

# Study on the methods of measuring power of the rotating mechanisms

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**Abstract.** This article is about the methods of measuring the power of rotating mechanisms, in which the sensors that measure the angular parameters of rotating mechanisms are analyzed. Also, several methods of measuring the power of rotating mechanisms are given in the article. The method of power dissipation through angular acceleration and torque is analyzed in more detail. Connections of input and output quantities are given.

## 1. Introduction

Today, electric motors are used in wide sectors of agriculture and water management, and loads of different power are connected to its shaft. When the motor is running under load, the weight on its shaft changes and this can sometimes exceed the rated power of the motor.

Various sensors [1, 2, 3, 4, 6, 7] have been developed to measure and monitor the power acting on rotating parts. These sensors make it possible to measure and control parameters such as angular displacement [5], angular velocity, and angular acceleration of rotating mechanisms. In addition, it is possible to measure the reactive power of asynchronous motors using angular acceleration sensors [8].

There are direct and indirect methods for measuring the force of rotating mechanisms, and these methods [9-16] have their own advantages and disadvantages. The construction presented in the literature works on the optical principle and can measure the torque, power and angular velocity of the shaft [17]. This device consists of clutch flat disc, metal ball, clutch wave disc, variable surface, inductive sensor, spring, non-pressurized connection, guide torque/rotation sensor, brake. However, this method has some drawbacks. The following:

- the proposed sensor converts the torque into an axial force, generating a measurable axial movement for the proximity sensor. This axial load increases the friction on the rotating parts, unless special devices are used.
- creates a break in the connection between the moving and controlled sides. As a result, each side must be installed separately and properly aligned, which increases production costs.
- in theory, at least two data points are needed to estimate absolute rotational position and torque. In practice, more data is required to achieve higher accuracy through filtering.

The principle of operation of the sensor [18] is based on measuring the amount of rotation of the rotating shaft when a torque is given to it. According to the method of reading the amount of rotation of the shaft, they are divided into two types:

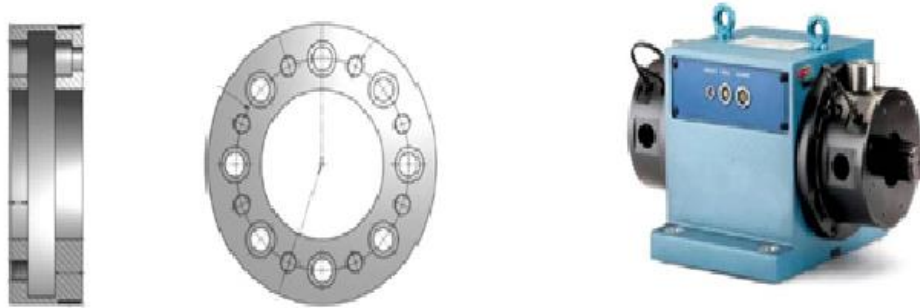
- measurement of voltage
- measurement of pulse

In the strainometric method, strain gauges are attached to the torsion shaft, the signal from it is amplified, converted into a serial digital code and transmitted to an external measuring device using a non-contact rotary transformer. The transformer also generates the voltage required to power the amplifier, the pulse transmitter, the devices located in the rotating part. The gap between the receiving device in the stator and the rotating transformer is 5 - 8 mm.

Figure 1 shows a pulse reading sensor that can measure rotational speed, vibration, and power simultaneously.

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**Fig. 1.** Sensor based on pulse counting

The disadvantage of this method is that there is a temporary shift in the pulses read by the sensors from the slots in the input and output flanges (or auxiliary gears), which are converted into rotational speed and torque by the receiver. This leads to measurement errors.

Torque measurement methods themselves are divided into contact and non-contact types, and you can see different designs for each method [19].

One such method is the determination of the surface acoustic wave response [10], in which an analysis of the relationship between the entropy of the response energy was carried out. It can be concluded that surface acoustic wave (SAW) sensors can be used. To measure temperature or torque in a rotating medium; however, some customization components are required to overcome the limitations imposed by off-the-shelf (COTS) sensor solutions.

In other words, new torque magnetostrictive [15] sensors using amorphous are presented, in which amorphous ribbons are cut to form a linear pattern and glued to a shaft. In this case, when a pair of tapes is installed, the multivibrator bridge circuit performs the function of torque measurement.

Another way to determine the torque in the tensometric method [20] is using a tensometric bridge circuit and non-contact transmission devices. In this way, signals can be controlled by a computer.

There are also flange type [21] and magnetoelastic ring type torque sensors, each of which has advantages and disadvantages.

For example, using a magnetoelastic ring sensor, it is impossible to determine the direction of the time. When designing, it is necessary to take into account the material of the shaft, and the flange sensor indicates that the maximum speed of the driven shaft is not high. To detect the torque at low speed, the diameter of the shaft should be small, and when the contact rings are used at high speed, the sensor will work for a short time. There are disadvantages, such as a decrease in the accuracy of resistance changes over time.

The optical [22-23] sensor is mounted on a two-pin reading tape shaft. Since this is a non-contact method, torque measurement has less error and can be used to determine power. However, in this method, it is necessary to take into account the influence of the external environment. For example, in dusty environments, there are disadvantages such as a decrease in light transmission or light shift due to vibrations.

Capacitive torque measurement [24] is also an example of non-contact measurement methods. The proposed capacitive torque sensor has two angular displacement sensors at a well-defined distance. These voltages are capacitively coupled from the stator to the rotor. The stator is also equipped with a reading electrode. The sine wave at this reading electrode is proportional to the rotor-stator.

There are more indirect measuring methods than direct methods for measuring the power of rotating mechanisms. These methods are different depending on the type and construction of measuring transducers.

## 2. Materials and Methods

We calculate the power of the rotation mechanisms using the following formula.

$$P = M \cdot \omega; \tag{1}$$

Here,  $M$  is the rotational moment of the shaft, and  $\omega$  is the angular velocity.

If we want to express this equation in terms of angular displacement, it looks like this:

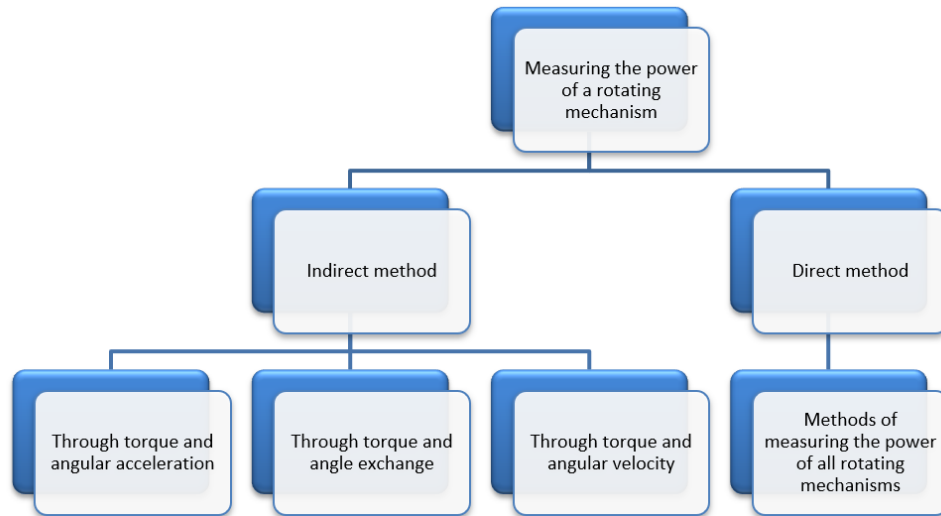
$$P = M \cdot \frac{d\theta}{dt}; \tag{2}$$

Here  $\theta$  is the angular displacement of the shaft

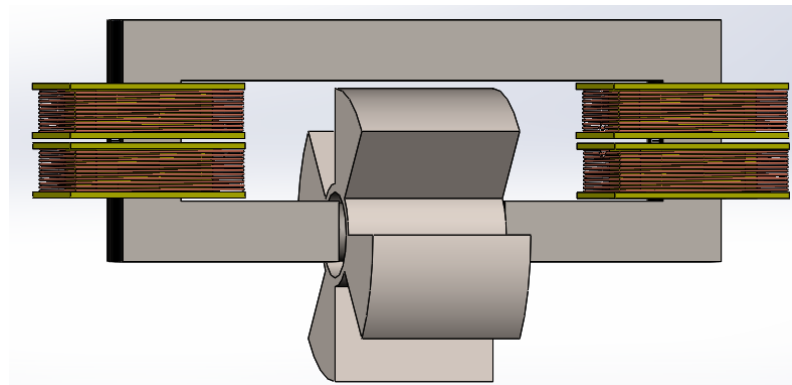
Alternatively, we can express formula (1) as angular acceleration:

$$P = M \cdot \int \varepsilon; \tag{3}$$

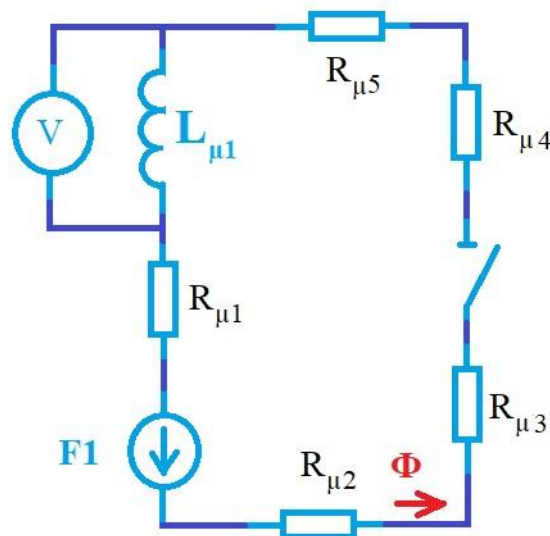
Based on these formulas, we can use angular displacement, angular velocity, and angular acceleration sensors in the case of torque converters to measure the power of rotating mechanisms (Figure 2).



**Fig. 2.** Methods of measuring the power of rotating mechanisms



**Fig. 3.** Angular acceleration sensor



**Fig. 4.** Equivalent electrical circuit of the angular acceleration sensor

Disputation 1. In this disputation, it is necessary to determine the angular velocity and torque when measuring the power of the rotating mechanism. For this, we need a torque sensor, an angular velocity sensor, and a microcontroller to process the results and calculate the power.

We used Matlab software to analyze the above power measurement methods. Figure 2 shows the mathematical model of measuring the power of rotary mechanisms in Matlab, where a sinusoidal source is used as the torque sensor signal, and an impulse signal is used for the angular velocity.

Disputation 2. Calculation of power through angular acceleration and torque. The advantage of this method is that it is possible to determine four quantities [1, 2, 3, 4, 7] at the same time. That is, angular acceleration and torque are measured separately. Angular velocity and power are determined by calculation. The angular acceleration sensor [19] is shown in Figure 3 below.

To study this sensor, we will replace it with its equivalent electrical circuit highlighted in Figure 4.

### 3. Results and Discussion

In this article, various methods of measuring the power of rotating mechanisms were considered and the following conclusions were reached:

- Most of the methods of determining the power of rotating mechanisms are based on the determination of torque.
- When measuring the power of rotating mechanisms, it is necessary to take into account external influences.
- Non-contact methods of power determination are simpler than contact methods, but the error is relatively high.
- The method of determining the power of rotation mechanisms using torque and angular velocity is simpler and more accurate.

Here,  $R_{\mu 1}$ ,  $R_{\mu 2}$ ,  $R_{\mu 3}$ ,  $R_{\mu 5}$  are the magnetic resistances of the magnetic conductor and  $R_{\mu 4}$  is the magnetic resistance of the air gap. The total magnetic resistance of the circuit is the sum of:

$$R_{\mu ekv} = R_{\mu 1} + R_{\mu 2} + R_{\mu 3} + R_{\mu 4} + R_{\mu 5} \quad (4)$$

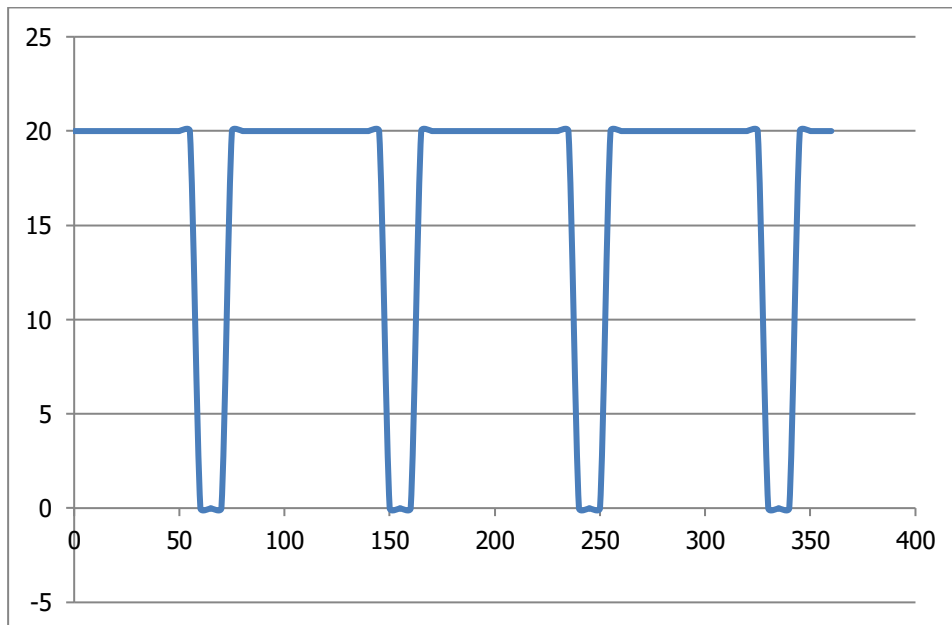
We can determine the time constant by solving this chain with respect to transient processes.

$$\tau = \frac{L_{\mu}}{R_{\mu 1} + R_{\mu 2} + R_{\mu 3} + R_{\mu 4} + R_{\mu 5}} \quad (5)$$

The general magnetic permeability is as follows

$$\gamma_{\mu ekv} = \frac{1}{R_{\mu ekv}} \quad (6)$$

In this chain, our total magnetic permeability changes over time as follows (Figure 5).



**Fig. 5.** Change of magnetic permeability

If we expand this function into a Fourier series, it will look like this.

$$\gamma_{\mu ekv} = \frac{\gamma_m}{2} + \frac{2\gamma_m}{\pi} \left( \sin \omega t + \frac{1}{3} \sin 3\omega t + \frac{1}{5} \sin 5\omega t + \frac{1}{7} \sin 7\omega t \right) \quad (7)$$

The electric driving force generated in the sensor's measuring range is calculated as follows:

$$E = w \frac{d\Phi}{dt} \tag{8}$$

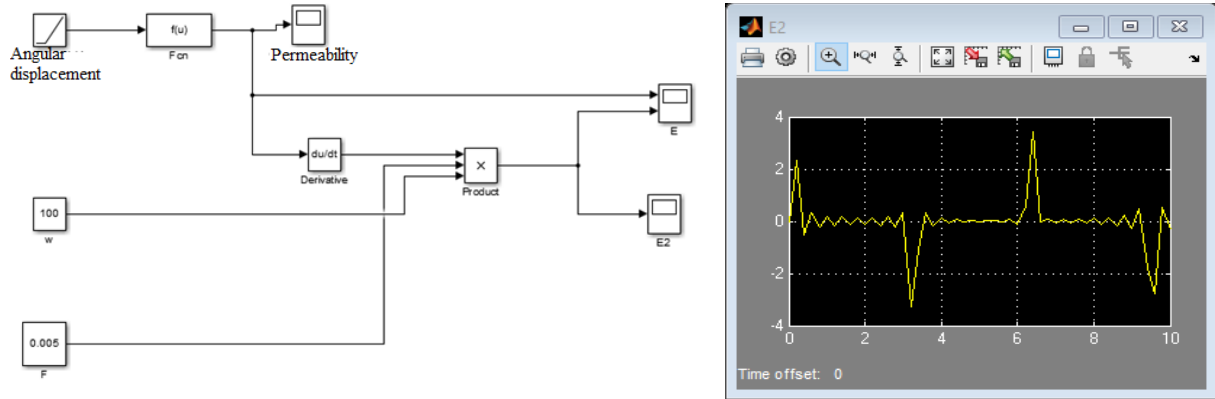
The magnetic flux follows:

$$\Phi = \frac{F}{R_{\mu}} = F \cdot \gamma_{\mu} \tag{9}$$

Summarizing the above formulas, we get the following formula:

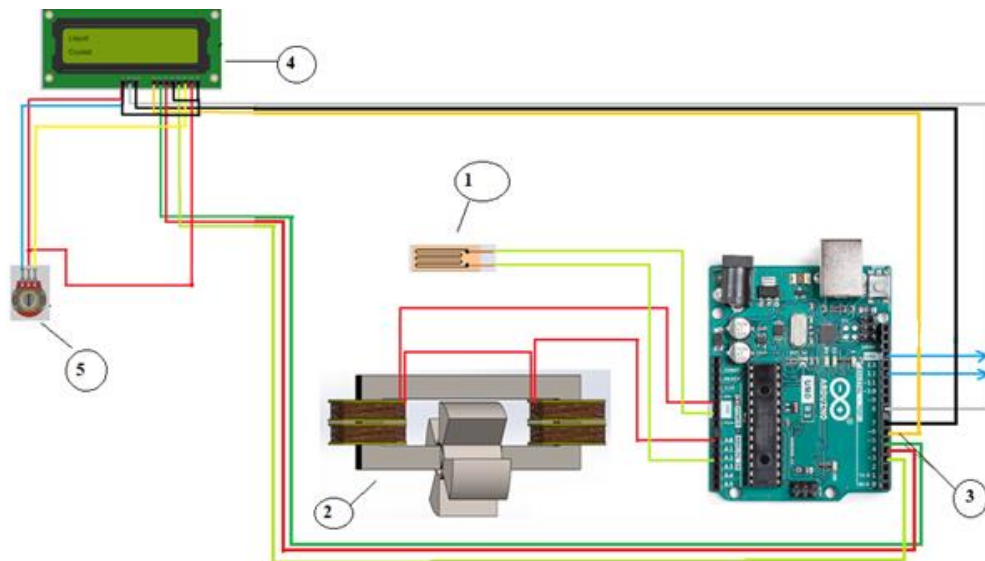
$$E = w \frac{d\Phi}{dt} = w \frac{d(F \cdot \gamma_{\mu})}{dt} = wF \frac{2\gamma_m}{\pi} \omega (\cos \omega t + \cos 3\omega t + \cos 5\omega t + \cos 7\omega t) \tag{10}$$

According to this method, we use the signal of the angular acceleration sensor and the signal of the torque sensor for power (Figure 6).



**Fig. 6.** Angular acceleration sensor output signal

Power detection in this method is shown in Figure 7 below, which consists of an angular acceleration sensor, a strain gauge and an Arduino platform. The signal from the sensors enters the analog input of the arduino platform. After executing the necessary algorithm, the microcontroller transmits the control signal to the motor through the digital legs. Through this system, it is possible to measure and control the power of rotating mechanisms. In this system, power, angular acceleration, angular velocity and torque of rotating mechanisms can be measured at the same time.



**Fig. 7.** Power measurement and control system through angular acceleration and torque: 1st strain gauge; 2nd angular acceleration sensor; 3-arduino platform; 4th monitor; Potentiometer 5.

Method 3. This method allows us to use the angular displacement sensor. It is possible to determine 5 sizes at the same time.

Calculation of power by the third method, that is, by angular displacement and torque.

The moment of force is directly proportional to the moment of inertia:

$$M = J \cdot \epsilon \tag{11}$$

The moment of inertia is directly proportional to the mass of the body:

$$J = \int r^2 \cdot dm \quad (12)$$

Summarizing these formulas, we derive the following formula:

$$P = \int r^2 \cdot dm \cdot \varepsilon \cdot \omega \quad (13)$$

Here  $r$  is the distance to the axis of rotation

If we express angular acceleration  $\varepsilon$  and angular velocity  $\omega$  by angular displacement, we get the following expression.

$$P = \int r^2 \cdot dm \cdot \frac{d^2\theta}{dt} \cdot \frac{d\theta}{dt} \quad (14)$$

Based on the formula (7), the power of rotating mechanisms can be determined by angular displacement and moment of inertia, or by knowing the mass of the object and the distance to the axis of rotation. However, here the variability of the mass leads to an increase in errors.

## 4. Conclusion

In this article, various methods of measuring the power of rotating mechanisms were considered and the following conclusions were reached:

- Most of the methods of determining the power of rotating mechanisms are based on the determination of torque.
- When measuring the power of rotating mechanisms, it is necessary to take into account external influences.
- Non-contact methods of power determination are simpler than contact methods, but the error is relatively high.
- The method of determining the power of rotation mechanisms using torque and angular velocity is simpler and more accurate.

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