Simplification Of The Prony Brake Dynamometer System Using Brake Caliper Load

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Abstract.

The torque of the DC motor needs to be known to determine the maximum load that can be exerted at a given speed. Torque measurement can be done with a dynamometer. The dynamometer uses the Prony Brake type, which uses the principle of frictional force to provide a load on the motor. The application of frictional force uses brake capillary load to produce a dynamometer with the Prony Brake type that is simple in manufacture and testing but reliable and accurate in making measurements. In the Prony Brake dynamometer, there are usually two pieces of wood used as a link between the motor and the torque arm; at the end of the torque arm, there is a ballast whose ballast value is multiplied by the length of the arm to produce the torque value of the DC motor. The results of the trials that have been carried out are that the reading results of RPM sensors, weight sensors, and voltage sensors have a deviation of less than 2%, and the current sensor readings have a deviation of less than 5%. The Prony Brake dynamometer that has been made can read the maximum torque value with a deviation of about 2% from the existing data.

Keywords: *DC motor, dynamometer, prony brake and torque.*

I. INTRODUCTION

DC motors, such as toy cars, electric bicycles, and other electronic equipment, are widely used in everyday life [1]–[3]. The large number of uses of DC motors makes the size and specifications of DC motors produced and circulated on the market diverse. When using a DC motor to manufacture or repair a product, DC motor specifications are important things that must be known. There are several ways to find out the specifications of the existing motorcycle. The easiest way to find out the motor specifications is to read the emboss on the motor body or datasheet to see how much the motor can release KW/HP and torque. However, often the plate that explains the specifications of the DC motor is not available, incomplete, lost, or damaged and makes it difficult for users to know the specifications of the DC motor. Rotary encoders can be used to measure torque [4]–[6]. The MSP430 microcontroller can process the signal from the encoder to get better results in torque measurement using an encoder [7]. In addition to using an encoder, motor torque measurement can be carried out using a linear relationship between torque and magnetic flux density [8]. Another way to determine the motor's torque is to test directly on the motor. Mechanical loading can be done using a dynamometer to test the motor [9].A dynamometer is a measuring instrument used to measure the power and torque of an object by absorbing and then spreading the measured power [10]. There are various types of dynamometers, such as the Eddy Current dynamometer, which is a dynamometer to determine torque with the principle of Eddy Current reading [11], [12].

There is also a dynamometer with a more effortless and cheaper calculation technique, which is a Prony Brake dynamometer. The principle of the brake pony is the provision of mechanical friction on the motor [13]. The measurement results using the dynamometer are the actual capabilities of the motor being tested, namely DC motor power and torque when measuring. In addition to measuring torque and power, Prony Brake dynamometers can also determine the efficiency of 3-phase motors [14].The design and construction of the Prony Brake dynamometer underwent various developments [15]–[18]. Prony brake dynamometer loading starts from loading using a water bottle; the pendulum changes to using a disc, which gives good results [19]. The dynamometer with disc brakes has been tested to measure the performance of a fuel motor with a specific capacity [20].This paper presents the design of the Prony Brake dynamometer with a different loading method from another loading. The loading on the built dynamometer uses brake capillaries intending to make it easier for users to change the load value and provide accurate results. In addition to the load difference, the Prony Brake dynamometer is specifically designed to measure the characteristics of single-phase DC motors commonly found in everyday electronic use.

II. METHODS

In the design and construction of the brake dynamometer used, there are three stages: the preparation of mechanical hardware, the preparation of electrical hardware, and the preparation of software.

Mechanical Hardware

A dynamometer is designed to measure motor torque to the specifications listed in Table 1.

Table 1. Scalable Motor Specifications

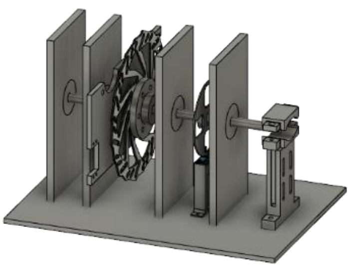
Criterion	Conditions
Motor Voltage	10 – 24 VDC
Motor Speed	500 – 10,000 RPM
Motor Type	DC with Permanent Magnets

The specifications of the prony brake dynamometer are listed in Table 2.

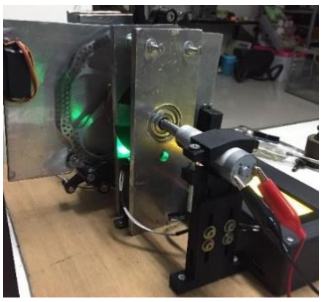
Table 2. Product Specification of Prony Brake Dinamometer

Criterion	Conditions
Construction Materials	Aluminium
Force Measurement	Load Cell
Diameter Shaft	10 mm
Maximum Torque	10 Kgcm
Load Manager	2 pcs servo motor
Number of Capillaries	2 Capillaries

The mechanical hardware in the dynamometer includes a disc adapter, brake capillary plate holder, speed reader stand, servo adapter, and brake cable. Most devices are made using a metal base. Fig. 1. A. shows the overall 3D design, and Fig. 1. B. shows the overall realization of the designed dynamometer.The flywheel, brake block, torque arm, and weight in the Prony Brake system are modified so that the manual calculation process can be done automatically using a microcontroller. The parts representing the components of the pony brake are depicted in Fig. 2. A., and Fig. 2. B. shows a typical Prony Brake system that uses Pendulum loads. In Fig. 2. A., there is part A, the part of the disc that replaces the flywheel function in Fig. 2. B. Part B replaces the brake block function. Section C is the length of the torque arm, whose length is depicted with a red line. The length of this torque arm is measured from the center point of the flywheel to the end of the torque arm. While part D is placed load cell, which replaces the weight function in Fig. 2. B.In the process of making the dynamometer design, it is necessary to pay attention to each size of each part, including shaft diameter, bearing diameter, disc diameter, disc adapter diameter and thickness, disc diameter for the tachometer, and plate size for servo motor and brake calipers. After getting the size used, then the supporting components can be made.

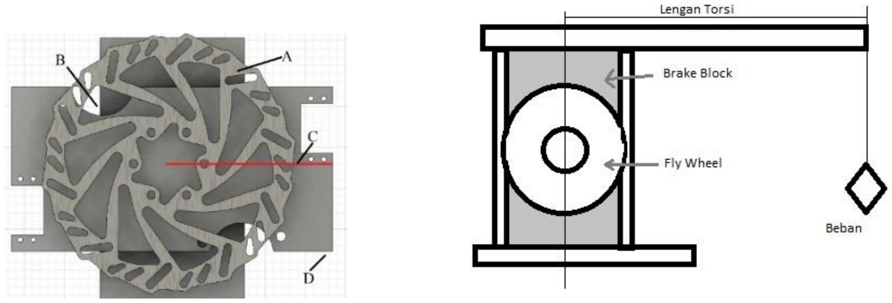


(A)



(B)

Fig 1. A) Proposed 3D Design, B) Implementation Results



(A) (B)

Fig 2. A) Prony Brake Implementation, B) Prony Brake System in General

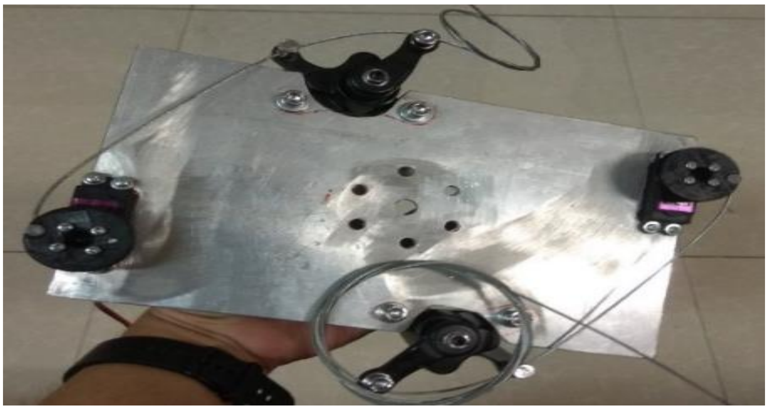


Fig 3. Load Adapter Plate

The brake block in Fig. 2. A. is connected to a load adapter, a plate in front of the brake block with several parts cut into semicircles and rectangles. The cut parts are connected with brake capillaries used to exert load on the system and provide servo motors to regulate the pulling or loading force of the brake capillaries. In giving the load, two brake capillaries are used to get more balanced load than when using a brake capillary. A brake capillary will connect each servo motor. Each servo motor has been calibrated in advance and is ensured to be able to perform simultaneous movements with the same angle changes so that the loading value given is as expected. Fig. 3. shows the results of installing brake capillaries and servo motors on the load adapter.

Electrical Hardware

The electrical hardware in the system needs to handle the calculation of the number of motor revolutions, read the motor voltage and current, get the braking weight, control the servo motor, store data on external memory, and display the results on the LCD screen. Appropriate sensors are installed on the microcontroller to handle all these assignments, such as the system block diagram in Fig. 4.

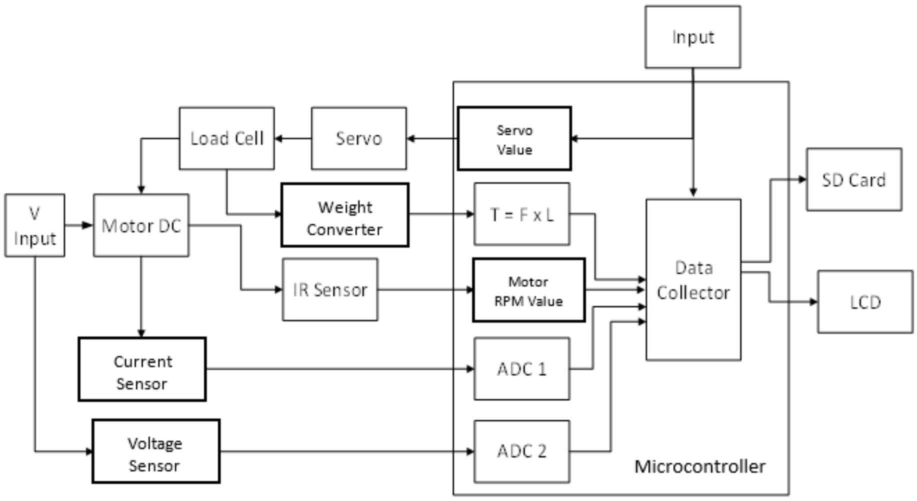


Fig 4. System Block Diagram

Software

Fig 5. shows a flow chart of software created and embedded into a microcontroller.

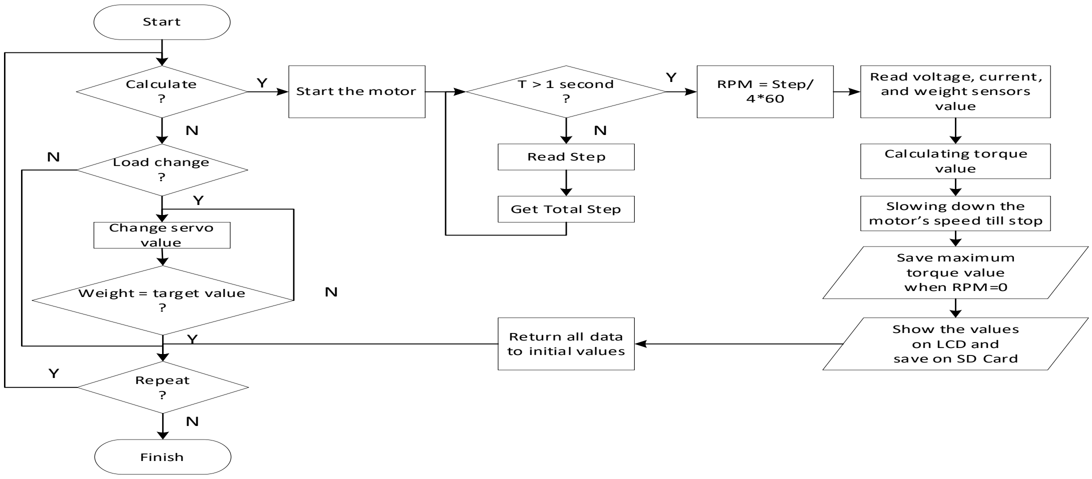


Fig 5. System Flow Diagram

After the microcontroller is turned on, the microcontroller can calculate the torque or determine the load to be given to the motor. If the load value is changed, the servo motor will move to pull the brake calipers until it reaches the desired load. However, if there is chosen to do the calculation, the microcontroller will start rotating the motor that is targeted to measure torque and its characteristics. The microcontroller calculates the number of revolutions of the motor in one second and then converts it into the rotational speed of the motor in units of RPM. After obtaining speed, values are taken from voltage, current, and weight sensors. From the values obtained from the sensor, the microcontroller can calculate the torque value with equation (1), where this equation is the relationship between power (P) expressed in watts, torque (T) expressed in kg-cm, and angular velocity (ω) expressed in RPM units in a circular motion.

$$P = T\ x\ \omega \qquad (1)$$

After the torque value is obtained, the next step is to add brake capillary withdrawal until the motor stops rotating. When the motor approaches a stop to rotate, the sensor value is retaken, and the torque value is calculated. The current torque value is stored as the maximum torque that the motor has. All the values obtained are displayed on the LCD on the device and stored on the SD card for processing if needed. After the calculation stage, the variable value is returned to start the following new calculation.

III. RESULT AND DISCUSSION

The value of motor speed, voltage, current, and weight of the sensors installed on the dynamometer is taken to obtain the torque value and motor characteristics measured. However, before retrieving values, these sensors need to be calibrated so that the value read by the sensor is close to the actual value. After calibration, the values read by the sensors are compared with commonly used measuring devices. The value of the speed reading is compared with the value of the tachometer, the value of the voltage sensor and current sensor is compared with the value of the multimeter, and the value of the weight sensor is compared with the mini-scale. Although it has been calibrated, there is still a slight comparison of values between the value of the sensor and the value of the comparison measuring instruments. Table 3 shows a summary of the comparison of the values from the sensor with the values from the comparison tool after 20 tests.

Table 3. Comparison of Sensor Value with Measuring Instrument Value

Rated Speed – Tachometer (RPM)	
Biggest Difference	2.561 %
Smallest Difference	0.952 %
Average difference	1.649 %
Rated Voltage – Multimeter (V)	

Biggest Difference	0.696 %
Smallest Difference	0.050 %
Average difference	0.245 %
Rated Current – Multimeter (A)	
Biggest Difference	5.00 %
Smallest Difference	0.00 %
Average difference	4.39 %
Rated Weight – Mini Scale (gr)	
Biggest Difference	4.427 %
Smallest Difference	0.101 %
Average difference	1.529 %

Even though it has gone through the calibration process, the sensor's values still differ from the value of the reading of the measuring instrument, even though the difference is not significant. This result will undoubtedly result in a slight difference in the calculation of torque values using a dynamometer built when compared to the motor datasheet being tested. Tests on the motor are carried out by providing different loads; from no load, the load will be added until the motor can no longer rotate. Table 4 displays the results of experiments on a 25GA370 motor with a shaft length of 25mm and a working voltage of 12 volts.Each experiment with the same loading was carried out three times to see the stability of the sensors and the reliability of the torque value readings from the built Pony brake dynamometer.

Table 4. 25GA370 Motor Test Results

Experiment To	Imposition (kg)	Speed (RPM)	Voltage (V)	Current (A)	Torque (kgcm)
1	0	1200	12.09	0.26	0
2	0	1200	12.08	0.27	0
3	0	1260	12.13	0.27	0
4	0.01	960	12.01	0.41	0.08
5	0.01	960	12.04	0.38	0.07
6	0.01	960	12.02	0.41	0.09
7	0.04	540	11.85	0.87	0.47
8	0.04	540	11.84	0.86	0.47
9	0.04	540	11.86	0.87	0.46
10	0.08	0	11.69	1.42	1
11	0.08	0	11.7	1.37	0.99
12	0.08	0	11.69	1.35	0.97

Voltage		No Load		Load Torque			Stall		Reducer
Workable	Rated	Speed	Current	Speed	Current	Torque	Torque	Current	Ratio
Range	Volt.V	rpm	MA	rpm	A	Kg.cm	Kg.cm	A	1:00
3-9V	6V	1360	≤100	1000	≤0.75	0.2	1	1.3	4.4
3-9V	6V	620	≤100	450	≤0.75	0.4	2	1.3	9.6
3-9V	6V	280	≤100	200	≤0.75	0.8	4.5	1.3	21.3
3-9V	6V	170	≤100	130	≤0.75	1.3	7.5	1.3	35
3-9V	6V	130	≤100	100	≤0.75	1.7	9	1.3	46
3-9V	6V	77	≤100	60	≤0.75	2.8	9	1.3	78
3-9V	6V	58	≤100	45	≤0.75	3.7	9	1.3	103
3-9V	6V	35	≤100	25	≤0.75	6.8	9	1.3	171
3-9V	6V	25	≤100	20	≤0.75	8	9	1.3	226
3-9V	6V	16	≤100	12	≤0.75	9	9	1.3	377
3-9V	6V	12	≤100	9	≤0.75	9	9	1.3	500
6-18V	12V	1360	≤100	1000	≤0.75	0.2	1	1.3	4.4
6-18V	12V	620	≤100	450	≤0.75	0.4	2	1.3	9.6
6-18V	12V	280	≤100	200	≤0.75	0.8	4.5	1.3	21.3
6-18V	12V	170	≤100	130	≤0.75	1.3	7.5	1.3	35
6-18V	12V	130	≤100	100	≤0.75	1.7	9	1.3	46
6-18V	12V	77	≤100	60	≤0.75	2.8	9	1.3	78
6-18V	12V	58	≤100	45	≤0.75	3.7	9	1.3	103
6-18V	12V	35	≤100	25	≤0.75	6.8	9	1.3	171
6-18V	12V	25	≤100	20	≤0.75	8	9	1.3	226
6-18V	12V	16	≤100	12	≤0.75	9	9	1.3	377
6-18V	12V	12	≤100	9	≤0.75	9	9	1.3	500

Fig 6. Pieces Bike Specs 25GA370

Table 4 displays the results of the Prony Brake dynamometer test to determine the torque of one of the DC motors where the DC motor specifications have been included in the DC motor purchase and are shown in Fig. 6. The motor specifications are divided into a no-load column, a loaded condition column, and a column when the motor is not rotating. However, the amount of loading given is not written, so the comparison can only be seen from the motor's rotational speed.When carried out a no-load test with a voltage of 12 volts, the motor speed was found a speed 1200 rpm and a current of 0.26 amperes which was slightly different from what was written in the motor specifications where it was written in no-load conditions with a speed of 1360 rpm requiring a current of less than or equal to 0.1 amperes.

In loaded conditions, with a loading of 0.01, the motor speed is read to 960 rpm, the current is 0.41 amperes, and with the calculation results, a torque of 0.08 Kgcm is obtained. The results of this loaded calculation are slightly different from those in the written specifications. Then at the maximum torque condition where the motor does not rotate anymore (stall), a current value of about 1.3 amperes and torque of 1 Kgcm is obtained where the current and torque values follow those in the specification table.The measurement results show that most of the measurement results are different from the values in the specification table, even though the difference is not so significant. The measurement result value closest to the value in the specification table is maximum torque measurement, which is when the motor can no longer rotate. Differences can occur because there is a difference between measurements using sensors attached to the dynamometer and the actual measuring instruments, as shown in Table 3.

IV. CONCLUSION

Based on the study's results, it is known that the Prony Brake dynamometer built can be used to read the torque value of the DC motor quite well, especially the maximum torque value, which has the highest difference of 3%. There is a difference in the calculation of torque values when compared between the calculation results using a dynamometer made with motor specifications included in the purchase due to the differences caused by the sensors used where the speed readings have an average difference of 1.649%, voltage sensors 0.245%, current sensors 4.39% and weight reader sensors 1.529%. Using brake capillaries as a load control device on a dynamometer can make it easier to adjust the amount given by changing the angle of the servo connected to the brake capillaries.

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