A Simple Speed and Torque Meter using Arduino

by Kadek Amerta Yasa

A Simple Speed and Torque Meter using Arduino

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Abstract: Speed and torque are crucial aspects of the operation of an electric motor. The general method to measure the speed and torque is using a speed meter and torque meter. Unfortunately, these instruments are pricy in the market. It is also difficult to fix those instruments because they fail in operation due to hardware problems. In this paper, a simple device for measuring speed and torque, voltage, and current are built using an Arduino as a central processor. This device also has a display and has a connection to a computer for storing data and displaying these data in LabVIEW. The test results for these instruments show the average error both for speed meter and torque meter were 0.11% and 0.81% consecutively.

1 INTRODUCTION

Induction motors are widely used in society, both in industry and for household appliances. This motor is cheap and easy to operate, so it is excellent as electrical equipment. In its operation, it is necessary to know the extent of the speed and the torque produced as part of a study of the characteristics of induction motors. Students must understand the rotational speed during operation and the value of torque generated, both at no and under load. This torque can be controlled or reduced ripple (Alsofyani and Idris, 2016), (Ma,2021), (Wang, 2020), (Sharma and Pal, 019). It is usually done in the laboratory of electrical machines using a torque meter to measure torque and a tachometer to measure motor speed. In general, measurement is also carried out using analog measuring instruments as modules according to suitable learning materials.

Nevertheless, this measuring tool is costly which can reach tens of millions of rupiah. Experience in the field, especially at the Electrical Machinery Laboratory, found that the measuring instruments used by students in carrying out practicals are easily damaged. A good quality measuring instrument also fails to operate due to a large number of people using this instrument. The replacement takes a long time because it is an imported product and must be ordered at a high price from a distributor. For this reason, it is necessary to build a torque and speed measuring instrument that is cheap, reliable, and can be replaced quickly in case of damage.

2 PROPOSED METHOD

This research has been conducted at the electrical machinery laboratory, Department of Electrical Engineering, Bali State Polytechnic. The initial survey was conducted to determine how the measurements were previously carried out, the number of repetitive measures, and the tools. The next step is to design a measuring instrument using the Arduino microcontroller and its supporting components. Furthermore, the finished device is tested by comparing the measurement results with standard tools owned by the Department of Electrical Engineering. The stages of this research are drawn as a figure that can be seen in Figure 1.

The next step is to build a system that can record data (data logger) to a computer. This operation can be performed using the LabVIEW software. From the results of this data recording, the data can be plotted, and also the necessary calculations are carried out, such as to find power losses.

The whole system, both measuring instruments that use a microcontroller and programs that have

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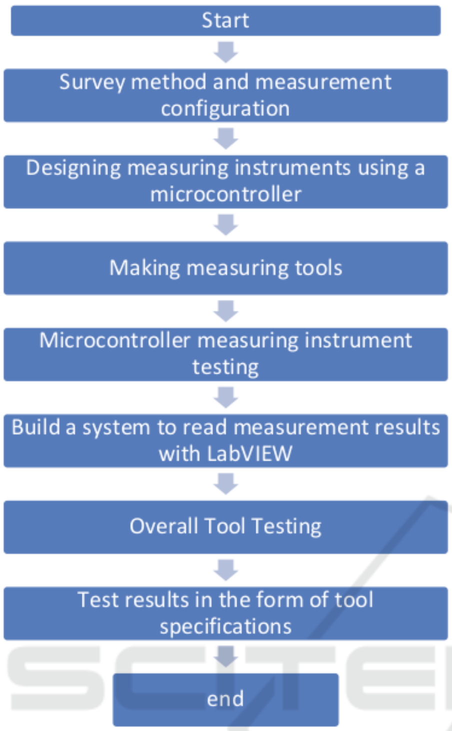

Figure 1: Research Stages.

been built using LabVIEW, will be tested to find the specifications of the tools.

Speed and Torque

Speed

The synchronous speed of an AC motor, ns is the rotational rate of the stator magnetic field with the equation:

$$s = (n_s - n_r) / n_s \quad (1)$$

where f is the frequency of the power supply, p is the number of magnetic poles, and with ns as a synchronous speed of the machine with units for f in Hertz and ns in RPM, the formula becomes (Steinmetz, 1997) and (Alger, 1949):

$$n_s = 2f/p.((60 \text{ s/min}) = 120f/p. (\text{s/min}) \quad (2)$$

b. Slip

Typical curve of the torque as a function of slip represented as "g" here. Slip, s, is defined as the difference between synchronous speed and operating speed, at the same frequency, expressed in rpm, or percentage or ratio of synchronous speed. So:

$$s = (n_s - n_r) / n_s \quad (3)$$

Where ns is the electric speed of the stator, nr is the mechanical speed of the rotor (NSW HSC, 2012) (NEMA MG-1 2007, 2008). The value of the slip is varied, which varies from zero at synchronous speed and 1 when the rotor is jammed determines motor torque. For some reason, the short-circuited rotor windings have negligible resistance. Even a tiny slip induces large currents in the rotor and produces significant torque (Penton Media, 2007). When the load reaches the highest value, the slip of small motors varies from more than 5%, while it has only less than 1% for large engines (Motor Formula, 1999). This speed variation can cause load sharing problems when motors of different sizes are mechanically connected.

c. Standard Torque

The speed-torque curves for the four types of induction motors can be seen in Figure 2.

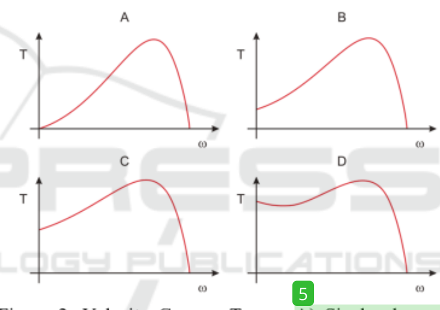

Figure 2: Velocity Curve - Torque A) Single phase, B) Polyphase cage, C) Polyphase cage deep bar, D) Polyphase double cage.

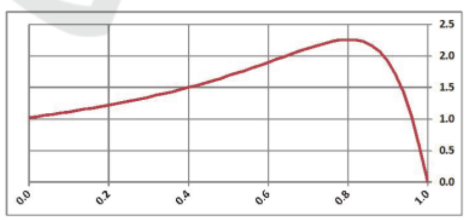

Figure 3: A typical speed-torque curve for a NEMA Design B Motor.

Figure 3 shows the curve of the typical speed-torque relationship of a standard NEMA Design B polyphase induction motor. Suitable for most low-performance loads such as pumps and centrifugal fans, The following typical torque range limits design B motors (Avinash and Ravi, 2013).

Breakdown torque (peak torque),
175-300% of rated torque

Rotor-locked torque (torque at 100% slip),
75-275% of rated torque

Pull-up torque,
65-190% of rated torque.

In the normal load range of the motor, the torque slope is approximately linear or proportional to the slip because the value of the rotor resistance divided by the slip, R'r/s, dominates the torque linearly (NEMA Standard, 2007). If the load increases above the rated load, the rotor and rotor leakage reactance factor gradually become more significant to R'r/s. The torque gradually curves towards breakdown torque. When the load torque increases beyond the breakdown torque, the motor stops.

Locked rotor torque or drive torque is the torque developed by an electric motor when it starts at zero speed.

High starting torque is highly used for applications or difficult-to-start machines, such as positive displacement pumps or cranes. Lower starting torque is acceptable for centrifugal fans or pumps where the starting load is low or near zero.

Pull-up Torque
Pull-up torque can be described as the minimum torque value developed by an electric motor when running from zero to full load speed (before reaching the breakdown torque point). When the engine starts and starts to accelerate, the pull-up torque value is decreased at a certain speed to a low point. The torque breakdown point increases its value to the highest torque at a higher speed. The pull-up torque may be necessary for applications that require power to pass through some temporary barrier to reach working conditions.

Breakdown Torque
Breakdown torque is the highest torque available before torque is reduced as the machine accelerates to a working state.

Full Load Torque or Brake Torque
Full Load Torque is the torque required to produce the rated power of the electric motor at full load speed. In imperial units, Full Load Torque can be expressed as

$$T = 5252\ Php/nr \qquad (4)$$

where:
T = full load torque (lb ft)
Php = rated horsepower
nr = rated rotation speed (rev/min, rpm)

The rated torque in metric units, can be denoted as:

$$T = 9550\ PkW/nr$$

where:
T = rated torque (Nm)
PkW = rated power (kW)
nr = rated rotational speed (rpm)

Torque measurement can be carried out in various ways and techniques, including using a rheometer on a permanent magnet motor (Letner et al., 2019), using a method based on an encoder (Liu et al., 2014), and based on Electromotive Force for Surface-Mounted permanent magnet motors (Simón-Sempere, 2015).

3 RESULT AND DISCUSSION

This speed and torque meter is built using Arduino as the microprocessor. This measuring instrument is made with Arduino so that the cost is not high with a

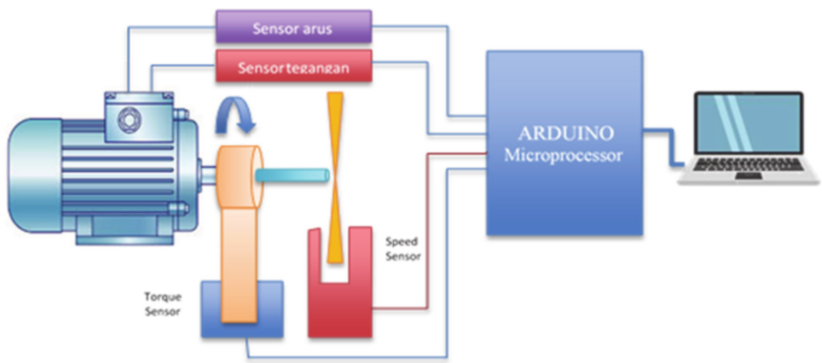

Figure 4: Speed and torque measuring circuit.

level of accuracy that meets the standards. The circuit built can be seen in Figure 4 for the schematic and Figure 5. and 6 for its application.

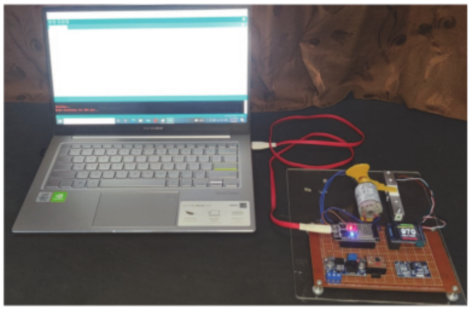

Figure 5: Details of the circuit prototype connected to the computer.

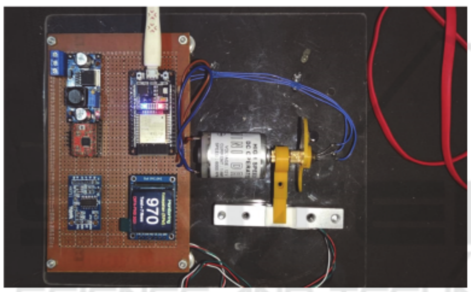

Figure 6: Circuit are made for measuring speed and torque.

The microprocessor processes the input voltage, current, speed, and torque sensors, and the output can be displayed on display or displayed to the computer. One way is to use LabVIEW, as can be seen in Figures 7, 8, and 9.

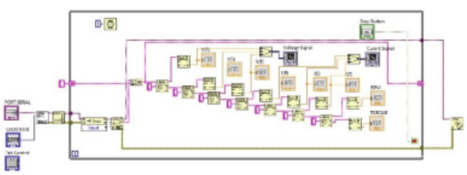

Figure 7: The Proposed system in LabVIEW.

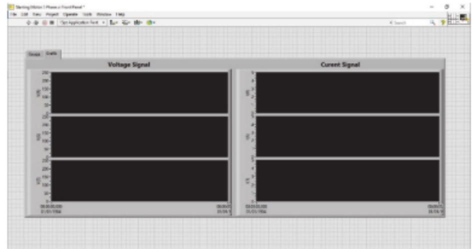

Figure 8: Display output on LabVIEW.

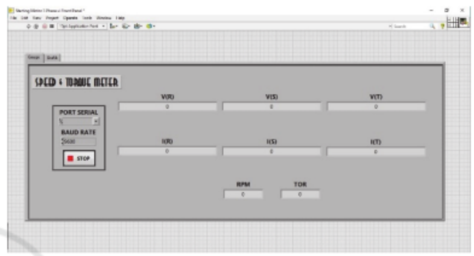

Figure 9: Display output on LabVIEW.

The research on making this motor speed and torque measuring instrument is intended for AC motors in the electric motor lab of the Bali State Polytechnic. Before that, the prototype was made using a smaller engine. The measurement results of voltage, current, speed, and torque produced can be seen in Table 1 to Table 4, respectively.

Table 1 shows results data for testing of the measuring voltage. The error results of the voltage measurement are between 0.001 and 0.050 volts, with an average error is 0.020 volts or 0.42%.

For the current measurement test, the result can be seen in Table 2. The maximum error is only 0.01A or 1.6% when this device is used for 1A measurement, while the minimum error is zero. For the test from 0.1A to 1A, the average error is only 0.35 A.

The speed meter is tested by comparing the result with the standard ones, and the results can be seen in Table 3. The test is conducted for various speeds at 10 to 5500rpm. From Table 3, the error increases gradually as the increase of speed of the motor. The minimum error for speed testing is 0.01 rpm at the lowest speed test of 10 rpm, while the maximum error is 6.85 rpm at 5500 rpm, or it is only 0.22% of error. The average error test for the speed meter is only 1.81 rpm or 1.11% of the measurement. This means that the speed meter has a good performance with an average error is less than 2%.

The test has also been conducted on the torque meter, with the result shown in Table 4. The torque values for the test are from 1 Nm then gradually increased with 0.5 to get a higher value at 7 Nm. The results show that the maximum error is found at the maximum value of 1.87% and the minimum is only 0.08 %. The average error is less than 1% or 0.81%, which makes this measurement device has a good performance.

Table 1: Voltage measuring instrument testing.

Voltage (V)		Error	
Standard	**Measurement**	**Value**	**%**
1.000	1.012	0.012	1.20%
2.000	2.001	0.001	0.05%
3.000	3.030	0.030	1.00%
4.000	4.020	0.020	0.50%
5.000	5.010	0.010	0.20%
6.000	6.013	0.013	0.22%
7.000	7.050	0.050	0.71%
8.000	8.037	0.037	0.46%
9.000	9.015	0.015	0.17%
10.000	10.012	0.012	0.12%
11.000	11.030	0.030	0.27%
12.000	12.011	0.011	0.09%
Average		***0.020***	***0.42%***
Minimum		***0.001***	***0.05%***
Maximum		***0.050***	***1.20%***

Table 2: Current measuring instrument testing.

Current (A)		Error	
Standard	**Measurement**	**Value**	**%**
0.100	0.100	0.000	0.00%
0.200	0.200	0.000	0.00%
0.300	0.300	0.000	0.00%
0.400	0.401	0.001	0.25%
0.500	0.508	0.008	1.60%
0.600	0.600	0.000	0.00%
0.700	0.702	0.002	0.29%
0.800	0.801	0.001	0.13%
0.900	0.902	0.002	0.22%
1.000	1.010	0.010	1.00%
Average		***0.002***	***0.35%***
Minimum		***0.000***	***0.00%***
Maximum		***0.010***	***1.60%***

In general, the measuring instruments that have been built for current and voltage measurements are under the standard. This also applies to the speed and torque measurements device that meet the standard.

Table 3: Speed measuring instrument testing.

Speed (rpm)		Error	
Standard	**Measurement**	**Value**	**%**
10	10.01	0.01	0.10%
50	50.01	0.01	0.02%
100	100.03	0.03	0.03%
200	200.11	0.11	0.06%
300	300.05	0.05	0.02%
400	400.87	0.87	0.22%
500	500.76	0.76	0.15%
750	751.20	1.2	0.16%
1000	1002.10	2.1	0.21%
1250	1251.55	1.55	0.12%
1500	1500.98	0.98	0.07%
2000	2002.31	2.31	0.12%
3000	3003.22	3.22	0.11%
4000	4003.97	3.97	0.10%
5000	5005.01	5.01	0.10%
5500	5506.85	6.85	0.12%
Average		**1.81**	**0.11%**
Minimum		**0.01**	**0.02%**
Maximum		**6.85**	**0.22%**

Furthermore, the error value is not significant for the current measurement, which is an average of 0.35% with a maximum of 1.6% and still below 2%, as shown in Table 4.

Table 4: Torque measuring instrument testing.

Torque (Nm)		Error	
Standard	**Measurement**	**Value**	**%**
1.00	1.001	0.001	0.10%
1.50	1.502	0.002	0.13%
2.00	2.018	0.018	0.90%
2.50	2.502	0.002	0.08%
3.00	3.021	0.021	0.70%
3.50	3.526	0.026	0.74%
4.00	4.017	0.017	0.43%
4.50	4.552	0.052	1.16%
5.00	5.046	0.046	0.92%
5.50	5.523	0.023	0.42%
6.00	6.107	0.107	1.78%
6.50	6.581	0.081	1.25%
7.00	6.825	0.125	1.87%
Average		**0.040**	**0.81%**
Minimum		**0.001**	**0.08%**
Maximum		**0.125**	**1.87%**

Testing speed and torque measuring instruments have been carried out with adding the calibration to ensure both meterings meet the standard. The result found that these devices only have a maximum error of 0.22% and 1.87% for the speed meter and torque meter, respectively.

4 CONCLUSIONS

The speed and the torque meter are built using Arduino Uno to make them inexpensive. These measuring instruments have been tested for current and voltage measurements. Both devices are under the standard, with the maximum error at less than 2 %. The speed and torque meter are also shown a good performance under the test with maximum error for both instruments is 0.22% and 1.87%, respectively. So, all the instruments meet the standard.

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