

University of Wales Trinity Saint David
Analysis and Simulation of a Centrifugal Clutch

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Apprenticeship in Mechanical and Manufacturing Engineering
(BEng)

6th of November 2023

Stress Analysis and Dynamics



Contents

Task A.....	2
Introduction.....	3
What is a Centrifugal Clutch	3
History Behind Centrifugal Clutch.....	3
Material for Centrifugal Clutches.....	4
Operating Conditions for Centrifugal Clutches.....	4
Advantages and Disadvantages	5
Electromagnetic Clutches	6
Conclusion	6
References:	7
Task B.....	8
1.What is the diameter of the outer drum?	9
2. Determine the engagement speed of the centrifugal clutch. You should provide your answer in RPM (revolutions per minute) and rounded to the nearest whole value of RPM.....	9
3.Calculate the radial force acting on the clutch face when the driving shaft is rotating at a speed of 550 RPM.	10
4.At the driving shaft speed of 550 RPM, what will be the value of torque transmitted to the driven shaft?.....	11
5.Using either MatLab or MS Excel, 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.	12
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.	12
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?.....	14

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Task A

Introduction

Clutches play an important role in enabling controlled power transmission in mechanical engineering. Centrifugal clutches have a long history and a wide range of applications due to their automatic engagement based on engine speed. Their ease of use, safety features, and low cost have all contributed to their popularity in a wide range of small-scale machinery. These clutches have distinct advantages and disadvantages, making them well-suited for specific applications. Electromagnet-driven electromagnetic clutches, on the other hand, play a critical role in modern manufacturing automation. They provide precise power transmission control, enabling efficient and synchronised operations in a wide range of industries, from printing and packaging to material handling and CNC machining.

What is a Centrifugal Clutch

A centrifugal clutch consists of five key parts, this is the drive shaft, shoes, friction material, springs and a spider. These parts are then cased inside a drum as shown in figure 1.

As the RPM of the driving shaft increases, the springs within the spider extend due to the centrifugal force pushing them outwards towards the casing of the drum. When a specific RPM is reached, the force increases and eventually closes the clearance gap between the shoe and the casing of the drum. When the drum and the casing make contact, the friction material locked on and engages the drum causing the driving shaft and drum to rotate at the same speed. This same action happens when the driving shaft slows down and the springs contract due to a lack of force, so the shoes disengage. (sireajjedine, 2023)

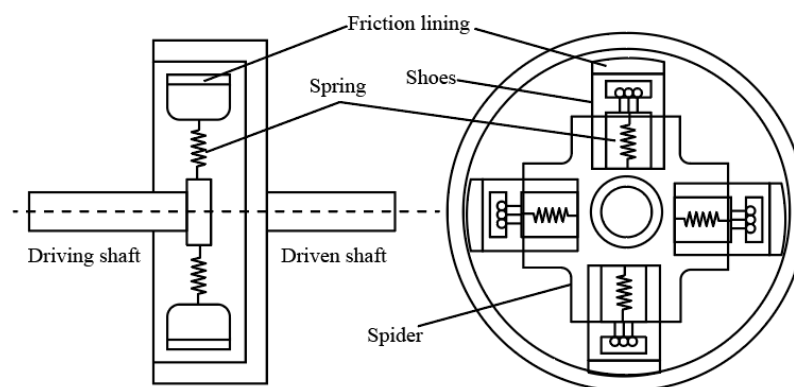


Figure 1 – Diagram of Centrifugal Clutch

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History Behind Centrifugal Clutch

Centrifugal clutches were originally used in railway locomotives around 1858 and were patented in relation to electric motors in 1899. Figure 2 shows the original patent application for the centrifugal clutch (Institution Of Civil Engineers, 2016). It was then Thomas Fogarty who was credited with invention of the centrifugal clutch for small motor applications in the 1940's (Mit.edu, 2019).

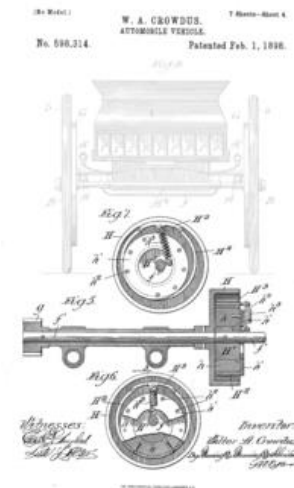


Figure 2 – Patent of Centrifugal Clutch

Material for Centrifugal Clutches

The material used is determined by factors such as the torque and speed requirements of the application, operating conditions, and the desired longevity and performance of the centrifugal clutch. Originally there was limited selection of materials for the shoes to be made from, however due to the creation of synthetic materials and availability of materials they are now suited to the application.

Steel and ceramics are commonly used in high-performance applications, whereas cast iron or aluminium are used in lower-cost applications. It is critical to select the proper material to ensure that the clutch can withstand the application's specific demands. (Lancereal, 2019)

Operating Conditions for Centrifugal Clutches

Not only is the material choice important but the choice of clutch for the operating conditions too. Operating conditions can range from; The load requirements which ensures that the clutch can transmit the required torque or power without slipping. Cooling and lubrication may also be required to maintain operating in high temperature and/or high-speed applications to prevent overheating. Enviromental conditions also need to be considered as

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temperature, humidity and exposure to dirt can affect performance and durability. (www.engineeringdesigner.co.uk, 2023)

Due to the centrifugal clutch having automatic engagement and disengagement it doesn't require the clutch to be controlled manually which is why it's a popular choice in small consumable applications where skill/experience is not necessary. These applications can include Go Karts, chainsaws and lawnmowers. (Testbook, 2023)

Advantages and Disadvantages

Centrifugal clutches have specific advantages and disadvantages for different applications and operating conditions. Some advantages are:

Centrifugal clutches engage and disengage automatically in response to engine speed. This feature is especially useful in applications where the operator may lack the experience or skill to effectively manage a manual clutch. It simplifies the process and reduces the possibility of human error.

Automatic engagement and disengagement improve safety. They prevent the rapid and unexpected engagement of power when the engine is started or running at idle, minimising the possibility of accidents and making them acceptable for applications with beginner or casual users, such as go-karts, small bikes, and lawnmowers.

The soft engagement and disengagement of centrifugal clutches reduces wear and tear on the equipment. This gradual transition reduces shock loads on drivetrain components, resulting in longer equipment lifespan and lower maintenance costs.

When compared to other types of clutches, centrifugal clutches are often more cost-effective to manufacture and install, making them a viable option for applications where cost constraints may exist. (BLM Team , 2019)

Some disadvantages of centrifugal clutches are:

One of the primary drawbacks of centrifugal clutches is the lack of control over power engagement and disengagement. They engage solely on engine speed, which can be inconvenient in applications requiring precise control over power delivery or immediate disengagement.

The engagement speed is set and cannot be changed. If the fixed engagement speed does not correspond to the application's specific requirements, it can result in suboptimal performance.

Centrifugal clutches may exhibit slippage at low engine speeds, affecting performance in applications that require constant power delivery, particularly at low engine speeds. (Mecholic, 2017)

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Electromagnetic Clutches

An electromagnetic clutch is a type of clutch that uses the magnetic force generated by an electromagnet to engage and disengage the power transmission between two rotating shafts (Figure 3). Electromagnetic clutches play an important role in modern manufacturing process automation by providing precise control over power transmission. (mectips.com, 2019) Some examples of current electromagnetic clutch applications in manufacturing automation:

Printing and packaging machines use electromagnetic clutches to control the engagement and disengagement of various components such as rollers, cylinders, and printing plates. They allow for accurate synchronisation and adjustment of printing and packaging processes, which is critical for quality control and efficiency. (W Bolton, 2015)

Electromagnetic clutches are frequently used to control material movement in automated material handling systems such as conveyor belts, sorting machines, and indexing tables. The clutches allow for the intermittent or variable movement of materials, guaranteeing smooth and precise material handling in production and logistics.

To control spindle engagement, electromagnetic clutches are integrated into computer numerical control (CNC) machines. In CNC machining operations, they offer rapid tool changes, precise speed control, and safety measures.

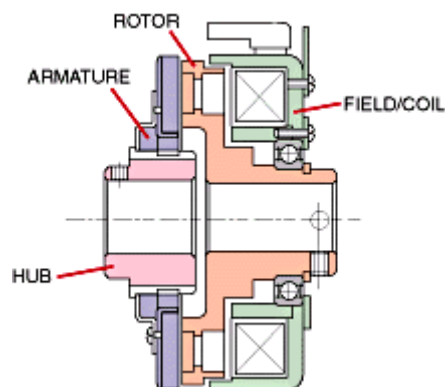


Figure 3 – Diagram of Electromagnetic Clutch

Conclusion

In conclusion, the evolution of clutches, particularly centrifugal and electromagnetic clutches, has had a significant impact on a variety of industries. Centrifugal clutches have proven to be extremely useful in small-scale applications, providing a safe and user-friendly method of power transmission. They are a popular choice due to their automatic engagement and disengagement, cost-effectiveness, and ease of maintenance. Electromagnetic clutches, on the other hand, have revolutionised manufacturing automation by allowing precise control over power transmission. They are used in critical processes to improve efficiency and quality in industries ranging from printing to material handling. Both types of clutches demonstrate the engineering ingenuity that is still shaping the modern industrial landscape.

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Task B

1. What is the diameter of the outer drum?

$$\text{Diameter} = (\text{COM Radius} + \text{Clearence Distance} + \text{Wall Thickness}) \times 2$$

$$\text{COM Radius} = 95\text{mm} = 0.095\text{m}$$

$$\text{Clearence distance} = 9\text{mm} = 0.009\text{m}$$

$$\text{Wall thickness} = 4\text{mm} = 0.004\text{m}$$

Calculating Radius

$$R = 95 + 9 + 4$$

$$R = 108\text{mm}$$

Calculating Diameter

$$D = R \times 2$$

$$D = 108 \times 2$$

$$\text{Diameter} = 216\text{mm} / 0.216\text{m}$$

2. Determine the engagement speed of the centrifugal clutch. You should provide your answer in RPM (revolutions per minute) and rounded to the nearest whole value of RPM.

$$\text{Centrifugal force (Fc)} = mr\omega^2$$

$$M = \text{mass of shoe} = 275\text{g} = 0.275\text{kg}$$

$$R = \text{radius of shoe} = 104\text{mm} = 0.104\text{m}$$

$$W = \text{angular velocity (Rad/s)}$$

$$\text{Spring Force (F}_s\text{)} = kx$$

$$K = \text{Spring stiffness} = 7.5\text{kN/m} = 7500\text{n/m}$$

$$X = \text{Clearence distance} = 9\text{mm} = 0.009\text{m}$$

Calculating spring force

$$F_s = 7500 \times 0.009$$

$$F_s = 67.5\text{ nm}$$

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Calculate Angular velocity

$$F_c = F_s$$

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

$$\omega^2 = \frac{kx}{mr}$$

$$\omega = \sqrt{\frac{kx}{mr}}$$

$$\omega = \sqrt{\frac{7500 \times 0.009}{0.275 \times 0.104}}$$

$$\omega = 48.581 \text{ Rad/s}$$

Convert to RPM

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

$$RPM = 48.581 \times \frac{60}{2\pi}$$

$$RPM = 463.972$$

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

Radial force = centripetal force

$$F_c = \frac{mv^2}{r}$$

$$F_c = \frac{0.275 \times 5.987^2}{0.104}$$

$$F_c = 94.78 \text{ N/m}$$

Considering the spring force

$$F_c = 94.78 - 67.5$$

$$F_c = 27.28 \text{ N/m}$$

Considering that there are 4 shoes

$$F_c = 27.28 \times 4$$

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$$F_c = 109.12 \text{ n/m}$$

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

$$\text{Torque } (T) = Fr$$

$$\text{Force} = \mu F_r$$

Calculate Force

$$F = \mu \times \text{Radial Force}$$

$$F = 0.35 \times 109.12$$

$$F = 38.19 \text{ N}$$

Calculate Torque

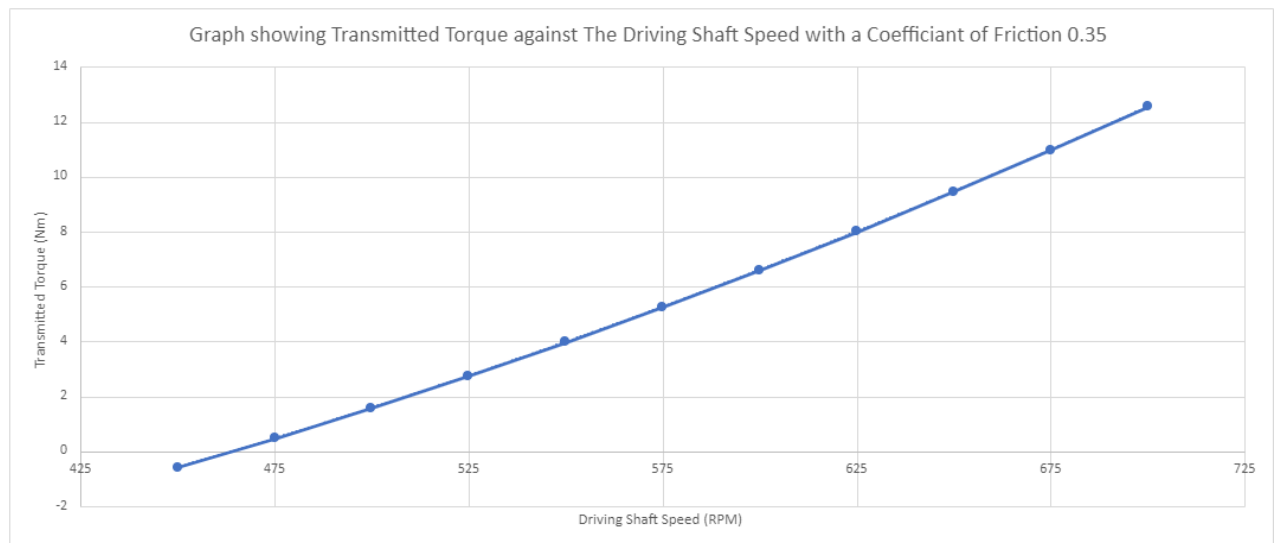
$$T = 38.19 \times 0.104$$

$$T = 3.97 \text{ Nm}$$

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5. Using either MatLab or MS Excel, 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.

Shaft speed			Centripetal Force				Radial force in shoes		Force		Transmitted torque (Nm)	
RPM	RPM/(60/2x3.1416) = Rad/s	Rad/s	$F_c = (m \cdot v^2)/r$				$F_{rTotal} = (F_c - F_s) \cdot 4$		$F = SC \cdot F_r$		$T = F \cdot r$	
			m	v	r	f_c	F_s	F_{rTotal}	SC	F	r	T
450		47.124	0.275	4.900896	0.104	63.5112	67.5	-15.9552	0.35	-5.58432	0.104	-0.58077
475		49.742	0.275	5.173168	0.104	70.76402	67.5	13.05609	0.35	4.569633	0.104	0.475242
500		52.36	0.275	5.44544	0.104	78.40889	67.5	43.63556	0.35	15.27245	0.104	1.588334
525		54.978	0.275	5.717712	0.104	86.4458	67.5	75.78321	0.35	26.52412	0.104	2.758509
550		57.596	0.275	5.989984	0.104	94.87476	67.5	109.499	0.35	38.32466	0.104	3.985765
575		60.214	0.275	6.262256	0.104	103.6958	67.5	144.783	0.35	50.67406	0.104	5.270102
600		62.832	0.275	6.534528	0.104	112.9088	67.5	181.6352	0.35	63.57232	0.104	6.611522
625		65.45	0.275	6.8068	0.104	122.5139	67.5	220.0556	0.35	77.01945	0.104	8.010023
650		68.068	0.275	7.079072	0.104	132.511	67.5	260.0441	0.35	91.01544	0.104	9.465605
675		70.686	0.275	7.351344	0.104	142.9002	67.5	301.6008	0.35	105.5603	0.104	10.97827
700		73.304	0.275	7.623616	0.104	153.6814	67.5	344.7257	0.35	120.654	0.104	12.54802



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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.

Coefficient of 0.35

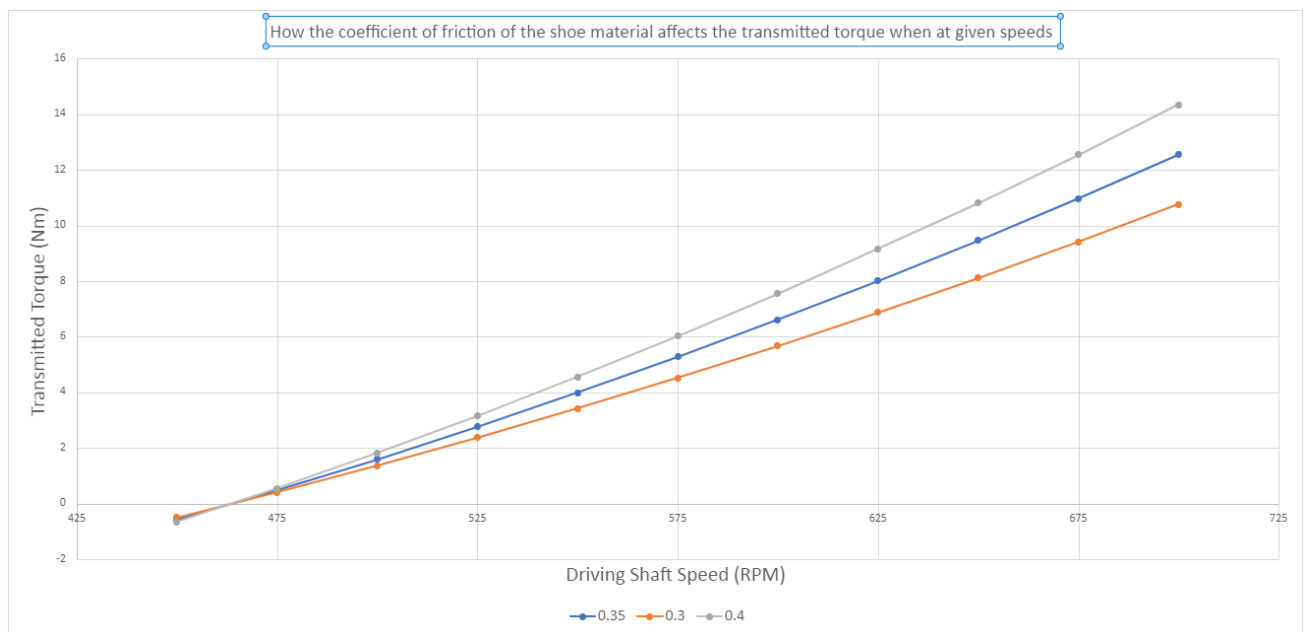
Shaft speed			Centripetal Force				Radial force in shoes		Force		Transmitted torque (Nm)	
RPM	RPM/(60/2π×1416) = Rad/s	Rad/s	m	v	r	fc	Fs	FrTotal	SC	F	r	T
450		47.124	0.275	4.900896	0.104	63.5112	67.5	-15.9552	0.35	-5.58432	0.104	-0.58077
475		49.742	0.275	5.173168	0.104	70.76402	67.5	13.05609	0.35	4.569633	0.104	0.475242
500		52.36	0.275	5.44544	0.104	78.40889	67.5	43.63556	0.35	15.27245	0.104	1.588334
525		54.978	0.275	5.717712	0.104	86.4458	67.5	75.78321	0.35	26.52412	0.104	2.758509
550		57.596	0.275	5.989984	0.104	94.87476	67.5	109.499	0.35	38.32466	0.104	3.985765
575		60.214	0.275	6.262256	0.104	103.6958	67.5	144.783	0.35	50.67406	0.104	5.270102
600		62.832	0.275	6.534528	0.104	112.9088	67.5	181.6352	0.35	63.57232	0.104	6.611522
625		65.45	0.275	6.8068	0.104	122.5139	67.5	220.0556	0.35	77.01945	0.104	8.010023
650		68.068	0.275	7.079072	0.104	132.511	67.5	260.0441	0.35	91.01544	0.104	9.465605
675		70.686	0.275	7.351344	0.104	142.9002	67.5	301.6008	0.35	105.5603	0.104	10.97827
700		73.304	0.275	7.623616	0.104	153.6814	67.5	344.7257	0.35	120.654	0.104	12.54802

Coefficient of 0.3

Shaft speed			Centripetal Force				Radial force in shoes		Force		Transmitted torque (Nm)	
RPM	RPM/(60/2π×1416) = Rad/s	Rad/s	m	v	r	fc	Fs	FrTotal	SC	F	r	T
450		47.124	0.275	4.900896	0.104	63.5112	67.5	-15.9552	0.3	-4.78656	0.104	-0.4978
475		49.742	0.275	5.173168	0.104	70.76402	67.5	13.05609	0.3	3.916828	0.104	0.40735
500		52.36	0.275	5.44544	0.104	78.40889	67.5	43.63556	0.3	13.09067	0.104	1.36143
525		54.978	0.275	5.717712	0.104	86.4458	67.5	75.78321	0.3	22.73496	0.104	2.364436
550		57.596	0.275	5.989984	0.104	94.87476	67.5	109.499	0.3	32.84971	0.104	3.41637
575		60.214	0.275	6.262256	0.104	103.6958	67.5	144.783	0.3	43.43491	0.104	4.517231
600		62.832	0.275	6.534528	0.104	112.9088	67.5	181.6352	0.3	54.49056	0.104	5.667019
625		65.45	0.275	6.8068	0.104	122.5139	67.5	220.0556	0.3	66.01667	0.104	6.865734
650		68.068	0.275	7.079072	0.104	132.511	67.5	260.0441	0.3	78.01323	0.104	8.113376
675		70.686	0.275	7.351344	0.104	142.9002	67.5	301.6008	0.3	90.48024	0.104	9.409945
700		73.304	0.275	7.623616	0.104	153.6814	67.5	344.7257	0.3	103.4177	0.104	10.75544

Coefficient of 0.4

Shaft speed			Centripetal Force				Radial force in shoes		Force		Transmitted torque (Nm)	
RPM	RPM/(60/2π×1416) = Rad/s	Rad/s	m	v	r	fc	Fs	FrTotal	SC	F	r	T
450		47.124	0.275	4.900896	0.104	63.5112	67.5	-15.9552	0.4	-6.38208	0.104	-0.66374
475		49.742	0.275	5.173168	0.104	70.76402	67.5	13.05609	0.4	5.222438	0.104	0.543134
500		52.36	0.275	5.44544	0.104	78.40889	67.5	43.63556	0.4	17.45422	0.104	1.815239
525		54.978	0.275	5.717712	0.104	86.4458	67.5	75.78321	0.4	30.31328	0.104	3.152581
550		57.596	0.275	5.989984	0.104	94.87476	67.5	109.499	0.4	43.79981	0.104	4.55516
575		60.214	0.275	6.262256	0.104	103.6958	67.5	144.783	0.4	57.91321	0.104	6.022974
600		62.832	0.275	6.534528	0.104	112.9088	67.5	181.6352	0.4	72.65408	0.104	7.556025
625		65.45	0.275	6.8068	0.104	122.5139	67.5	220.0556	0.4	88.02223	0.104	9.154312
650		68.068	0.275	7.079072	0.104	132.511	67.5	260.0441	0.4	104.0176	0.104	10.81783
675		70.686	0.275	7.351344	0.104	142.9002	67.5	301.6008	0.4	120.6403	0.104	12.54659
700		73.304	0.275	7.623616	0.104	153.6814	67.5	344.7257	0.4	137.8903	0.104	14.34059



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From this graph we can see that the coefficient of friction of the shoe material does affect the transmitted torque at given speeds. From the graph we can see that the Coefficients have more of an impact when the driving shaft speed is higher. The impact being that the transmitted torque is lower with a lower coefficient. The Torque at 675RPM for 0.3coefficient is 9.4Nm whereas the torque at 675RPM for 0.4coefficient is 12.5Nm, this is a difference of 3.1Nm. From this graph it is clear that if a higher transmitted torque is required, a material with a high coefficient of friction will be needed.

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?

$$\text{Angular acceleration } (a) = \frac{T}{I}$$

$$T = \text{Maximum Transmitted torque} = 14.34\text{Nm}$$

$$I = \text{The moment of inertia of the drum}$$

$$\text{The moment of inertia } (I) = \frac{1}{2}mr^2$$

$$M = \text{Mass of the drum} = 750\text{g} = 0.75\text{kg}$$

$$R = \text{radius of the drum} = 108\text{mm} = 0.108\text{m}$$

Calculate the moment of inertia

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

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

Calculate angular acceleration

$$a = \frac{14.34}{0.004374}$$

$$a = 3278.46 \text{ Rad/s}^2$$

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