 500N$$

$$r_{shaft}: \frac{Diameter}{2} = \frac{17.5}{1000 \cdot 2} = 0.00875m$$

$$T_{max}: 15.13Nm$$

Calculation:

1. Calculate the braking torque using the formula:

$$T_{brake} = F_{brake} \cdot r_{shaft}$$

2. Add values to the formula:

$$T_{brake} = 500 \cdot 0.00875 = 4.375Nm$$

3. Calculate the T_{net} using the following formula:

$$T_{net} = T_{max} - T_{brake}$$

4. Add values to the formula:

$$T_{net} = 15.13 - 4.375 = 10.755Nm$$

5. Calculate α using the following formula: $\alpha = \frac{T_{net}}{I}$

6. Add values to the formula:

$$\alpha = \frac{10.755}{0.004374} = 2458.85 \text{ rad/s}^2$$

The maximum possible angular acceleration of the drum is **2458.85rad/s²**.

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