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An Investigation into the Lifespan of Brush DC Motor with Different Oil Properties

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ABSTRACT

A DC motor is an electromechanical device that converts electrical energy to mechanical torque. DC motors are widely used in industry and electrical appliances such as adjustable seats and electric toothbrushes. However, DC motors have a short lifetime and applying lubricant is one of the solutions for this problem. This study aims to determine the properties of oil that are suitable for lubrication and compare the maximum speed, lifetime and final temperature of a DC motor after applying different lubricants and without applying any lubricants. Two different oils (Oil A and Oil B) with different properties were used in this experiment. Each motor in this experiment needed to be run and stopped for 3-minute intervals and repeating this cycle until the motor's RPM was dropped. The results show that both oils have the same density, that is 840 kg/m^3 but the viscosity of the oil is different that is, 2.081×10^{-5} m^2/s for oil B compared to 2.497×10^{-5} m^2/s for oil A by using a 1.590 mm diameter steel ball. This experiment also shows that by applying lubricant, it increases the maximum speed and the lifespan of the DC motor. The lifespan for the DC motor with oil B to maintain its maximum speed of 28500 RPM is longer, which is 13 cycles, or about 39 minutes, while the DC motor with oil A could maintain its maximum speed *of 27500 RPM for only 12 cycles, or 36 minutes. Therefore, the motor with lubricant that has a lower viscosity (Oil B) gives a better result than the motor with a higher viscosity lubricant (Oil A) in terms of maximum speed, lifetime and the rise of the DC motor temperature is between 37.7°C and 39.5°C not exceeding 40°C.*

Keywords: DC motor; Lubricant; Lifespan; Fluid properties

INTRODUCTION

A DC motor is a component of electromechanical that is widely used in industry. This is because it is easy to adjust the rotating speed, position control and it has a wide adjustability range [1]. There are two types of DC motors which are brush DC motors and brushless DC motors. The brush DC motor is more commonly utilized than the brushless DC motor, primarily due to the cost factor, since brush DC motors are not expensive, easy to conduct and available in many types of sizes and shapes [2]. There are also many applications of brush DC motors starting from toys to adjustable car seats.

For a permanent magnet brushed DC motor, it is based on the basic components which are the commutator, stator and brushes. For brushed DC motors, commutation of the winding process is done mechanically. In a brushed DC motor, a segmented component named commutator that is attached to the motor winding is turned with the motor. When a carbon brush slides from one segmented commutator to another segmented, the dynamic magnetic field is generated inside the motor and the voltage that is supplied to the brush can transfer to the commutator and winding. The current at the motor winding becomes AC current and makes it continuously rotate. Thus, the important parts of a brushed DC motor are the brush itself and the commutator [3].

However, in a brushless DC motor, the commutator and brush are replaced by a control system. The segmented commutator is replaced with an electronic servo system that will work as a control system [4]. In order to produce torque in the same direction, the current through the winding is switched by a controlled semi-conductor switch such as transistors either in the opposite direction of the current or turning it off at the proper angle by an electronic sensor. The advantage of a brushless DC motor is that it has less friction which makes the motor less heated and therefore has a longer lifespan. Figure 1 shows the difference between a brush and a brushless DC motor.

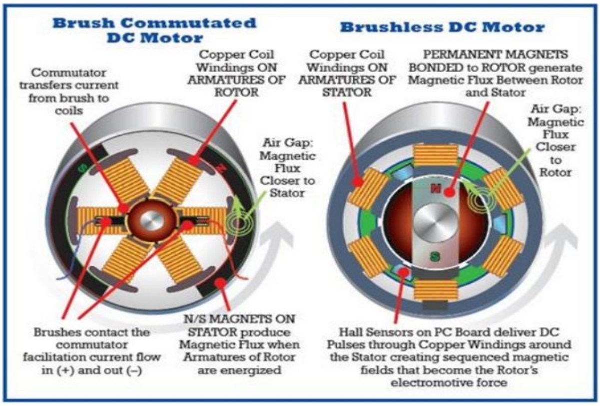

Figure 1: Brush and brushless DC motor

Therefore, the biggest challenge in brush DC motors nowadays is to prevent them from having a short lifespan. The factor of the brush DC motor failure is because of commutation between brush and commutator [5]. This is because when brushed slides on commutator surfaces, friction is produced. Friction also comes from mechanical problems such as high brush pressure, a feather edge on a copper bar or other imperfections of the commutator surface. Friction will cause brush abrasion and reduce the motor lifespan [6]. Other than that, the friction can also increase the temperature of the commutator, and it will affect the motor overheating and make it stop running and fail. Other than that, the increasing temperature cause wear rate to increase [7]. The heat was produced by mechanical friction and motor winding resistance. The increasing of temperature in winding is because of the impurities make atoms in copper vibrate faster when more current flow on it [8]. The heat that makes the rising of temperature is transfer starting from brush to commutator, from commutator to shaft and lastly to winding that connected to the commutator [9]. The pressure on the brush and commutator will increase and cause the failure of the motor. The rising temperature also comes from the improper lubrication on the brush or commutator, and it eventually develops too much internal friction [10].

One of the best solutions to solve the problem is by adding lubricant to the brush DC motor. This is because lubricant can be a cooling agent in the system because it helps in cooling the main part of the motor [11]. Lubricant is important because it can reduce temperature, noise, and extreme pressure of mechanism. Other than that, lubricant can increase the lifespan and reduce friction [12]. Film or layer created by lubricant is effective in reducing frictional force and frictional wear that produced by two contacting surface that slide each other [13]. The lubricant is film that smoothens the sliding load and the principle is known as lubrication. This lubrication started with farmers lubricated their cart using animal fat centuries ago. The concept is still used nowadays especially in mechanical machines and motors [14]. As a result, it can increase the DC motor lifetime.

METHODOLOGY

Properties of lubricant

Two experiments were conducted to investigate the properties of oil A and oil B which is hydrometer experiment to determine the density of the oil and falling ball viscometer experiment to find the kinematic viscosity of the oil. These two properties were important because they were the main properties in lubricant and these properties are related to each other.

Density measurement

For density measurement, the hydrometer jars were prepared and labelled with oil A and oil B. Each hydrometer needed to be filled with 750 ml of oil. The universal hydrometer needed to be dried with tissue to make sure that the hydrometer is cleaned from any fluid and foreign matter that can affect the accuracy of the reading. After that, the universal hydrometer was floated in a hydrometer jar that contained oil A and oil B, as shown in Figure 2. Before taking the reading, the hydrometer needed to be stable and not touching the surface of the hydrometer jar. All data are recorded and the density of each oil is calculated.

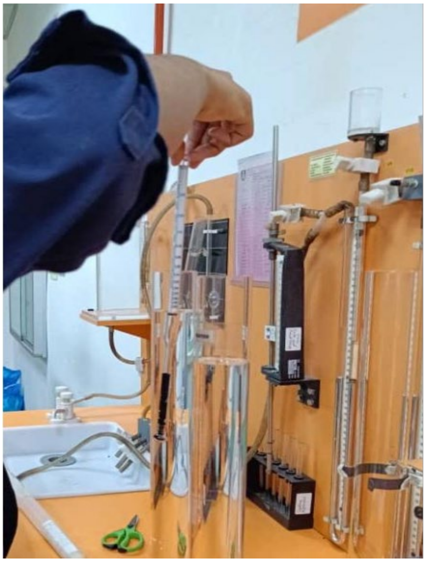

Figure 2: Floating the Universal Hydrometer

Kinematic viscosity measurement

Falling Sphere Viscometer is used to measure the viscosity of oil A and oil B. First, 2 viscometers were prepared and 2 points with a distance 75 mm were marked. The viscometers were filled with oil A and oil B to a level just below the exit from the capillary tube. After that, steel balls with a specific gravity of 7.8 with 3 different diameters which are 1.59 mm, 2.38 mm and 3.175 mm were prepared. The ball starting with a diameter 1.59 mm is released into a viscometer that is filled with oil under test, starting with oil A. Stopwatch was started when the ball reached the first mark point and stopped when the ball reached the second mark. The time taken for the ball falling through two marked points is needed in this experiment to use in the calculation. This step is repeated for diameter balls of 2.38 mm and 3.175 mm. Figure 3 shows the process of dropping the steel ball into the viscometer. All the data were recorded and the kinematic viscosity was calculated.

Figure 3: Dropping the steel ball into viscometer

Life span of brushed DC motor

The main objective is to compare the lifespan of DC motors with different oil properties applications and DC motors that without any oil application. A voltage regulator is used to supply a constant 3 volts of voltage to the DC motor. The procedure for this experiment starts with preparing 3 mini 4WD car DC motors and a voltage regulator. A mini 4WD car tyre with reflector needed to be putted on the shaft of the DC motor to measure the motor speed in RPM using a tachometer. To connect voltage regulator and mini 4WD DC motor, the positive and negative terminals of voltage regulator must be connected correctly. Figure 4 shows the connection of the wire to the DC motor used in this research.

The maximum motor speed and final motor temperature are measured in a cycle for every 3 minutes of run and 3 minutes of stop to analyse the lifespan of the DC motor. This step was repeated until the difference in maximum DC motor speed in RPM was significantly changed. An infrared thermometer was used to measure the final temperature of the DC motor and tachometers were used to check the speed of the motor.

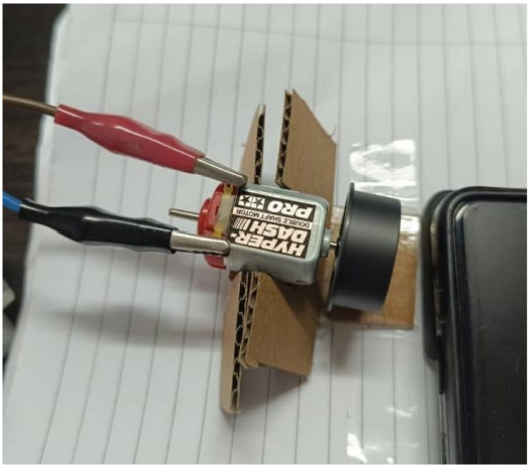

Figure 4: Brush DC Motor Lifespan Test

For the motor with applying oil A and oil B, before the voltage regulator is started, the oil needs to be applied to the motor. After the oil was applied, the DC motor needed to be tuned up with a motor tuner for a few seconds to let the oil properly film the surface of the carbon brush inside the DC motor. Figure 5 shows the process of applying the oil to the DC motor.

Figure 5: Process of applying oil A and oil B

The period of the DC motor running and maintaining the speed in constant supply voltage is considered as the lifespan of the 4WD mini car DC motor. This step was repeated until the DC motor maximum RPM dropped and the changes were significant.

All the data obtained from the experiment are recorded and the lifespan of each DC motor and each temperature need to be compared especially with the DC motor without applying any lubricant to determine which oil was the best lubricant to use in the DC motor.

RESULTS AND DISCUSSION

Properties of lubricant

For density measurement, the results from the hydrometer test show that both oils have the same density and the same specific gravity. Table 1 shows the result from the hydrometer test experiment.

Table 1: The value of specific gravity and density of Oil A and Oil B

Type of Oil	Specific Gravity	Density, ρ, kg/m^3
Oil A	0.84	840
Oil B	0.84	840

However, for kinematic viscosity measurement, based on the results in Table 2 and the graph shown in Figure 6, both oil A and oil B have different values of kinematic viscosity. The result shows that the kinematic viscosity of the oil B was lower than that of oil A, that is 2.081×10^{-5} m^2/s compared to 2.497×10^{-5} m^2/s respectively for a 1.590 mm diameter steel ball. For both oil A and oil B, the value of the kinematic viscosity was increased when the diameter of the steel ball was increased. Since viscosity is the resistance of relative movement of a moving part, the larger the diameter of the steel ball, it experiences more resistance from the fluid as it falls through and leads to a longer fall time [15].

Table 2: The value of kinematic viscosity of Oil A and Oil B

Type of oil	Ball, mm	Distance, m	Time, s	Velocity, m/s	Coefficient of viscosity, kg/ms	Kinematic viscosity x 10^{-5} m^2/s
Oil A	3.175	0.075	0.30	0.250	0.153	18.208
	2.380	0.075	0.21	0.357	0.060	7.162
	1.590	0.075	0.18	0.417	0.021	2.497
Oil B	3.175	0.075	0.25	0.300	0.127	15.173
	2.380	0.075	0.19	0.395	0.054	6.479
	1.590	0.075	0.15	0.500	0.017	2.081

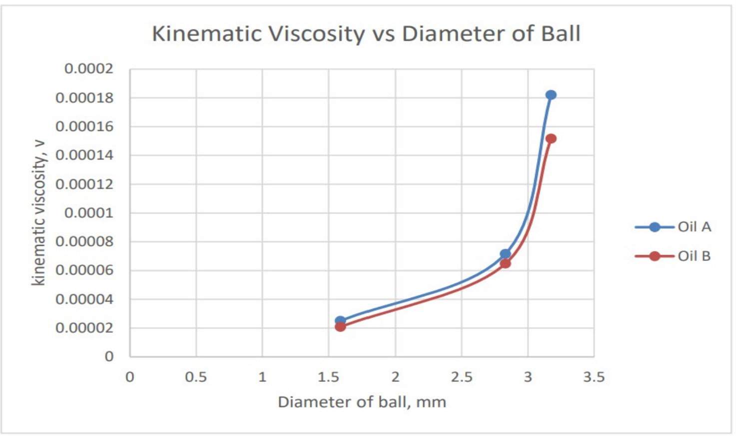

Figure 6: Comparison of kinematic viscosity value for Oil A and Oil B

Life span of brushed DC motor

Three tests that have been done are Test 1 for DC motors without any oil applied, Test 2 for oil A applications and Test 3 for oil B applications. Based on the graph in Figure 7, for Test 1, the maximum RPM for each cycle is around 26000 RPM and because of that, the change in maximum RPM seems not to be significant. The maximum RPM for each cycle initially increases and maintains above 26500 RPM for 10 cycles. The lifespan of a DC motor without oil to maintain its speed was about 10 cycles or 30 minutes before it dropped its RPM rapidly.

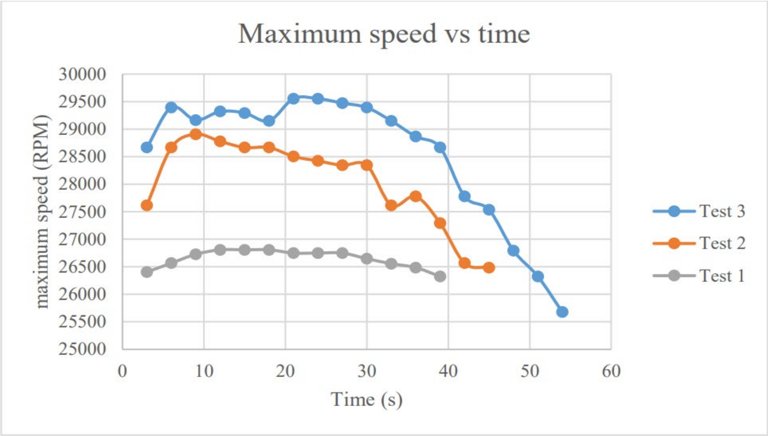

Figure 7: Graph of maximum speed vs time

For Test 2, the motor with oil A could maintain the maximum speed for each cycle above 27500 RPM for about 12 cycles which is higher than the motor without oil by 2 cycles. This shows that the lifespan of the DC motor with oil A maintains its performance slightly better than the lifespan of the DC motor without oil. Perhaps 14 cycles were needed for the motor to have the same range of speed as the DC motor without oil application.

However, for Test 3, the result was the highest since the motor with oil B could maintain the maximum speed for each cycle above 28500 RPM for 13 cycles, which is better than the DC motor with oil A. This shows that the lifespan of the brush DC motor with oil B is better than the brush DC motor with oil A and without oil in terms of maintaining its performance. Other than that, the motor takes 16 cycles for the maximum speed to be in the same range with the DC motor without oil application.

Figure 8 shows the graph of final temperature vs. time. The final temperature of 41.5°C for Test 1 was the highest in this experiment. Beside friction, one of the reasons for this happened is because the impurities from the carbon dust inside the brush DC motor make the atom in winding resistance vibrate faster and make the temperature increase [8]. On the other side, for Test 2 and Test 3, the final temperature for both tests were lower than Test 1. This shows that the oil does act as a cooling agent for the DC motor during the experiment. For the value for Test 2, the changes were not significant for each cycle until 13 cycles, that is between 38°C and 39.2°C. However, for the last 2 cycles, the temperatures were exceeding 40°C. For Test 3, the temperatures were increased and decreased for each cycle, but the changes were not significant because the values were around 37.7°C to 39.5°C. This shows that oil B is a better cooling agent [11].

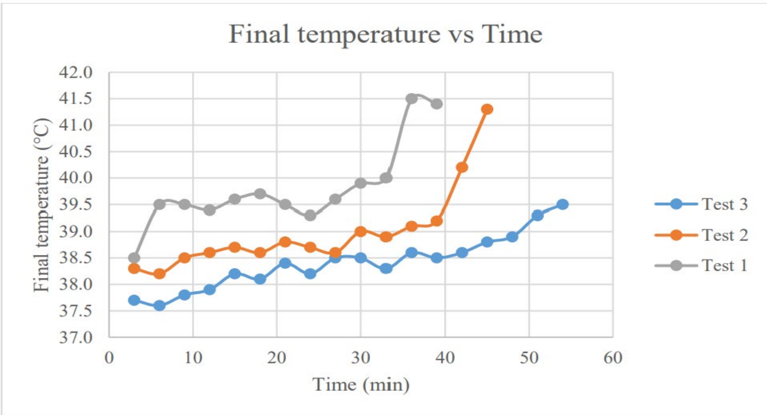

Figure 8: Graph final temperature vs time

CONCLUSION

This project is focused on the effect of different oil applications on DC motor lifespan. Based on the results in this experiment, applying oil to the DC motor does increase the maximum speed and the lifespan of the DC motor. Both oil applications have a positive impact on the DC motor lifespan because the lifespans of both DC motors with oil were higher than the DC motors without oil. The final temperature values in each cycle for both DC motors with oil were lower than the DC motor without oil. From the results, it can be seen that oil B gives a better result than oil A. This is because the lifespan for the DC motor with oil B to maintain its maximum speed that is 28500 RPM is longer, which is 13 cycles, or about 39 minutes, while the DC motor with oil A could maintain its maximum speed that is 27500 RPM for only 12 cycles, or 36 minutes. Other than that, oil B is also better as a cooling agent because the final temperature for each cycle is between 37.7°C and 39.5°C not exceeding 40°C. Since the kinematic viscosities of oil B were lower than oil A, this concludes that the lubricant with lower viscosities is suitable to increase the brushed DC motor lifespan.

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