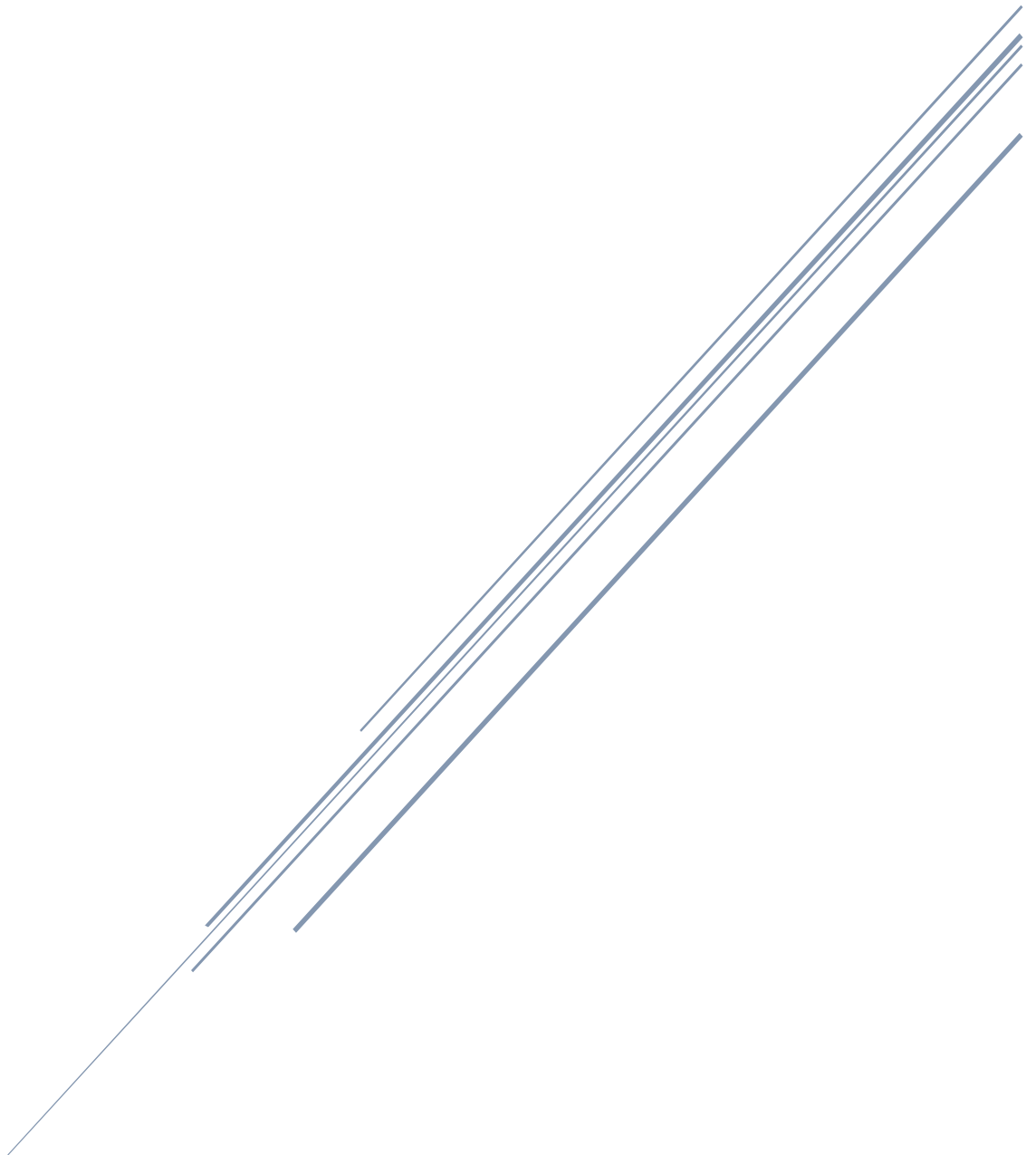


ANALYSIS AND SIMULATION OF A CENTRIFUGAL CLUTCH

ACMA5010



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Task A

Introduction

A clutch is a mechanical device that transmits power between a power source and a driven component or load – usually via two concentric shafts - allowing for controlled engagement and disengagement. Thus, the driven component can be started or stopped without stalling the driving power source; changing between gears without stopping the power source is also possible. Various types of clutches exist, including friction, cone, hydraulic, and diaphragm. Each type serves different applications and offers distinct advantages based on their design and operation. This paper focuses on the development of the centrifugal friction clutch - a design that transmits torque as a function of the driving speed – and how electromagnet clutches are superseding these.

History

The centrifugal friction clutch was first patented by Rensselaer Reynolds in 1857, making it the earliest known clutch to use centrifugal force to press friction linings against an outer drum; his invention is illustrated in Figure 1 (Reynolds, 1857). Initially designed for textile power looms, it was later adapted for steam engines, conveyor belts, and agricultural machinery. In these applications, the clutch operates in harsh environments characterised by high levels of dirt, debris, and heat. Unlike previous designs that required an external power source, Reynolds' clutch enabled automatic power transmission, reducing manufacturing complexity, costs, and human operation.

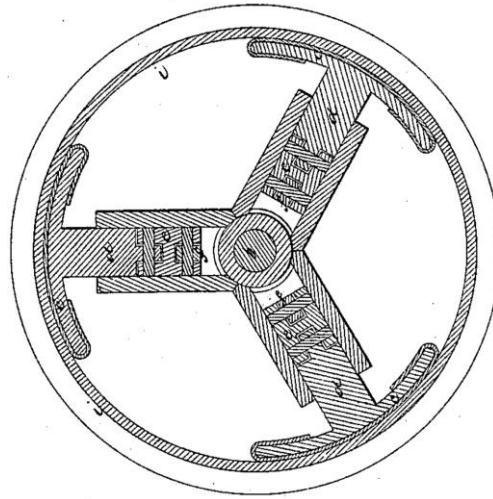


Figure 1: First patented centrifugal clutch (Reynolds, 1857)

In 1898, Walter A. Crowds (1898) filed a patent for an innovative automobile design, which notably included a centrifugal clutch. This vehicle utilised an electric motor as its power source, though this was not the first instance of electric power in an automobile. By incorporating a centrifugal clutch, Walter addressed the challenge of accelerating electric motors from a standstill, which typically requires a much higher current to generate the torque necessary. The clutch mechanism is depicted in Figure 2 (Growdus, 1898). Fine-tuning the spring tension enabled the electric motor to be engaged at an RPM (revolutions per minute), where it operates most efficiently.

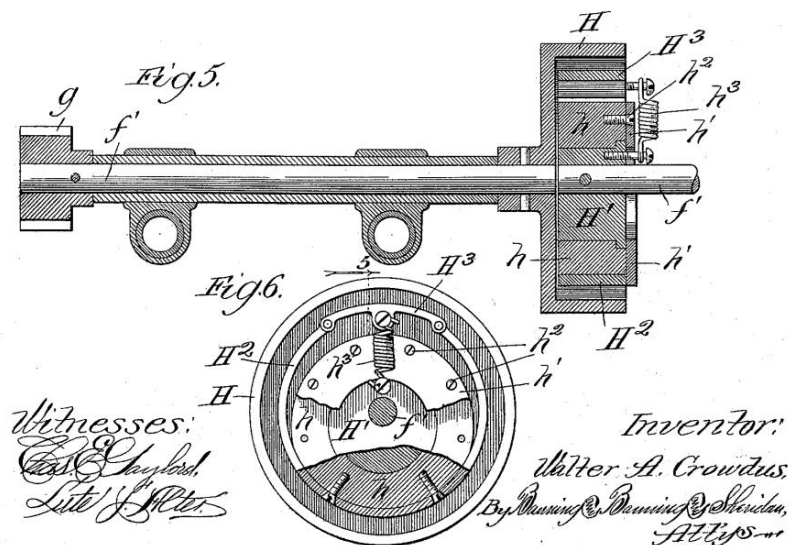


Figure 2: Centrifugal clutch from automobile patent (Growdus, 1898)

Stihl, founded in 1926, revolutionised forest work by introducing an electric-powered chainsaw, drastically reducing the labour requirements in logging operations (UKEssays, 2018). Similar in principle to automotive integration, this chainsaw incorporated a centrifugal clutch, which significantly enhanced logging productivity by automating the engagement of the cutting chain.

In 1940, the Cushman Company integrated a centrifugal clutch in their scooters, continuing its use in small motor applications. The ease of operation contributed significantly to the popularity of the Cushman Auto Glide Model 53, widely used by the US military for transportation around military bases (Shattuck, 2005). By the 1950s, numerous scooter manufacturers embedded centrifugal friction clutches; today, they remain the predominant means of the clutch mechanism.

Other typical applications of centrifugal clutches include go-karts, lawnmowers, small watercraft like mini boats, and even high-performance vehicles such as top-fuel dragsters.

Characteristics of Centrifugal Friction Clutches

With its versatility established across industries, the centrifugal friction clutch's construction relies on robust components designed to withstand environmental challenges. The proceeding section discusses the critical elements of a four-shoe centrifugal friction clutch, illustrated in Figure 3.

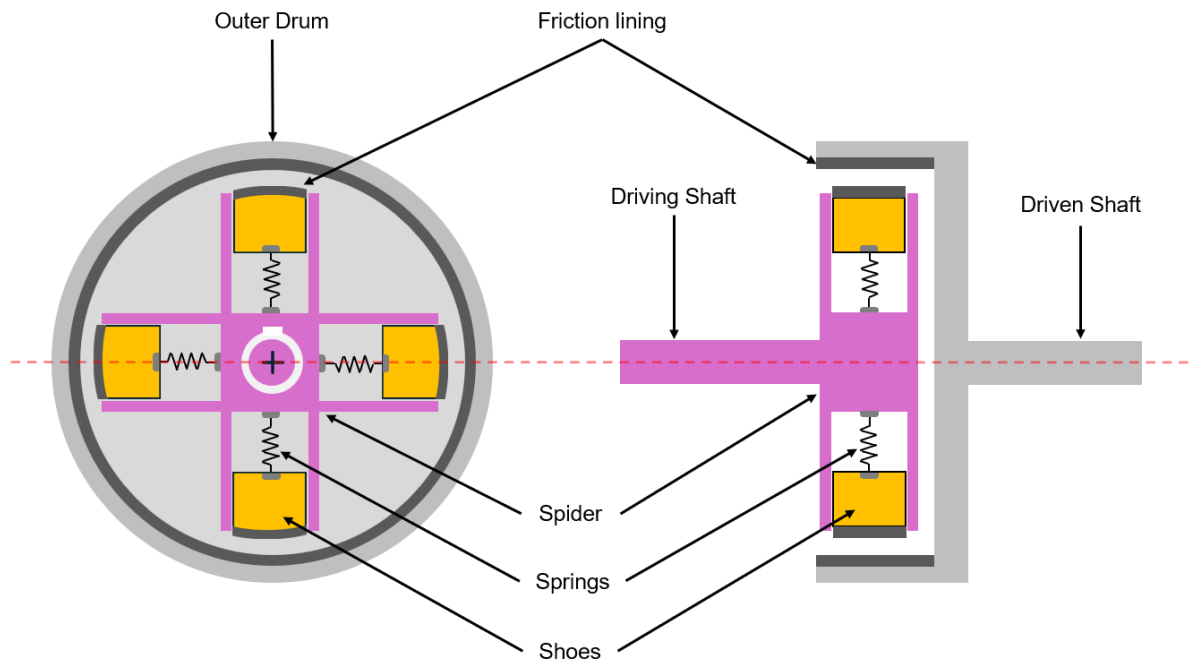


Figure 3: Diagram of a static four-shoe centrifugal friction clutch assembly.

1. Construction

The clutch consists of two major sections: the driving assembly and the driven assembly. The driving shaft connects the driving assembly to the power source—commonly an internal combustion engine or electric motor. This shaft is typically constructed of durable materials such as alloy or hardened steel to tolerate the high torque and heat generated within these clutches.

The driving shaft is coupled with what is widely known as a “spider,” which houses the shoes and helical springs. High-strength metals such as steel or alloy steel are frequently used to manufacture these as they can handle the high centrifugal forces without distorting and provide good wear properties for the sliding shoes. Aluminium alloys are sometimes used in applications where the clutch is not subjected to heavy loads.

Shoes are housed within the spider; these move radially as the rotational speed increases. At the outmost region of the shoe resides the friction lining, composed of a material with high frictional properties and resistance to heat and wear. Materials are

similar to those found in braking systems: sintered metal composites and asbestos-free friction composites. The surface of the friction liners is often smooth—however, Panchal et al. (2023) advocate that adding grooves in liners can help maintain surface roughness for longer, is more durable, generates higher clutch torques, and reduces clutch judder. Typically, the number of shoes ranges from two to six, depending on the clutch design and application. The number of shoes is determined by the power and engagement requirements, with more shoes generally equating to a smoother and more reliable engagement, more so at higher speeds and loads.

Helical springs connect the shoes to the spider, applying a constant, radially inward force. Adjusting the spring tension alters the engagement speed (a stiff spring increases engagement speed, and a soft spring reduces engagement speed). The greater the engagement speed, the greater the shock loading. When the centrifugal force (low rotational speed) is low, the springs ensure the shoes do not contact the driven member. When the centrifugal force acting on the shoes is greater than the tension in the springs, the shoes' weight causes them to move outward onto the surface of the driven member. As the speed increases, the centrifugal force also increases, allowing more torque to be transmitted between the shoes and the driven member. The mass of the shoes can affect the engagement speed and torque transmission; heavier shoes engage at higher rotational speeds and produce higher torque transmission, albeit at the expense of engagement responsiveness (Schmid, et al., 2024).

The driven assembly consists of a driven shaft connected to the output source, usually a gearbox or piece of machinery. The driven shaft is coupled to the outer drum, both of which comprise similar materials used for the driving shaft assembly. Selected heavy-duty or high-performance applications require a friction liner to be added to the inner periphery of the drum to enhance friction, heat resistance, and durability, especially when subjected to extreme loads.

A characteristic curve of a centrifugal friction clutch is shown in Figure 4 (Goud, et al., 2017). The torque transmitted to the driven shaft is a function of the driving speed; however, this statement is only valid once the force exerted by the springs has been overcome, as shown by Pos. 1. When the clutch reaches its torque capacity, it

will slip harmlessly – this is depicted in Pos. 2. A clutch's torque capacity is dependent on the coefficient of friction of the friction linings, the spring rates, and the mass of the shoes (Crane, 2003).

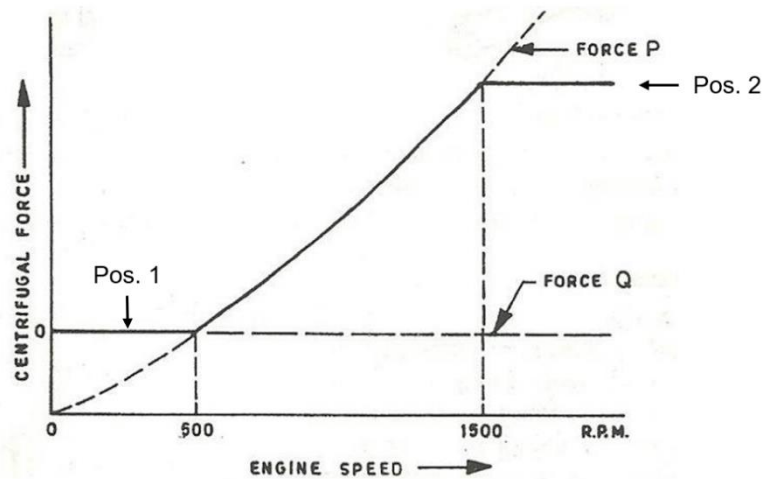


Figure 4: Characteristic curve of a centrifugal clutch (Goud, et al., 2017)

2. Advantages

Some of the key advantages that have made centrifugal friction clutches popular include:

- **Simple Design:** Few moving parts, reducing the likelihood of mechanical failure, simplifying maintenance, and reducing cost.
- **Lightweight:** Suitable for small motor applications.
- **Overload Protection:** Slips when excessive torque is applied, protecting connected machinery.
- **Automatic Operation:** Self-engaging mechanism requiring no control systems.
- **Anti-Stall:** Allows the driven member to stop without stalling the driving force.
- **Low Startup Torque Requirement:** Eliminates the need for high torque power sources to initiate load.

(Goud, et al., 2017) (BLM Automatic Clutch, 2019)

3. Disadvantages

While there are many advantages to centrifugal friction clutches, there are also disadvantages, these include:

- **Power Loss at Low RPM:** Slippage at low speeds reduces efficiency in some applications.
- **Overheating:** Friction between the shoes and drum at high RPMs and loads can lead to excessive heat build-up.
- **Clutch Judder:** Torsional vibrations during engagement may cause judder, especially under varying load conditions.
- **Application-Specific Design:** Since centrifugal force varies with speed, standardising for multiple uses is challenging; clutches often need customisation (Crane, 2003).

Electromagnetic Clutches in Modern Automation

Electromagnetic clutches follow the same principle as centrifugal friction clutches: they allow for the transfer of rotary motion and the ability to connect/disconnect power sources from loads. However, electromagnetic clutches are controlled electrically using electromagnetic induction to engage the clutch plate; torque is still transmitted mechanically (Chowdhary, et al., 2020). Single-plate clutch designs first appeared in the 1920s. However, it wasn't until the 1950s that they became commonly used in industrial applications, such as milling machines & lathes (control spindle operation) and textile machines (control start and stop of threads) (Vorob'yeva, 1965). The significant advantage over centrifugal clutches is the ability to control equipment remotely, along with increased response/engagement rates; this contributed to the inception of automation, resulting in substantial increases in operational efficiency throughout the manufacturing industry.

Contemporary electromagnetic clutches come in various designs, including toothed models, single- and multi-friction plate configurations, and particle-based types. Figure 5 (Ogura Clutch, 2024) displays the core elements of an electromagnetic

clutch. Today, electromagnetic clutches can be found in servo motors and robots, automated conveyor systems, such as vehicle assembly lines, and various oil and air pumps (pneumatic air compressors) (Ogura Clutch, 2024).

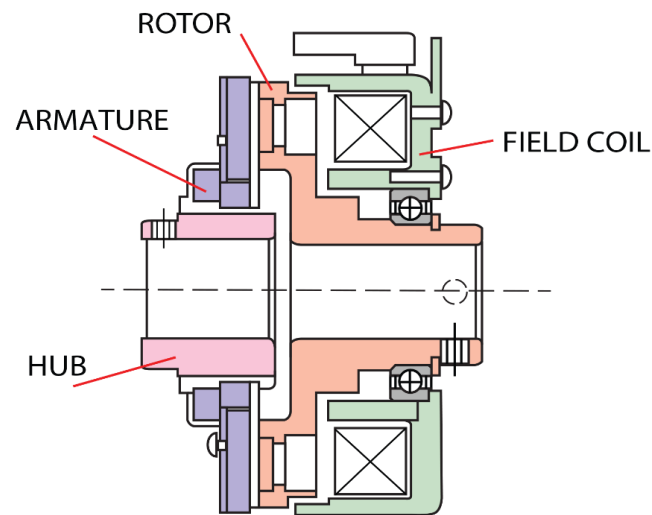


Figure 5: Diagram of an electromagnetic clutch (Ogura Clutch, 2024)

Task B

Question 1

The known dimensions of a centrifugal clutch are illustrated in Figure 6 (University of Wales Trinity Saint David, 2024). The sum of the known dimensions outputs the radius of the centrifugal clutch:

$$r = 95 + 9 + 4 = 108 \text{ mm}$$

Doubling the radius obtains the diameter:

$$\phi = 108 \times 2 = 216 \text{ mm}$$

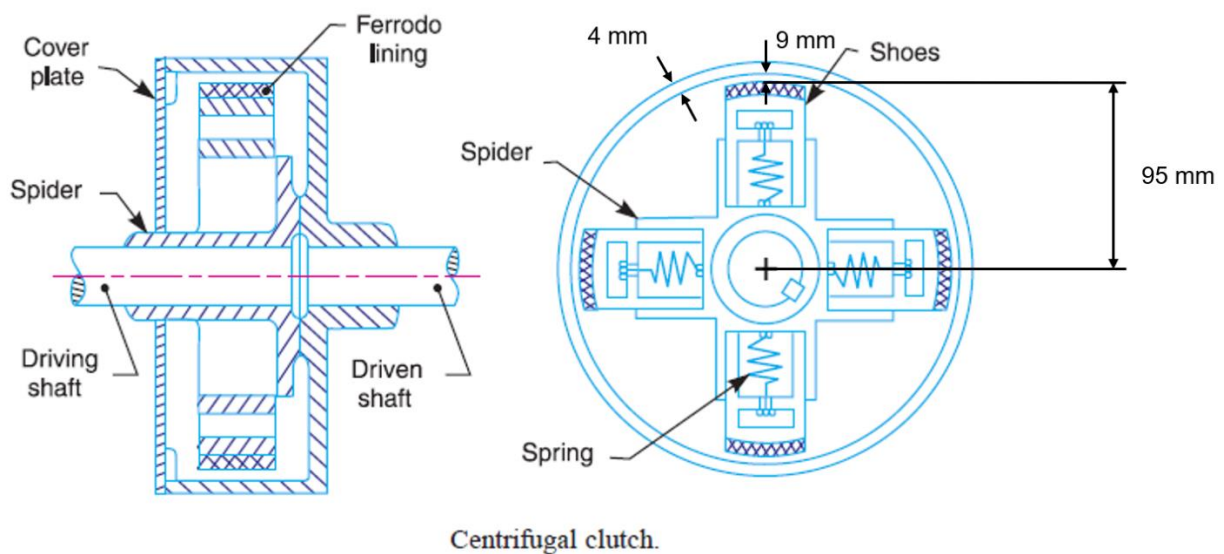


Figure 6: Centrifugal clutch dimensions (University of Wales Trinity Saint David, 2024)

Question 2

To calculate the clutch engagement speed in RPM, it's necessary to use the available information: the mass of each shoe (275 g), the spring stiffness (7.5 kN/m), the coefficient of friction (0.35), and the diameter (216 mm) obtained in Part 1. Since the clutch operates in a rotational system, centripetal force is a key factor. This inward force, which depends on the object's mass and velocity, accelerates it toward the center of rotation, counteracting the natural tendency to move in a straight line. The equation for calculating centripetal force, $F_{CP} = m\omega^2 r$, can be applied to determine the force required for clutch engagement.

where m = the mass of the object, measured in kg (kilograms)

ω = the angular velocity of the object, measured in rads/s (radians per second)

r = the radius of the object, measured in m (metres).

Rearranging the formula for angular velocity gives:

$$\omega = \sqrt{\frac{F_{CP}}{mr}}$$

The only unknown from the equation above is the centripetal force, F_{CP} . However, according to Newton's third law of motion:

For every force, there is an equal and opposite reacting force.

Thus, a reaction force to the centripetal force, known as centrifugal force, moves the shoes radially outward. To engage with the outer drum, the shoes must first overcome the spring tension and travel a clearance distance of 9 mm; the following equation from Hooke's Law expresses this force:

$$F_{CF} = kx$$

where k = the spring constant, measured in N/m (Newtons per metre)

x = the change in length, measured in m.

Hence,

$$F_{CF} = 7.5 \times 10^3 \times 9 \times 10^{-3}$$

$$F_{CF} = 67.5 \text{ N}$$

Substituting the known values into the angular equation gives:

$$\omega = \sqrt{\frac{67.5}{275 \times 10^{-3} \times 104 \times 10^{-3}}}$$

$$\omega = 48.6 \text{ rads/s}$$

Finally, rad/s must be converted to RPM:

$$RPM = \frac{60\omega}{2\pi}$$

$$RPM = \frac{60 \times 48.6}{2\pi}$$

$$\mathbf{RPM = 464}$$

At 464 RPM, the shoes engage with the clutch face.

(Bird & Ross, 2020)

Question 3

The radial force acting on the clutch face when the driving shaft is rotating at 550 RPM can be calculated using the equation for centrifugal force:

$$F_{CF} = m\omega^2 r$$

First, however, the RPM must be converted to rads/s:

$$\omega = \frac{RPM \times 2\pi}{60}$$

$$\omega = \frac{550 \times 2\pi}{60}$$

$$\omega = 57.6 \text{ rads/s}$$

Substituting the known values into the centrifugal force equation gives:

$$F_{CF} = 275 \times 10^{-3} \times (57.6)^2 \times 104 \times 10^{-3}$$

$$F_{CF} = 94.9N$$

The centrifugal force present at the radius in which the shoes engage with the clutch face is 94.9 N. However, this is not the force acting on the clutch face, as overcoming the spring tension absorbs a portion of the force. The following equation gives the actual radial force applied to the clutch face:

$$F_{CF} = 94.9 - 67.5$$

$$F_{CF} = 27.4 N$$

Question 4

To calculate the torque transmitted to the driven shaft at 550 RPM, the following equation must be considered:

$$T = Fr$$

where F = the force applied perpendicular to the point of rotation, measured in N (Newtons)

r = radius – the distance between the centre point of rotation and the point at which the force is being applied, measured in m (metres).

The centrifugal force is known, but the force acting perpendicular to it is not. However, since the coefficient of friction is given, it can be used to calculate the frictional force between the shoes and the clutch face. This frictional force, acting perpendicular to the centrifugal force, can then be used in the torque calculation – this relationship is illustrated in Figure 7.

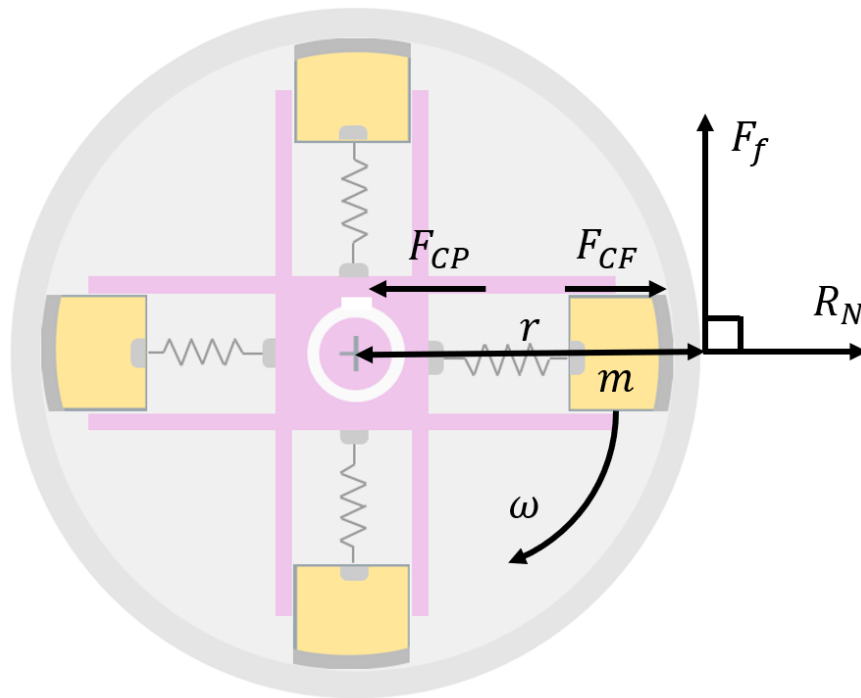


Figure 7: Force relationships within a centrifugal clutch.

First, the frictional force must be calculated using the following equation:

$$F_f = \mu R_N$$

where μ = the coefficient of friction (this relates to the ferrodo coating on the shoes)

R_N = the reaction force (this is equal to the centrifugal force, F_{CF})

Substituting the known values into the frictional force equation gives:

$$F_f = 0.35 \times 27.4$$

$$F_f = 9.59 \text{ N}$$

This value can then be substituted into the torque equation:

$$T = 9.59 \times 104 \times 10^{-3}$$

$$T = 1 \text{ Nm}$$

At a speed of 550 RPM, one shoe applies 1 Nm of torque to the driven shaft; this value must be multiplied by four to account for the four shoes. The total torque applied to the driven shaft is 4 Nm.

Question 5

The graph in Figure 8 displays the torque output at the driven shaft of the centrifugal clutch between 450 RPM and 700 RPM. The red dashed line indicates a nonlinear relationship between the RPM and torque output due to the requirement of overcoming the force of the spring tension, which doesn't occur until 464 RPM.

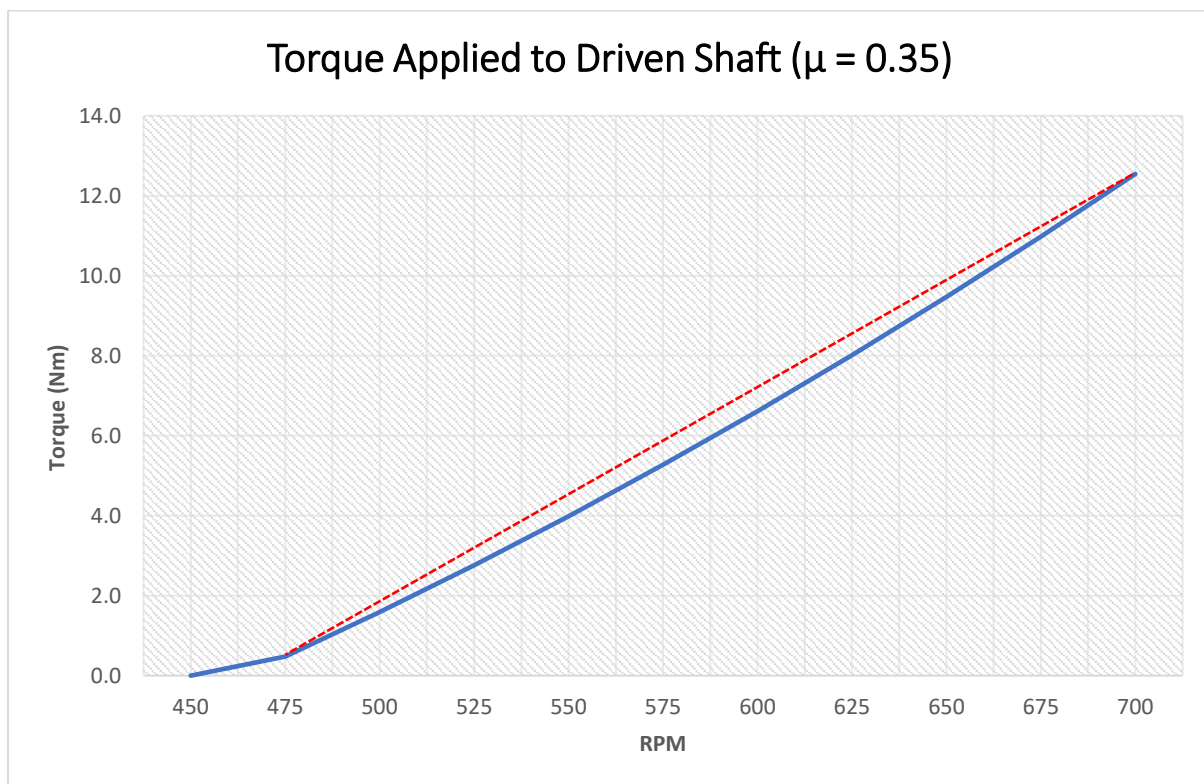


Figure 8: A graph of the torque applied to the driven shaft of the centrifugal clutch between 450 and 700 RPM.

Table 1: Torque calculations for the driven shaft of the centrifugal clutch between 450 and 700 RPM.

	Units	RPM										
		450	475	500	525	550	575	600	625	650	675	700
Angular Velocity	Rads/s	47.1	49.7	52.4	55.0	57.6	60.2	62.8	65.4	68.1	70.7	73.3
Fc (centrifugal force)	N	-4.0	3.3	10.9	18.9	27.4	36.2	45.4	55.0	65.0	75.4	86.2
μ (coefficient of friction)	N/A	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Ff (frictional force)	N	-1.4	1.1	3.8	6.6	9.6	12.7	15.9	19.3	22.8	26.4	30.2
T (torque per shoe)	Nm	-0.1	0.1	0.4	0.7	1.0	1.3	1.7	2.0	2.4	2.7	3.1
T (total torque)	Nm	0.0	0.5	1.6	2.8	4.0	5.3	6.6	8.0	9.5	11.0	12.5

Question 6

Figure 9 shows the torque output based on various coefficients of friction. Since the frictional force is directly proportional to the coefficient of friction, any increase or decrease will lead to a corresponding change in the torque applied to the driven shaft. As the RPM increases, the difference (delta) in torque output between each coefficient of friction increases, indicating a nonlinear relationship.

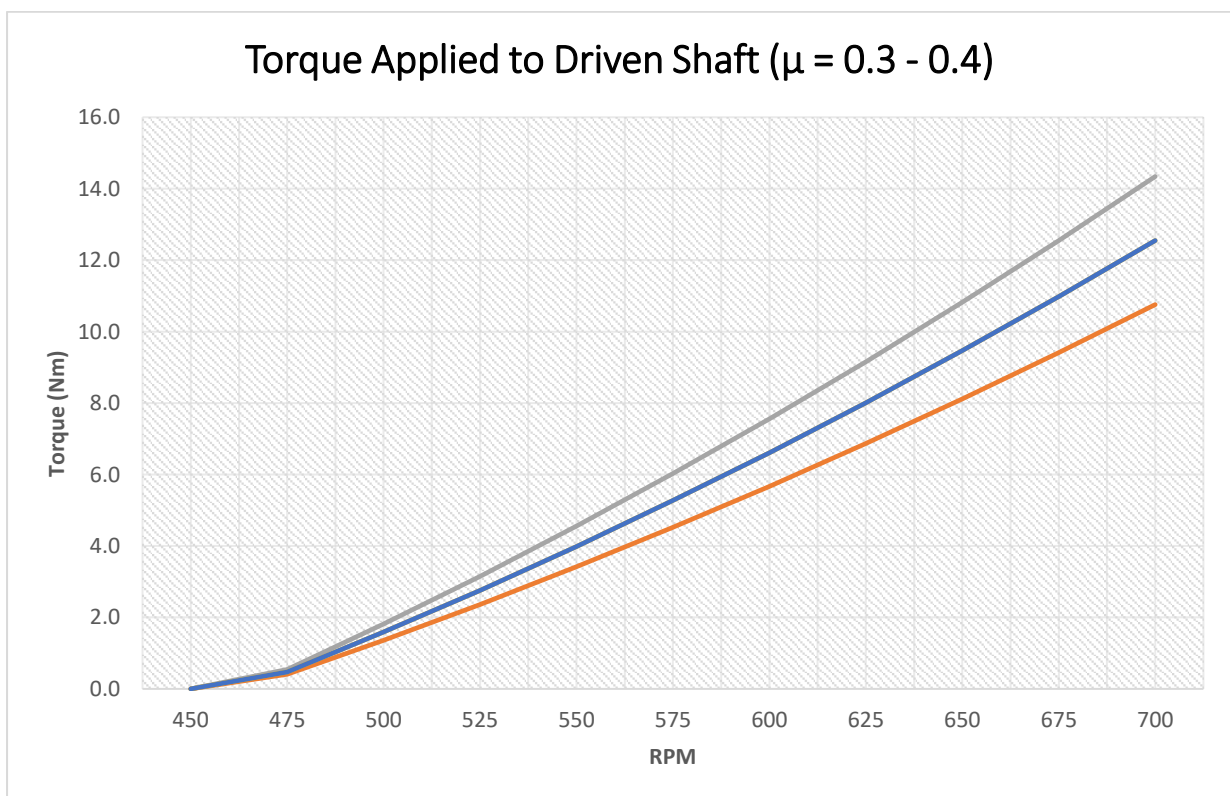


Figure 9: A graph of the torque applied to the driven shaft of the centrifugal clutch between 450 and 700 RPM, using coefficient of friction values 0.3, 0.35 and 0.4.

Table 2: Torque calculations for the driven shaft of the centrifugal clutch between 450 and 700 RPM, using coefficient of friction values 0.3, 0.35 and 0.4.

		RPM										
		450	475	500	525	550	575	600	625	650	675	700
Total Torque (Nm)	$\mu = 0.30$	0.0	0.4	1.4	2.4	3.4	4.5	5.7	6.9	8.1	9.4	10.8
	$\mu = 0.35$	0.0	0.5	1.6	2.8	4.0	5.3	6.6	8.0	9.5	11.0	12.5
	$\mu = 0.40$	0.0	0.5	1.8	3.2	4.6	6.0	7.6	9.2	10.8	12.5	14.3

Question 7

The highest torque output from the previous question was 14.3 Nm, achieved with a coefficient of friction of 0.40 and a rotational speed of 700 RPM. Knowing that the mass of the outer drum is 750 grams and is considered a solid disc, the angular acceleration can be calculated by rearranging the following torque equation:

$$T = I\alpha$$

where I = the moment of inertia, measured in kg m²

α = the angular acceleration, measured in rads/s².

Rearranging for angular acceleration:

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

Next, the moment area of inertia must be calculated. Since the outer drum is considered a solid disc, the following equation is used:

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

$$I = \frac{1}{2} \times 750 \times 10^{-3} \times (108 \times 10^{-3})^2$$

$$I = 4.37 \times 10^{-3} \text{ kg m}^2$$

The values for moment of inertia and torque are now used to calculate the angular acceleration:

$$\alpha = \frac{14.34}{4.37 \times 10^{-3}}$$

$$\alpha = 3281 \text{ rads/s}^2$$

The angular acceleration of the drum at 700 RPM and a coefficient of friction of 0.4 is 3281 rads/s².

(Bird & Ross, 2020)

Question 8

A constant tangential braking force of 500N applied to the driven shaft with a diameter of 17.5 mm will reduce the torque and angular acceleration. To be able to calculate the actual reductions, first, the tangential braking force must be converted to a braking torque:

$$T = Fr$$

$$T = 500 \times \left(\frac{17.5}{2}\right) \times 10^{-3}$$

$$T = 4.38 \text{ Nm}$$

The braking torque applied to the driven shaft is 4.38 Nm, as Figure 10 illustrates.

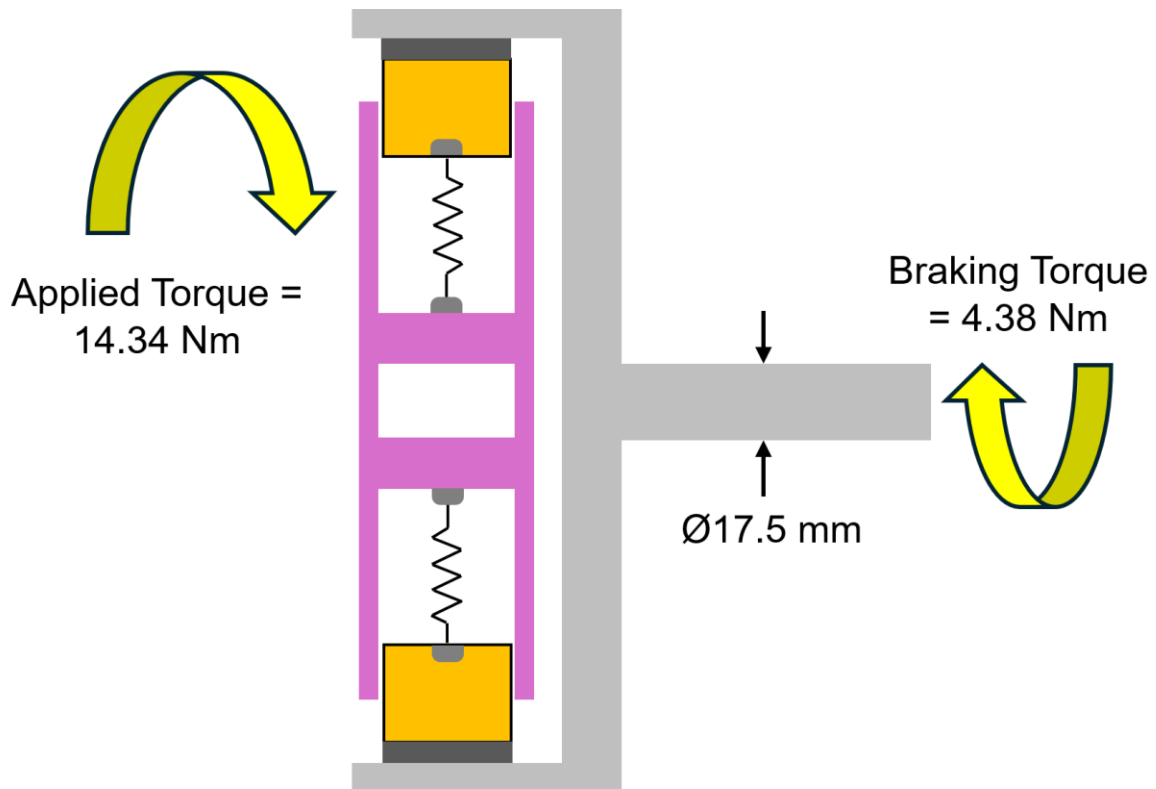


Figure 10: Diagram showing a centrifugal clutch's applied and braking torques.

The accelerating torque is calculated by subtracting the braking torque from the applied torque:

$$T = 14.34 - 4.38$$

$$T = 9.96 \text{ Nm}$$

The new torque value is now inputted into the angular acceleration equation:

$$\alpha = \frac{9.96}{4.37 \times 10^{-3}}$$

$$\alpha = 2279 \text{ rads/s}^2$$

The maximum possible angular acceleration of the drum at 700 RPM and a coefficient of friction of 0.4 is 2279 rads/s².

Bibliography

Bird, J. & Ross, C., 2020. *Mechanical Engineering Principles*. 4th ed. Oxford: Routledge.

BLM Automatic Clutch, 2019. *The How and Why of Centrifugal Clutches*. [Online] Available at: <https://www.centrifugalclutches.com/blog/the-how-and-why-of-centrifugal-clutches/#:~:text=Centrifugal%20clutches%20are%20widely%20used,with%20reliable%20and%20durable%20components>. [Accessed 03 November 2024].

Bolton, W., 2020. *Engineering Science*. 7th ed. London: Routledge.

Chowdhary, A., Kumar, A. & Singh, S. K., 2020. Design and Analysis of an Electro-Magnetic Clutch. *International Journal of Progressive Research in Science and Engineering* , 1(3), pp. 89 - 95.

Crane, N. B., 2003. *Compliant Centrifugal Clutches: Design, Analysis, and Testing*, Brigham Young University: s.n.

Goud, C., Patil, M. & Patil, G., 2017. A REVIEW ON CENTRIFUGAL CLUTCH. *NATIONAL CONFERENCE ON EMERGING TRENDS IN ENGINEERING AND TECHNOLOGY*, pp. A93 - A97.

Growdus, W. A., 1898. *Automobile Vehicle*. United States, Illinois, Patent No. US598314A.

Meriam, J. L., Kraige, L. G. & Bolton, J. N., 2015. *Engineering Mechanics Dynamics*. 8th ed. Hoboken, New Jersey: Wiley.

Ogura Clutch, 2024. *Electromagnetic Clutches and Brakes*. [Online] Available at: https://ogura-clutch.com/electromagnetic_clutch.php [Accessed 8th November 2024].

Panchal, D., Patel, B. & Gohil, H., 2023. Experimental Investigation on Performance Characteristics of Dry Centrifugal Clutch with Grooved Friction Liners. *Internaltional Journal Of Automotive And Mechanical Engineering* , 20(1), pp. 10152 - 10163.

Reynolds, R., 1857. *Centrifugal friction-clutch*. United States, New York, Patent No. US16748A.

Schmid, S. R., Hamrock, B. J. & Jacobson, B. O., 2024. *Fundamentals of Machine Elements*. 3rd ed. Florida: CRC Press.

Shattuck, C., 2005. *Scooters: Red Eyes, Whitewalls and Blue Smoke*. Denver: Speck Press.

UKEssays, 2018. *Historical Products Report: The Chainsaw*. [Online] Available at: <https://www.ukessays.com/essays/engineering/historical-products-report-the-chainsaw.php> [Accessed 28th October 2024].

University of Wales Trinity Saint David, 2024. *Analysis and Simulation of a Centrifugal Clutch*. Swansea: s.n.

Vorob'yeva, T., 1965. *Electromagnetic Clutches and Couplings*. s.l.:Pergamon.