

Analysis and Simulation of a Centrifugal Clutch

STRESS ANALYSIS AND DYNAMICS (ACMA5010)

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1.0 Introduction

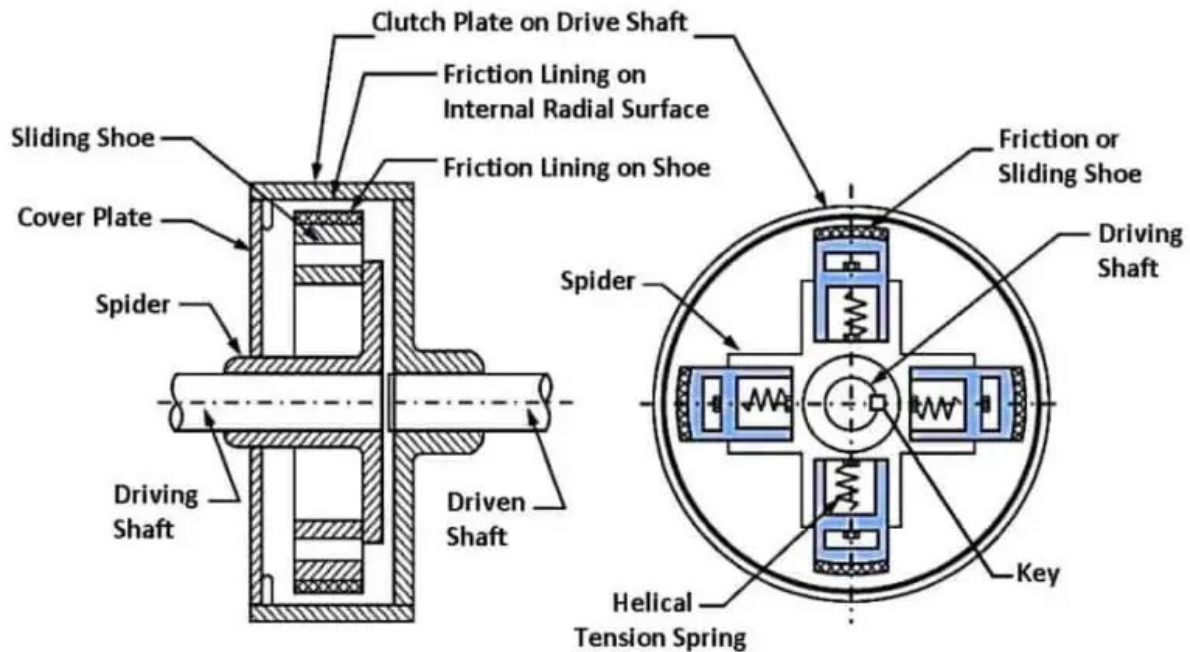
This report is on centrifugal friction clutches and contains two main sections, analysis and simulation. The analysis discusses the development and history of centrifugal friction clutches in engineering industries. This includes material choices, major development strides and suitable applications. Lastly, it discusses the current applications of electromagnetic clutches in modern day engineering activities.

The simulation section of this report consists of seven mathematical questions regarding centrifugal friction clutch equations and formulas. Including Hookes law, Newtons 3rd Law of Motion and formulae for Torque, Angular velocity/ acceleration, mass moment of inertia and others. Microsoft excel has been used to produce tables and graphs for some of the questions.

2.0 Task A - Analysis of Centrifugal Friction Clutches

2.1 What is a Centrifugal Friction Clutch?

A clutch can be defined as a mechanical device which, when engaged transmits power from one shaft to the other coaxial shaft. A friction clutch is a specific type of clutch that works on the principle that when a rotating disc comes in contact with a stationary disc, the stationary disc starts rotating because of the friction between them. The design for centrifugal friction clutches can vary but the main parts can be seen in Figure 1 below (The Engineers Post, 2023b).



Parts of Centrifugal Clutch

Figure 1 Parts of Centrifugal Clutch (The Engineers Post, 2023b)

The driving shaft is rotated via a mechanism, normally an engine or motor. This in turn rotates the spider. Attached to the spider are the shoes, the number of shoes may vary on different designs. The shoes are attached to the spider via a spring with a known tension force. As the driving shaft rotates the shoe are forced outward due to the centrifugal force acting upon them. Once the centrifugal force is greater than the tension force of the springs, the shoe or shoes will start to contact the clutch plate on the driven shaft. The shoes are coated with a friction lining to aid contact and encourage the two surfaces to bind. Once the shoes and clutch plate have made contact, they will start to rotate as one and the driven shaft will rotate at the same rate as the driving shaft (The Engineers Post, 2023a).

A centrifugal friction clutch will automatically engage and disengage at a precise RPM, this is due to the known weight, dimensions, and tension force within the clutch. This attribute means that a system using a centrifugal clutch does not need a clutch pedal such as a manual car.

2.2 History of the Centrifugal Friction Clutch

It has been documented that centrifugal clutches were used on railway locomotives in the mid 1800's. The centrifugal design allowed the steam powered engine to slowly come up to operating speed and then the clutch would engage transferring the rotational energy to the driven shaft and then through the system and eventually to the wheels. Without the use of the centrifugal clutch the driver would have had to manually engage the system, similarly to a manual car today. The auto engaging nature of the clutch also allowed the driving shaft to engage at a suitable known point which enables engines to overcome the initial inertia of the locomotive (Engineering Designer, 2023).

In the early 20th century, the centrifugal friction clutch was widely used in the electric automotive industry following a patent issued in 1898 by the United States patent office. This patent was for the whole electric automobile vehicle design, including the centrifugal friction clutch element (Crowdus, 1898).

2.3 Advantages and Disadvantages of a Centrifugal Clutch

A centrifugal clutch can effectively transfer energy from the driving shaft to the driven shaft without losing any torque or power. As the RPM of the driving shaft increases the centrifugal force within the clutch increases forcing the shoes onto the clutch plate with a higher and higher force. As the clutch automatically engages and disengages the centrifugal friction clutch lends itself towards applications and systems that repeatedly stop and start such as conveyer belts, go-karts and lawn mowers.

Due to the friction contact design the shoe can temporarily lose contact and slip along the clutch plate in high torque applications. Wear and tear is also key downfall on centrifugal clutches as the friction lining on the shoes will degrade and wear down over time leading to a failure point if the clutch is not well maintained (Engineering Designer, 2023).

2.4 Applications for a Centrifugal Friction Clutch

Automotive systems such as cars, motorcycles and mopeds all use centrifugal clutches as they offer greater fuel efficiency due to the smooth operation of the clutch. Away from automotive user cases the centrifugal friction clutch is used in manufacturing conveyor belts due to its low operating noise level (Engineering Designer, 2023) (Lancereal, 2019).

An example of a consistent centrifugal clutch application is within chainsaws. The standard two stroke chainsaw will use a centrifugal friction clutch to connect the engine to the chain driving mechanism. Appendix A shows the Stihl MS 211 chainsaw parts diagram. As can be seen on page 13/14 Drawing G "Hand Guard, Chain break" a centrifugal friction clutch is used to connect the engine shaft to the chain assembly.

2.5 Material choices

Material choice is a fundamental section of the engineering design process as poor material choice can cause component failures. Material choice can have a massive impact on the final component such as cost, strength, operating conditions and ensuring the component is fit for purpose.

The main body of the centrifugal clutch would be made from a metallic substance such as steel or aluminium depending on the application, for instance aluminium might be used in lightweight designs whereas steel alloys would be used in more generic designs such as lawnmowers and go-karts due to its strength and cost. The friction lining material can vary, but the properties required are: high coefficient of friction within the operating conditions of the system, be able to withstand high pressure, withstanding repeated impacts, compatible with the metallic components within the rest of the design. Due to these required characteristics ceramics are commonly used alongside semi-metallic linings. These semi-metallic linings are made from sintered iron or copper based bronze alloys (When-What-How, 2011).

2.6 Electromagnetic clutches

The electromagnetic clutch is the 21st century upgrade to the centrifugal friction clutch. The electromagnetic clutch works by applying a current to an electromagnet to engage the clutch and removing the current to disengage the clutch, Figure 2 shows the components of an electromagnetic clutch (MechTips, 2023).

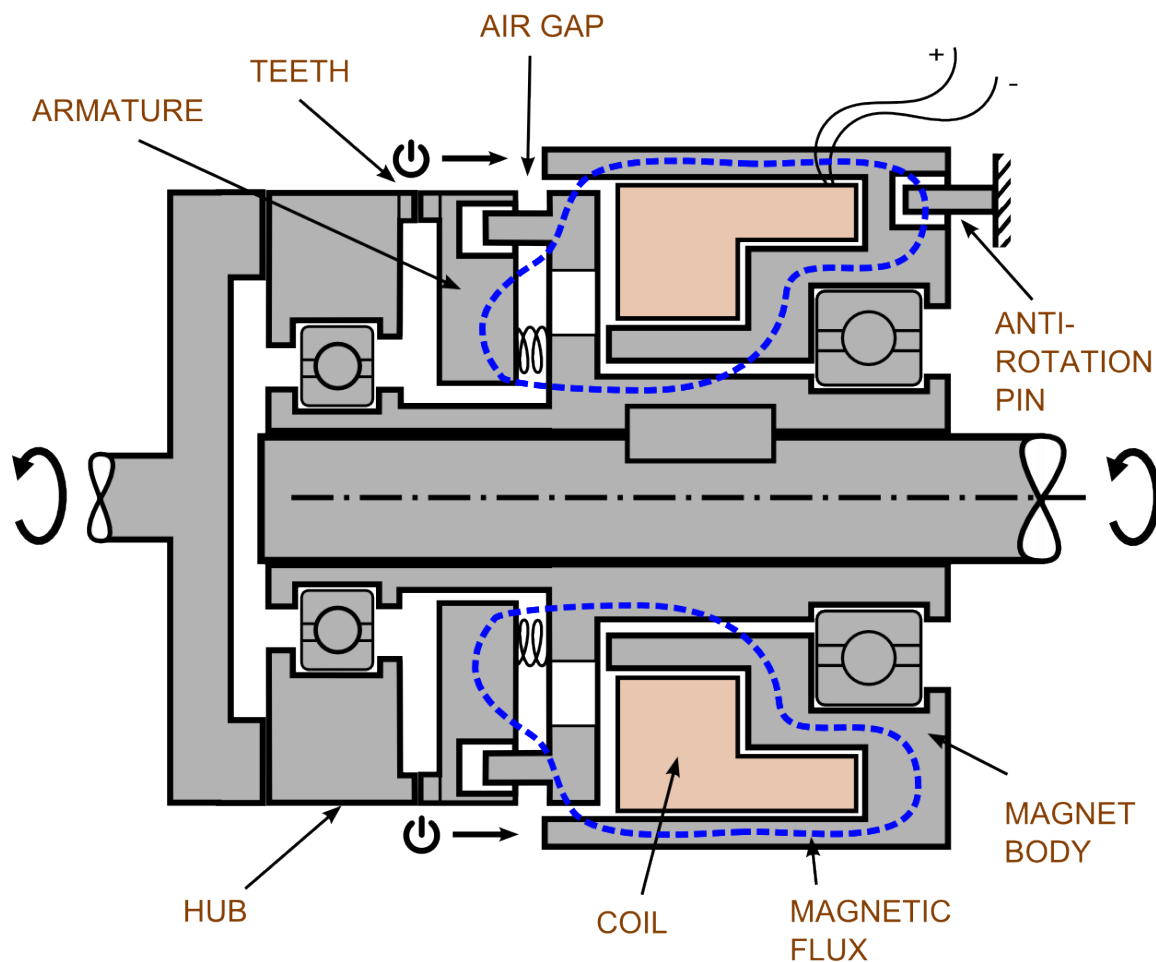


Figure 2 Parts of electromagnetic clutch (MechTips, 2023)

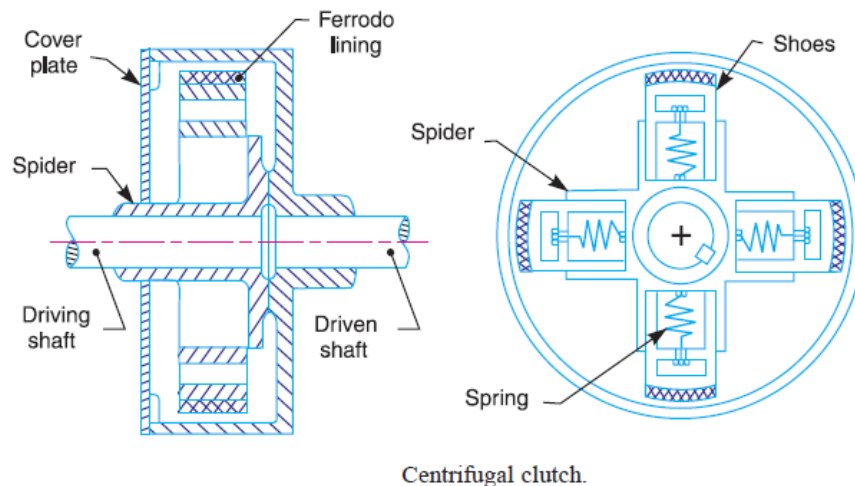
The driving shaft is connected to the rotor and locked in place with a key, when the driving shaft is rotated the rotor will also rotate. The electromagnet sits just behind the rotor and is stationary at all times. The armature is connected to the driven shaft and kept concentric to the driving shaft via a bearing assembly. When the electromagnet is energised the armature is pulled towards the rotor, with help of a friction lining, and the force applied via the electromagnet the armature and rotor will

rotate as one. Once the electromagnet is shut off, the armature will spring back to its resting position causing the drive shaft to stop rotating.

Electromagnetic clutches are commonly used in manufacturing and assembly lines as the electromagnet can be energised and de-energised by a computer-controlled programme. Programmable logic controllers (PLC's) are used in most modern-day factories.

3.0 Task B – Mathematical Calculation on a Centrifugal Friction Clutch

3.1 Question Overview



"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 and has a clearance distance of 9 mm to the outer drum. The outer drum has a wall thickness of 4 mm" (UWTSD, 2023).

3.2 Question 1

“What is the diameter of the outer drum?” (UWTSD, 2023).

From the question shown in section 3.1 we know the centre of mass of each shoe is at a radius of 95 mm from the shaft centres in the rest position, they also have a clearance of 9 mm to the outer drum and lastly the outer drum has a wall thickness of 4 mm.

Below (Figure 3) is an illustration showing the known values, from the known values we can work out the inner diameter of the drum is 208 mm and the outer diameter is 216 mm.

$$\text{Inner Diameter} = 2(0.095 + 0.009)$$

$$\text{Inner Diameter} = 0.208 \text{ m}$$

$$\text{Inner Diameter} = 208 \text{ mm}$$

$$\text{Outer Diameter} = \text{Inner Diameter} + 2 * 0.004$$

$$\text{Outer Diameter} = 0.216 \text{ m}$$

$$\text{Outer Diameter} = 216 \text{ mm}$$

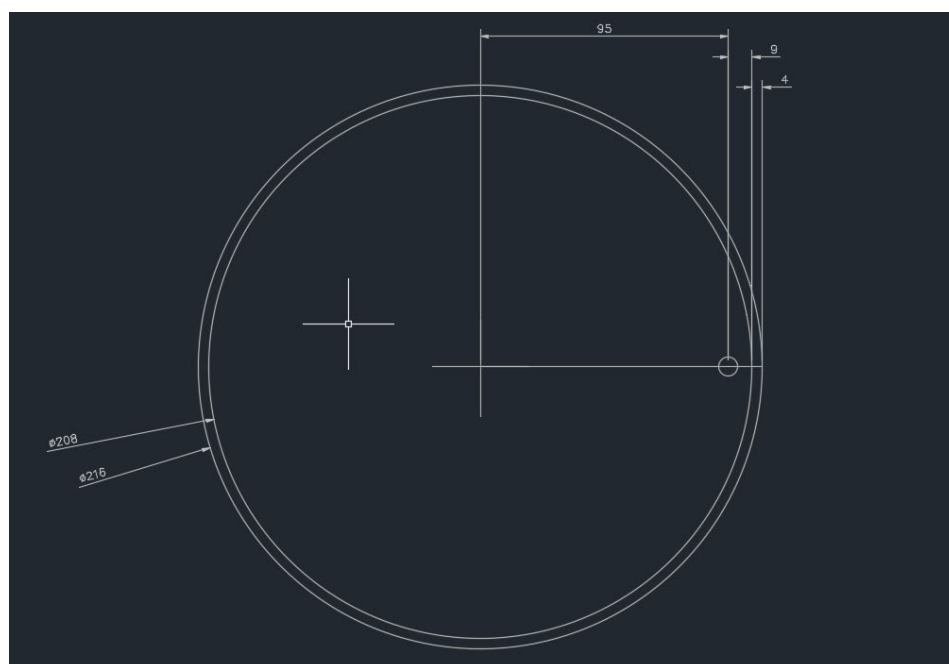


Figure 3 AutoCAD illustration 1

3.3 Question 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” (UWTSD, 2023).

The engagement speed of the clutch will be at the point the friction lining on the shoes contact the outer drum due to the centrifugal force forcing the shoe outward. The shoes need to overcome the tension force on the spring and extended 9mm to the outer drum face.

The centripetal force is a product of the mass and centripetal acceleration of the body, this force acts in the direction of acceleration, i.e. towards the centre of rotation.

$$\text{Centripetal Force, } F_c = m\omega^2 r$$

Due to Newtons 3rd Law of Motion, there will be a reaction to this inwards centripetal force which is equal in magnitude but opposite in direction. This is the centrifugal force.

Rearranging for ω we get the below formula.

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

F_c is the centripetal force due to the mass and angular velocity. The shoes are held in place at rest due to the spring force so for the clutch to engage the shoes need to overcome this force. As all 4 shoes are the same weight and have the same centre of mass we can look at one shoe for this calculation.

Using the below formula we can work out the force required to extend the spring the 0.009m (9mm) required to engage the clutch.

$$F = ke$$

$$F = 7.5 \text{ kNm}^{-1} * 0.009\text{m}$$

$$F = 7.5 * 10^3 * 0.009$$

$$F = 67.5N$$

So it will take 67.5 Newtons to extend on of the springs 9mm. Putting this back into the equation for centripetal force and using 275g for the mass and 95 mm for the radius to the centre of mass.

$$\omega = \sqrt{\frac{67.5 * 4}{(0.275 * 4) * 0.095}}$$

$$\omega = 50.83 \text{ rad/s}$$

To convert radians per second into revolutions per minute the following formula is used.

$$RPM = rad/s \left(\frac{60}{2\pi} \right)$$

$$RPM = 485.39$$

Therefore the engagement speed of the centrifugal clutch rounded to the nearest whole value in RPM is 485 Revolution per minute.

3.4 Question 3

“Calculate the radial force acting on the clutch face when the driving shaft is rotating at a speed of 550 RPM” (UWTSD, 2023).

The radial force acting on the clutch face is the resultant force (R_n) within the clutch system. The other forces in play is the following.

Spring force acting inwards (F) = 67.5 N

Centrifugal force acting outwards (F_{cen}) = ?

Resultant force (R_n) = ?

The centrifugal force can be calculated using the following equation.

$$\text{Centripetal Force, } F_c = m\omega^2 r = \text{Centrifugal Force} = F_{cen}$$

To work out the centrifugal force the angular velocity in rad/s is needed.

Rearranging the RPM formula, rad/s is shown as.

$$\text{rad s}^{-1} = \text{RPM} / \left(\frac{60}{2\pi} \right)$$

The RPM given in the question is 550 RPM so the angular velocity in rad/s is 57.6 rad/s.

Putting this into the centrifugal force equation.

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

$$F_{cen} = (0.275 * 4) * 57.6^2 * (0.095 + 0.009)$$

$$F_{cen} = 379.55 \text{ N}$$

$$R_n = F_{cen} - 4F$$

$$R_n = 379.55 - (4 * 67.5)$$

$$R_n = 109.55 \text{ N}$$

The radial force acting on the clutch face at 550 RPM is 109.55 Newtons.

This is assuming the centre of mass has moved to the end of each shoe.

3.5 Question 4

"At the driving shaft speed of 550 RPM, what will be the value of torque transmitted to the driven shaft?" (UWTSD, 2023).

There are two equations to work out torque.

$$T = I * \alpha$$

Where I is the moment on inertia and α is the angular acceleration.

The other formula is.

$$T = F * r$$

Where F is the force and r is the radial distance.

The second formula will be used there is currently no value for moment of inertia or angular acceleration, however the force and radial distance is know.

The force for this equation will be the resultant force on the clutch plate worked out in question 3. And the radial distance will be the inner diameter of the drum.

Lastly, the coefficient of friction must be accounted for when working out the torque. This is simply done by multiplying the torque value by the coefficient of friction given in the question.

$$Tf = F * \mu * r$$

$$Tf = 109.55 * 0.35 * 0.104$$

$$Tf = 3.99 Nm$$

3.6 Question 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" (UWTSD, 2023).

The following table was produced using Microsoft Excel. As can be seen the values worked out in questions 2 through 4 have been calculated for RPM's 450 through to 700 in increments of 25 RPM.

Radial distance (m) 0.104
Friction Coefficient 0.35

RPM	rad/s	Fc	Normal Force	Torque (Nm)
450	47.1	253.79	-16.21	-0.59
475	49.7	282.58	12.58	0.46
500	52.4	314.11	44.11	1.61
525	55.0	346.06	76.06	2.77
550	57.6	379.55	109.55	3.99
575	60.2	414.59	144.59	5.26
600	62.8	451.18	181.18	6.59
625	65.4	489.31	219.31	7.98
650	68.1	530.54	260.54	9.48
675	70.7	571.83	301.83	10.99
700	73.3	614.66	344.66	12.55

Figure 4 Excel table for question 5

The following graph, Figure 5 has been produced from the data in Figure 4.

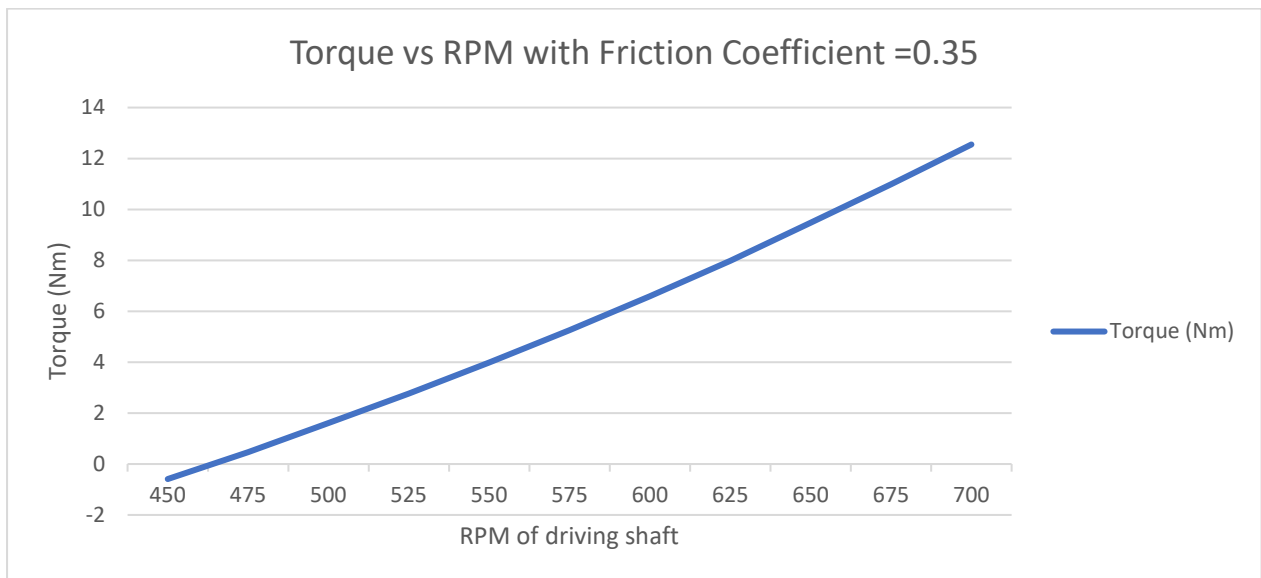


Figure 5 Graphical plot of data in Figure 4

3.7 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” (UWTSD, 2023).

The following table was produced using Microsoft Excel. Extending the table created in question 5 and adding 2 new columns with the new values for the coefficient of friction.

RPM	rad/s	Fc	Normal Force	Friction Coefficient at 0.3	Friction Coefficient at 0.35	Friction Coefficient at 0.4
450	47.1	253.79	-16.21	-0.51	-0.59	-0.67
475	49.7	282.58	12.58	0.39	0.46	0.52
500	52.4	314.11	44.11	1.38	1.61	1.83
525	55	346.06	76.06	2.37	2.77	3.16
550	57.6	379.55	109.55	3.42	3.99	4.56
575	60.2	414.59	144.59	4.51	5.26	6.01
600	62.8	451.18	181.18	5.65	6.59	7.54
625	65.4	489.31	219.31	6.84	7.98	9.12
650	68.1	530.54	260.54	8.13	9.48	10.84
675	70.7	571.83	301.83	9.42	10.99	12.56
700	73.3	614.66	344.66	10.75	12.55	14.34

Figure 6 Excel table for question 6

The following graph, Figure 7, plots the torque values for the various friction coefficients against each other.

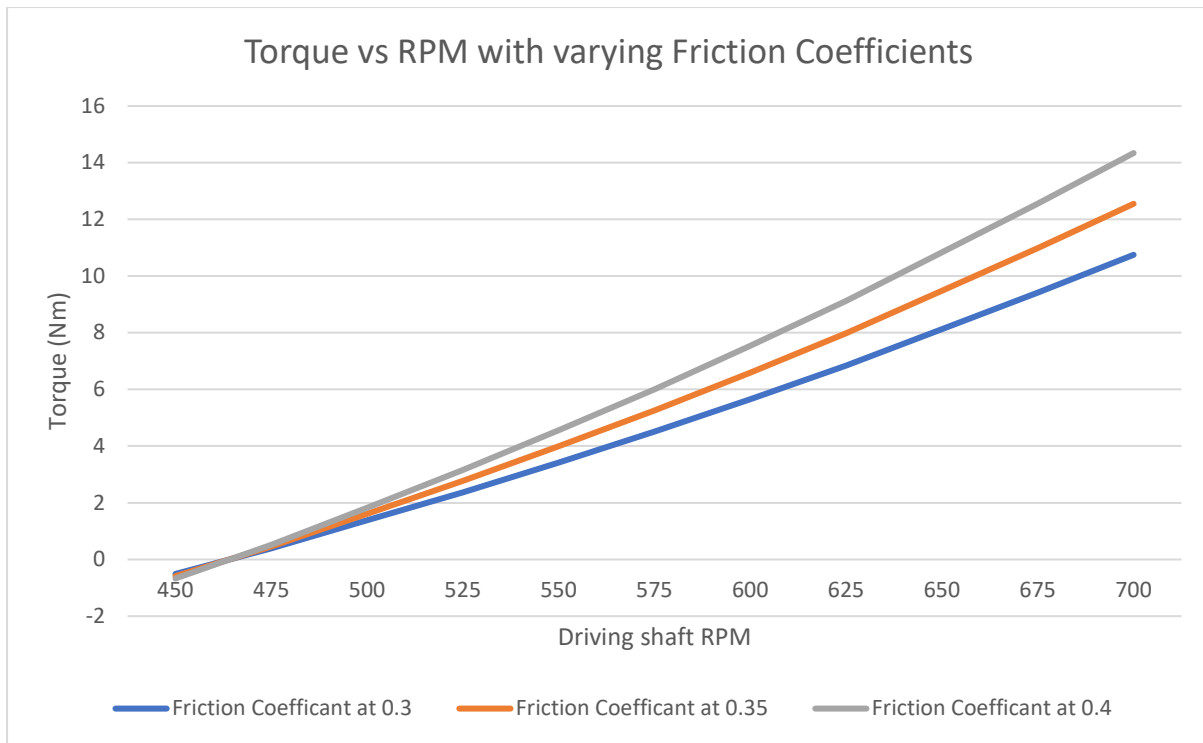


Figure 7 Graphical plot of data in Figure 6

As can be seen in Figure 7, as the RPM increases the variation of the coefficient of friction has a greater effect on the transmitted torque. As the coefficient of friction increases the transmitted torque value increases. Materials with a high coefficient of friction are more skid-resistant than materials with a low coefficient of friction. In terms of the centrifugal friction clutch, the friction lining on the shoe would ideally have a high coefficient of friction, so it grips the clutch plate and less force is lost due to slipping.

3.8 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?” (UWTSD, 2023).

Torque can be shown as.

$$T = I\alpha$$

Where I is the mass moment of inertia and α is the angular acceleration.

For a solid disc the mass moment of inertia is shown.

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

So using the values given in the question and r being half of the diameter (216mm).

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

$$I = 0.004374 \text{ kgm}^2$$

Using a maximum torque value of 14.34 Nm obtained using a friction coefficient of 0.4 and RPM of 700 in question 6 we can calculate the required angular acceleration to be.

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

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

$$\alpha = 3278.46 \text{ rad s}^{-2}$$

4.0 References

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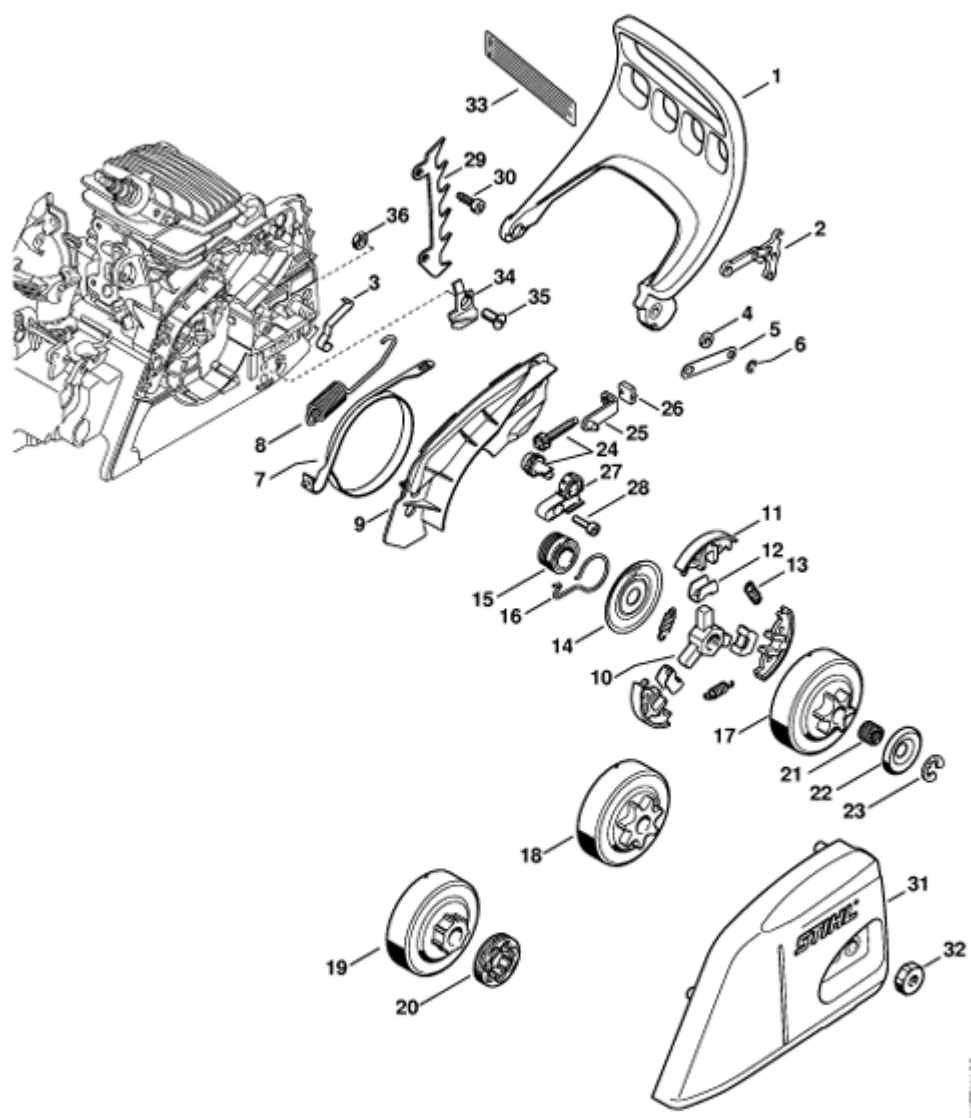
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Appendix A

Drawing

G Hand guard, Chain brake



Drawing G Hand guard, Chain brake

Reference	Item number	Qty	Description
1	1139 792 9100	1	Hand guard
2	1121 160 5000	1	Lever
3	1123 162 7800	1	Flat spring
4	0000 958 0521	1	Washer
5	1123 162 5800	1	Strap
6	9460 624 0400	1	E-clip 4
7	1139 160 5400	1	Brake band
8	1139 162 7900	1	Tension spring
9	1139 021 1100	1	Cover
	1139 160 2000	1	Clutch
			□ 10 - 13
10	1121 162 3201	1	Carrier
11	1139 162 0800	3	Clutch shoe
12	1127 162 3000	3	Retainer
13	0000 997 5600	3	Tension spring
14	1121 162 1001	1	Cover washer
15	1123 640 7102	1	Worm
			□ 16
16	1123 647 2400	1	Spring
17	1123 640 2073	1	Chain sprocket 3/8" Picco 6T
18	1123 640 2072	1	Chain sprocket 3/8" Picco 7T (B)
	1123 007 1030	1	Rim sprocket kit 3/8" Picco 7T (B)
			□ 19, 20, 22
19		1	Clutch drum (D)
20	0000 642 1240	1	Rim sprocket 3/8" Picco 7T (B)
21	9512 933 2260	1	Needle cage 10x13x10
22	0000 958 1022	1	Washer Ø 27 mm
23	9460 624 0801	1	E-clip 8x1.3
	1123 007 1000	1	Chain tensioner kit (B) (1,3)
			□ 24 - 28
24	1123 007 1004	1	Spur gear / chain adjusting screw kit (1,3)
25	1123 640 1900	1	Tensioner slide (1,3)
26	1123 664 1400	1	Thrust pad (1,3)
27	1123 664 2200	1	Cover (1,3)
28	9075 478 3015	1	Pan head self-tapping screw IS-D4x15 (1,3)
29	1123 664 0500	1	Bumper spike (1,3)
30	9075 478 4115	2	Pan head self-tapping screw IS-D5x16 (1,3)
31	1139 640 1700	1	Chain sprocket cover (1,3)
32	0000 955 0801	1	Hexagon nut M8 (1,3)
33	0000 967 3630	1	Instruction label (3,4) USA
34	1139 650 7700	1	Chain catcher (20.2007)
			□ 35, 36
35	9062 319 1270	1	Countersunk screw M6x14 (20.2007)
36	9214 320 0900	1	Lock nut M6 (20.2007)

(1) MS 211, (2) MS 211 C-BE, (3) MS 211-Z, (4) MS 211 C-BE Z