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Performance of Dynamometer with Sensor Type Single Bar for Measuring Drive Power of Rotary Friction Welding Machine

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ABSTRACT

This study aims to determine the performance of the dynamometer design as a measure of mechanical power on a rotary friction welding machine. The design of the dynamometer includes the design, manufacture, calibration, and testing of the dynamometer. The design and manufacture of strain dynamometers is adjusted to the motor of the rotary friction welding machine at the University of Riau's Mechanical Engineering Production Technology Laboratory. The design of the strain dynamometer has a dimension of 175 mm \times 3 mm \times 50 mm and serves to determine the motor torque value with the help of a 120 ohm strain gauge sensor. The device designed is equipped with an electrical microcontroller device and an optocoupler sensor to measure the angular speed of the motor. Next, the dynamometer performance testing is performed on the rotary friction welding machine. The results of testing in the rotary welding process, the greater the pneumatic pressure exerted during welding, the greater the measured power. The largest measured power value is 2452.92 Watt in the forging process, and the smallest measured power value is 2050.24 Watt in the first time of the initial motor rotation. After doing the research, it can be concluded that the tools designed and built can work and have a fairly good performance.

KEY WORDS: Mechanical Power, Dynamometer, Rotary Friction Welding Machine.

NOMENCLATURE

P	Power (Watt)
T	Torque $(N.m)$
ω	The angular velocity (rad/s)
n	Rotation Speed (rpm)
ε	Strain (<i>m</i>)
L	Length (<i>m</i>)
ΔL	Elongation (<i>m</i>)
σ	Stress (N/mm ²)
F	Force (<i>N</i>)
A	Large (m^2)
w	Weight (N)
F_a	Tensile Side Pull of the Belt (<i>N</i>)
F_b	Sagging Belt Side Voltage (N)
F_e	Belt tension (<i>N</i>)
%Error	Large Percent Error (%)
$\omega_{effective}$	Effective Angular Velocity (rad/s)
$\omega_{Measured}$	Measured Angular Velocity (rad/s)
$P_{effective}$	Effective Power (<i>Watt</i>)
$P_{Measured}$	Measured Power (Watt)
LCD	Liquid Cristal Display

1.0 INTRODUCTION

Friction welding is welding without using welding wires or electrodes so that it can be ascertained that the connection is obtained between the two welded material is a homogeneous connection. In addition, connecting the shaft with this process can minimize the shift of the axis from the welded material [1].

The phenomenon of the friction welding process is the heat generation through friction and abrasion. Furthermore, the heat that arises is stored in the material that is connected to raise the temperature. At certain temperatures the material is in perfect plasticity and the press will be easily deformed. With the chemical diffusion event there will be a connection process on the surface of the metal that is joined [2].

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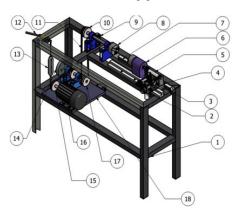
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The working principle of a rotary friction welding machine is that two materials, especially steel, will be subjected to a friction welding process, one material is gripped on a rotary chuck and one material is gripped by a static chuck, simultaneously a rotary of rotary chuck and a static chuck will be driven by pneumatic pressure so that two materials will rub together. From the friction arises heat which can make the two materials will be connected, for regulating the pneumatic pressure rate flow control valve is used [3]. The rotation of the rotary chuck is transmitted by the rotation power of the main shaft driving motor. Shaft generally transmit power through belt, gear and chain [4]. To find out how much power during rotary friction welding, it is necessary to make an effort to make a simple dynamometer at an affordable price.

2.0 FUNDAMENTAL THEORY

2.1 Rotary Friction Welding Machine

Rotary friction welding machine is used to connect two cylindrical materials using a 3 HP electric motor. A rotary friction welding machine is usually used to connect two cylindrical specimens with a diameter of 8 mm [5].



Information:

No	Part name	amount
1	Table	1
2	Pneumatic screen	1
3	Pneumatic position lock	1
4	Pneumatic position	1
5	Pneumatics	1
6	Tail Stock withChuck	1
7	Rail Tail Stock	2
8	Chuck and transmission shaft	1
9	Bearing stances and Bearing	4
10	Upper Pulley	1
11	V-Belt	2
12	Holder Belt	1
13	Iron holder Belt	2
14	Flywheel	1
15	Pulley	2
16	Motors	1
17	Big Pulley	1
18	Position of drive Motor	1

Figure 1: Rotary Friction Welding Machine (Yohanes and Siregar, E. 2017) [5]

Some rotary welding stages are initial rotation, then constant rotation by applying 2 bar pneumatic pressure, then friction phase by applying 4 bar pressure, and forging process by applying 6 bar pressure.

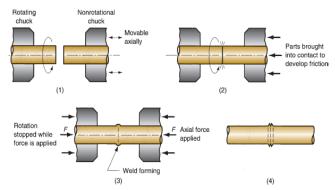


Figure 2: Rotary Friction Welding Process (Groover, M.P. 2013)

2.2 Motor Power

The electric motor functions as the main driving source of the shaft. The required motor power can be determined by the following equation (Sularso, and Suga, K. 1997) [4].

$$P = T.\,\omega\tag{1}$$

Calculating of torque is the following equation (Sularso, and Suga, K. 1997) [4].

$$T = \frac{P}{n} \tag{2}$$

Meanwhile, to calculate the angular velocity using the following substitution equation (Sularso, and Suga, K. 1997) [4].

$$\omega = \frac{2\pi n}{60} \tag{3}$$

2.3 Stress and Strain

In general, the strain that occurs can be formulated as follows. (Sularso, and Suga, K. 1997) [4].

$$\epsilon = \frac{\Delta L}{L} \tag{4}$$

Any material that is stressed will cause tension which is perpendicular to the cutting plane and cross-sectional area. In general, the stress formula is as follows (Sularso, and Suga, K. 1997) [4].

$$\sigma = \frac{F}{A} \tag{5}$$

2.4 Strain Gauge

Strain gauge is the most widely used electrical device for strain measurement. Its operation is based on the principle of electrical resistance of conductors to change when subjected to mechanical deformation [6]. There are three types of strain gauge resistance, as shown in Figure 3.

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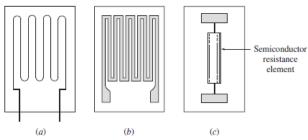


Figure 3: (a) *Wire gauge*, (b) *Foil gauge*, (c) *Semiconductor gauge* (Holman, J. P. 2012) [6]

2.5 Wheatstone Bridge

The Wheatstone Bridge is used to obtain accuracy in evaluating relatively small prisoners [7].

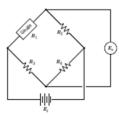


Figure 4: Wheatstone Bridge (Figliola and Beasley, 2011) [7]

This circuit is formed by four resistors (R) which are quadrilateral A-B-C-D in which case the circuit is connected to a voltage source.

2.6 Optocoupler Sensor

Rotation or angular velocity sensors can be made with a "U" type optocoupler and a chop wheel. This rotation sensor can be used to read the rotation of a rotating object such as a vehicle wheel, electric motor rotation and others. This speed or speed sensor is made with a "U" type optocoupler in the middle of which is placed a chop wheel.



Figure 5: Optocoupler Sensor (Figliola and Beasley, 2011) [7]

2.7 Chop Wheel

The chop wheel is a circular paper with a perforation which is perforated to send a signal to the optocoupler sensor to calculate the rotational angle of the motor. This chop wheel is mounted on the motor shaft.



Figure 6: Chop Wheel

2.8 Module HX711

This component is used as a signal amplifier from analog sensors. Amplifier here is a tool where the voltage difference that occurs in the strain gauge is strengthened so that the voltage difference can be read or known by the microcontroller.

The HX711 module functions to amplify the output signal from the sensor and convert analog data into digital data. By connecting it to the microcontroller, we can read the change in resistance from the strain gauge sensor.



Figure 7: HX711

2.9 Arduino Uno

Arduino is an electronic kit or an open source electronic circuit board in which there are main components, namely a microcontroller chip with AVR type from the Atmel company [8].

Arduino has 14 input / output pins of which 6 pins can be used as Pulse Width Modulation (PWM) outputs, 6 analog inputs, 16 MHz crystal output, USB connections, Power Jacks, ICSP heads, and reset buttons. Arduino is able to support microcontrollers; can be connected to a computer using a USB cable. Arduino can be given power via a USB connection or Power Supply. Power supply can use a DC adapter or a battery.



Figure 8: Arduino Uno

2.10 LCD (Liquid Cristal Display)

LCD is a dot matrix display with the function to display (text: numbers and letters), as you wish. LCD is widely used in various fields such as televisions, calculators, or computer screens [9].



Figure 9: LCD

2.11 Data Logger

Data loger is used to store data on dynamometer test results.



Figure 10: Data Loger

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3.0 METHODOLOGY

3.1 Dynamometer Design

The design of the stretch rod dynamometer is adjusted to the size of the main drive motor seat holder of the rotary welding machine used in the Laboratory of Mechanical Engineering, University of Riau.

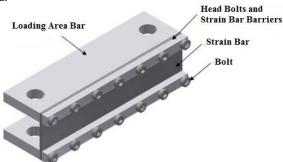


Figure 11: Form of Dynamometer Design

Design of a dynamometer shall have the following conditions:

- The dynamometer to be manufactured must be sensitive enough for precise measurement
- b. The dynamometer to be created needs to be rigid enough to withstand power without causing a lot of deflection which may affect the engine condition.
- c. dynamometer that will be made at affordable or cheap manufacturing prices
- d. The dynamometer to be made is easy to assemble.
- e. The dynamometer made can be easily calibrated.

The stretch bar dynamometer that was designed was made to measure the force of the motor torque by utilizing the strain gauge as a strain gauge caused by the force from the influence of loading of the two main driving motor legs during the engine operating process.

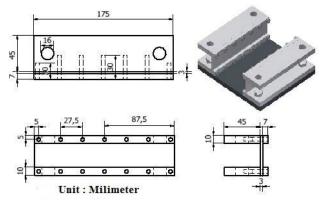


Figure 12: Size Dimensions Selected

Each motor leg is supported by a stretch bar dynamometer. To determine the dimensions of the stretch rod dynamometer requires some analysis on the stretch rod with different dimensional variations so that the stretch rod does not experience material failure during testing.





F. Motor Runway

Figure 13: Laying Position of Dynamometer

3.2 Material Selection

The material used for stretch bar dynamometer is Aluminum 6061. Aluminum 6061 is a material that is resistant to corrosion. Corrosion resistant material is very necessary for the sensor rod because the sensor used is a very thin strain gauge sensor. If the selected material is not resistant to corrosion, the sensor will be released due to corrosion.

3.3 Autodesk Inventor Simulation

After determining the dimensions, design, and material to be used from the dynamometer, the next simulation is using Autodesk Inventor software. This analysis will determine the voltage that occurs when the dynamometer supports the weight of the driving motor.

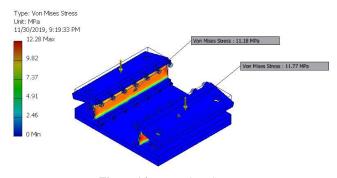


Figure 14: Von Mises Stress

For stresses that occur in the stretch bar of the dynamometer, the critical stress value experienced by the dynamometer with a maximum value of 12.28 MPa. While the yield strength for the dynamometer strain rod material is 276 MPa, so the dynamometer still experiences elastic deformation because the stress that occurs in the stretch bar is smaller than the yield strength stress. So, the dynamometer size is designed according to and suitable for research.

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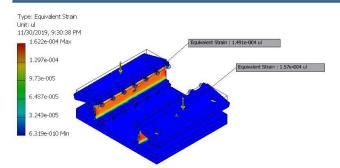


Figure 15: Equivalent Strain

While the strain that occurs on each bar dynamometer is $149.1~\mu\epsilon$ and $157~\mu\epsilon$. It can be interpreted that the strain level is not more than $1500~\mu\epsilon$ and in accordance with the limit range of the 120~ohm strain gauge sensor used.

3.4 Process of Making Dynamometer Components

The manufacture and assembly of the dynamometer was carried out at the University of Riau's Mechanical Engineering Production Technology Laboratory. Making a dynamometer consists of 2 parts, namely the assembly of mechanical components of dynamometers and the assembly of electrical components of dynamometers.

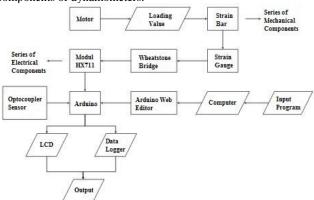


Figure 16: Electric Circuit Dynamometer

a. Assembling the dynamometer mechanical components.
After the manufacturing process is carried out, then the assembly process between components is carried out.

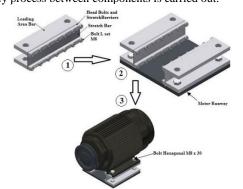


Figure 17: Assembling the dynamometer mechanical components

The dimensions of the dynamometer size are adjusted to the driving motor footprint, which are 175 mm long and 45 mm wide. Specifically for the loading area, the dynamometer rod is adjusted to the length of the bolt and the nut used is the hexagonal M8 x 30 bolts. Whereas the dimensions of the stretch bar area are adjusted to the capability of the strain gauge sensor reading limit. This dynamometer has a stretch bar area with dimensions measuring 175 mm long, 50 mm wide and 3 mm thick. The stretch bar and the load area bar are joined by joining the L set M6 bolt



Figure 18: Strain Dynamometer Testing

Because the purpose of this design is to determine the motor power, in addition to the stretch bar dynamometer to determine motor torque, a sensor is needed to calculate the angular speed of the motor consisting of a countertop wheel mounted on the motor shaft and also an optocoupler sensor to receive the counter speaking wheel signals.



Figure 19: Angular Velocity Measurement

b. Assembling the dynamometer electronic components.

Dynamometer that is made requires several electronic circuits so that the power generated can be displayed in a computer in digital form. This circuit is a communication path from the change in strain gauge sensor resistance due to deflection of the stretch bar dynamometer and the value measured from the optocoupler sensor to a digital number on the computer.

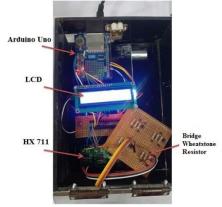


Figure 20: Circuit of Electrical Components

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3.5 Setting Dynamometer

The device that has been designed needs to be adjusted whether it operates properly or not before data collection is performed.

a. Determine the correlation of input and output loading.

The results of loading on the dynamometer will be input in graphical form to find the multiplier factor. Output data from the results of loading are analyzed by linear regression method. The linear regression method is a method that can be used to determine the pattern of relationships between two variables. So, that it can be seen the correlation between the force (F) with the loading output.

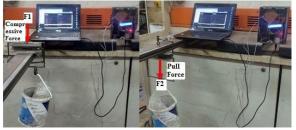


Figure 21: Loading dynamometer

The input and output correlation is loading where y is the dependent or output variable (gr) while x is the free or load variable (N). Given a simple linear regression equation for the compressive force (F1) y = 0.01 x, then x = 100 y or F1 = 100 times the output value, this is the multiplier factor to be entered into the program. As for the tensile force (F2) y = 0.005 x, then x = 200 y or F2 = 200 times the output value and this is also a multiplier factor to be entered into the program.

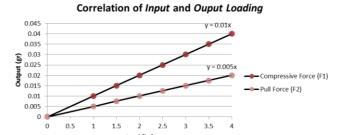


Figure 22: The Correlation of Input and Output Loading

b. Determine the calculation formula.

The angular velocity (ω) can be calculated using an optocoupler sensor that reads the signal from the chopping wheel mounted on the motor shaft.

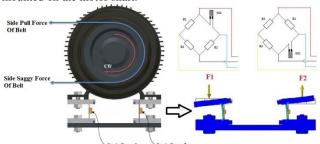


Figure 23: Determination of Calculation Formulas

And for the torque value (T) is calculated through the force measured by the strain gauge. During the drive motor operates, belt pull occurs which gives the compressive and tensile forces to the dynamometer. The torque value can be determined by pulling the belt. The value of F_e is the sum of F1 (the pull side of the belt) and F2 (the loose side of the belt) measured by the strain gauge, and it can be seen the value of the torque formula.

$$F_e = 0.716. \left[618,5025N - \left(\frac{0.152kg}{0.065m} \cdot \left(\frac{\pi.0,13m \cdot \frac{3HP}{T}}{60} \right)^2 \right) \right]$$
(6)

$$T = \frac{15,23kg.m^3.s^{-3}}{\sqrt{264,719N.m/kg - (F_e.0,597m/kg)}}$$
(7)

So, the calculation formula obtained to determine the power is as below:

$$P = \frac{15,23kg.m^3.s^{-3}}{\sqrt{264,719N.m/kg - (F_e.0,597m/kg)}}.\omega rad/s$$
 (8)

4.0 RESULTS AND DISCUSSION

4.1 The calculation results

After the experiment, the measurement results are explained in graphical form.

Torque vs Time

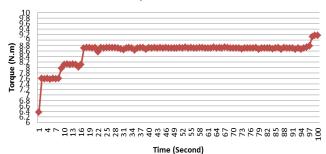


Figure 24: Graph of Torque vs Time

Angular Velocity (ω) vs Time

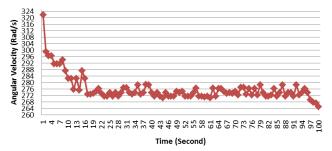


Figure 25: Graph of Angular Velocity vs Time

It can be seen in the graph in Figure 24 that the motor torque value from the initial rotation of the motor turned on for 8 seconds until the welding process of the last 3 seconds i.e. the

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forging stage has increased. At the data retrieval stage it has been mentioned that there are 4 welding stages, namely 8 seconds of initial motor rotation, 8 seconds of constant rotation of welding by applying 2 bar pneumatic pressure, and the friction stage by applying 4 bar pneumatic pressure. The final stage is the forging stage by applying pneumatic pressure of 6 bars. So the greater the pneumatic pressure exerted on rotary welding, the rotary motor drive welding machine will have a large torque value.

As for the motor rotational speed, from the beginning of the motor rotation to the welding forging stage, the angular velocity decreases in value. So, the greater the increase in welding pneumatic pressure, then there will be a decrease in the rotational speed of the rotary motor drive motor, which is shown in the graph from Figure 25.

In this study, the angular speed of the motor was measured with the help of a chopping wheel and an optocoupler sensor. If the effective rotating speed of the motor used is 2800 rpm or 293.21 rad/s, it is necessary to determine the difference in value or% Error measured value of rotating speed during welding with the value of the effective rotating speed of the motor used with the following equation.

$$\%Error\omega = \left[\frac{\omega_{effective} - \omega_{Measured}}{\omega_{effective}}\right] x 100 \tag{9}$$

The largest value of %Error yang measured in the initial rotation in the first time is -9.71%, because %Error is absolute, the value is considered positive. %Error ω in the first time of the initial rotation indicates that when the motor is turned on, the angular speed exceeds the effective angular speed of the motor. And the biggest %Error ω is the last time when forging is 9.61%, due to the angular speed of the motor when the forging slows down.

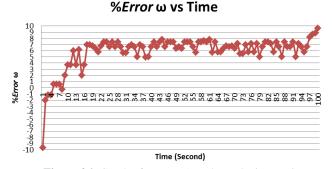


Figure 26: Graph of %Error Angular Velocity vs Time

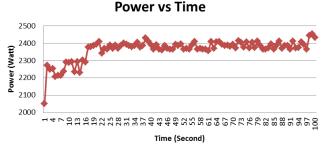


Figure 27: Graph of Power vs Time

Similar to the torque conditions is the power from the initial rotation to the final stage of welding increases in value. It can be interpreted that the greater the pneumatic pressure exerted when welding, the measured power is also greater. The largest measured power value is 2452.92 Watt in the forging process, and the smallest measured power value is 2050.24 Watt in the first seconds of the initial motor rotation.

If the effective power of the motor used is 3 HP or 2238 Watt, it is necessary to determine the difference in value or %Error measured power during welding with the effective power of the motor used in the following equation.

$$\%ErrorP = \left[\frac{P_{effective} - P_{Measured}}{P_{effective}}\right] x 100\%$$
 (10)

The largest measured %Error P value occurs in the initial rotation in the first second of 8.39%. %Error P in the first time of the initial cycle indicates that when the motor is initially started, it produces a very large amount of power in excess of the effective power of the motor. And the other %Error P is when the forging is equal to -9.6%, because %Error is absolute, the value is considered positive.

%Error Power vs Time

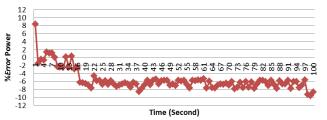


Figure 28: Graph %Error Power vs Time

5.0 CONCLUSION

From the research, it has been concluded that as a torque gauge, the dimensions of the strain bar for attaching a 120 ohm strain gauge are 175 mm long, 3 mm wide, and 50 mm high, and an optocoupler sensor is also needed to measure the angular speed of the motor. The electrical circuit is arranged as a communication path from the change in the resistance value of the strain gauge sensor due to the flexural stem deflection of the dynamometer and the value measured from the optocoupler sensor to a digital number on the computer. The greater the pneumatic pressure applied during welding, the greater the measured power. The largest measured power value is 2452.92 Watt in the forging process, and the smallest measured power value is 2050.24 Watt in the first seconds of the initial motor rotation. To perfect this research further research needs to be done by increasing the accuracy of the dynamometer because this designed tool has weaknesses in the accuracy of measuring values and also needs to be developed tool design for better measurement results.



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