SILESIAN UNIVERSITY OF TECHNOLOGY
FACULTY OF ENERGY AND ENVIRONMENTAL ENGINEERING
INSTITUTE OF POWER ENGINEERING AND TURBOMACHINERY

INSTRUCTIONS

to „Measurements of energetic quantities”
(Pomiary wielkości energetycznych)

Laboratory Exercise M-2

Power measurements

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1. The objective of laboratory

The expected objective of this laboratory exercise is introduction to basic techniques of mechanical and electric power measurement of electric motors. For this purpose, the power of electric motor is measured, allowing the determination of its operating characteristics and the comparison of results from two different methods of mechanical power measurement.

2. General scheme of the system

In figure 1 is presented a general scheme of a system powered by electric motor, in which can be distinguished:

- Electric power supplied to the motor (P_{el})
- Mechanical (effective) power (P_{m})
- Power output used by a driven machine or device (P_{out})

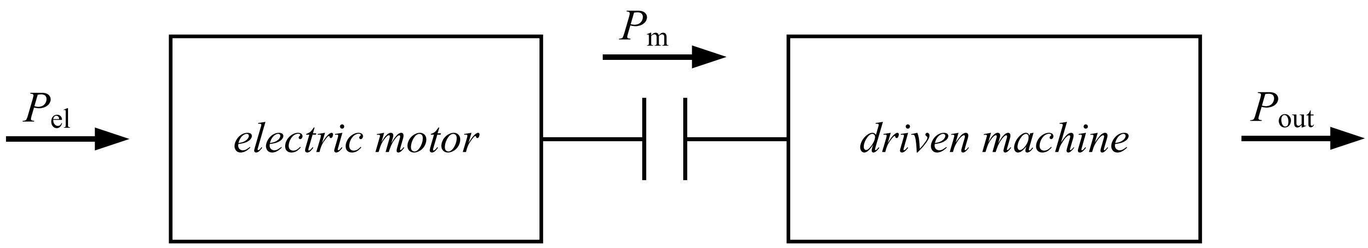

Figure 1. General scheme of a system powered by electric motor

The objective of laboratory exercise is to measure the electric power P_{el} and mechanical power P_{m} of a motor, which allows to determine <u>electric (internal) efficiency of the motor</u> η_{el} using the relation:

$$\eta_{\text{el}} = \frac{P_{\text{ef}}}{P_{\text{m}}} \tag{1}$$

Power output P_{out} is the part of mechanical power, which is effectively used or converted into another type of energy by driven machine. The methods used to measure the power output depend on the type of driven machine or device.

3. Electric power measurements

<u>Three-phase electric power systems</u> have at least three conductors carrying alternating current voltages that are offset in time by one-third of the period. It is commonly used to power large motors and other heavy loads. The receiver of electric power in three-phase system can be connected in two ways:

- in four-wire power network (with neutral)
- in three-wire power network

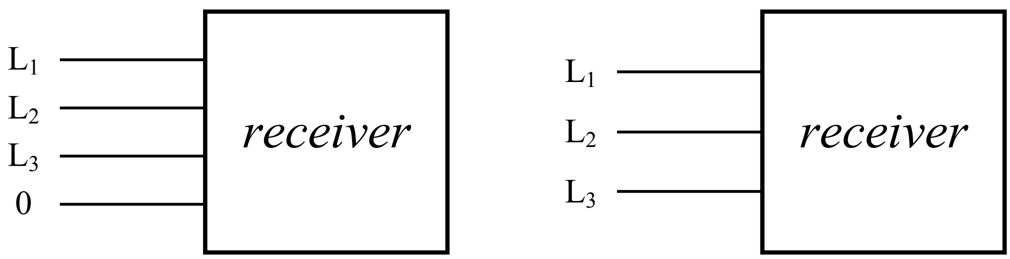

Figure 2. Receivers of electric power in four-wire system and in three-wire system

In four-wire power network to measure active power in the case of asymmetrical phase load should be used 3 watt-meters according to the scheme:

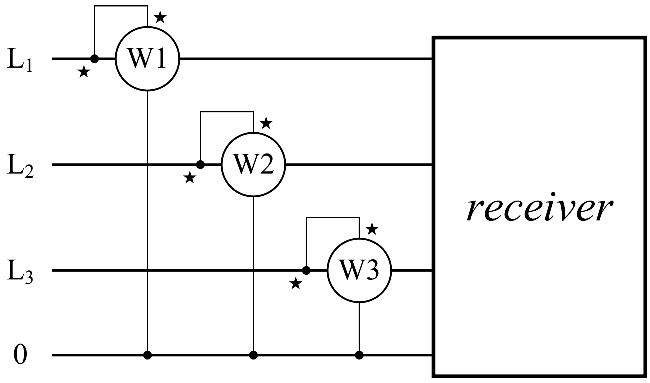

Figure 3. Active power measurement of receiver in four-wire system

Total active power P_{el} consumed by the receiver is the sum of the individual wattmeter's indications:

$$P_{\text{el}} = P_{\text{W1}} + P_{\text{W2}} + P_{\text{W3}} \tag{2}$$

If the load of each phase is the same (the receiver is symmetric) you can use one wattmeter, and the total active power P_{el} of the four-wire system is three times higher than the indication of the wattmeter:

$$P_{\text{el}} = 3 \cdot P_{\text{W}} \tag{3}$$

If the receiver is connected to a three-wire power network, to measure the active power two watt-meters are used, connected in the Aron system. In this system, watt-meter's current circuits are connected to any two phases of the three-phase system, and the ends of voltage circuits are connected to the phase, which is not connected with current circuits. In presented system the current amperage measurement by ammeter has only a supporting role. Measurements of active power in Aron system are correct both in symmetric and asymmetric load of individual phases. The measurement system is illustrated in figure 4.

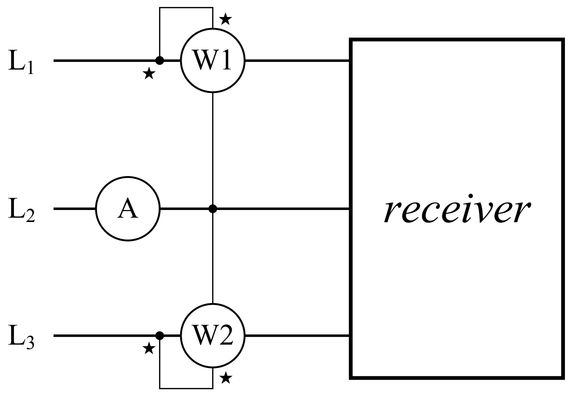

Figure 4. Active power measurement of receiver in three-wire power network (Aron system)

Total active power P_{el} consumed by the receiver is the sum of the individual watt-meter's indications:

$$P_{\text{el}} = P_{\text{W1}} + P_{\text{W2}} \tag{4}$$

4. Mechanical power measurements

Measurement of mechanical power can not be done directly. There are several indirect methods of power measurement, which, due to the energy change in measured system, can be classified into non-destructive, destructive and special.

- Non-destructive methods of power measurement are used to measure indicated power (internal) of motors or working machines operating in a periodic manner. They consist in determining the indicator diagrams of the indicated work with a known rotational speed of the machine. An important advantage here is the ability to measure power of devices in real conditions, without introducing additional loads.
- Destructive methods are based on the change of mechanical work to a different form of energy more convenient to measure, e.g. into heat or electricity, or to a torque and rotational speed with loading motor with brake. The conversion of mechanical energy into heat does not give very accurate results, due to the large energy losses. In the method using conversion to electric energy it is necessary to know the efficiency characteristics of generator depending on the rotational speed and load. Most often effective power is determined in the test with a motor load by means of the brake.

  Destructive methods are used for example in determining the characteristics of the motor and in the preparation of energy balances of the devices. These methods do not allow for the continuous power measurement in real conditions, ie. without removing the connected machine from the motor.
- In difficult cases a special methods are used, which measures torque without destroying the power by means of the brake. Motor load provides driven machine here. For this type of measurement coupling dynamometers or torsiometers are used.

Mechanical power P_{m} is obtained by multiplying the torque M and angular speed ω:

$$P_{\mathrm{m}} = M \cdot \omega \tag{5}$$

4.1. Angular speed measurement

Measurement of the rotational speed n (defined as number of rotations in period of time, here rpm – *rotations per minute*) is performed by means of optical tachometer counting pulses of reflected light. The motor is loaded by the band-brake, with a reflective element located on brake disc. The measured rotational speed shall be converted into angular speed ω (rad/s) according to the following equation:

$$\omega = n \cdot \frac{2\pi}{60} \tag{6}$$

4.2. Torque measurement using the brake (1st method)

Torque (moment of force) is the tendency of a force to rotate an object about an axis. The motor is loaded by the band-brake producing friction torque (torque caused by the frictional force that occurs when two objects in contact move), which causes a change of mechanical energy into heat.

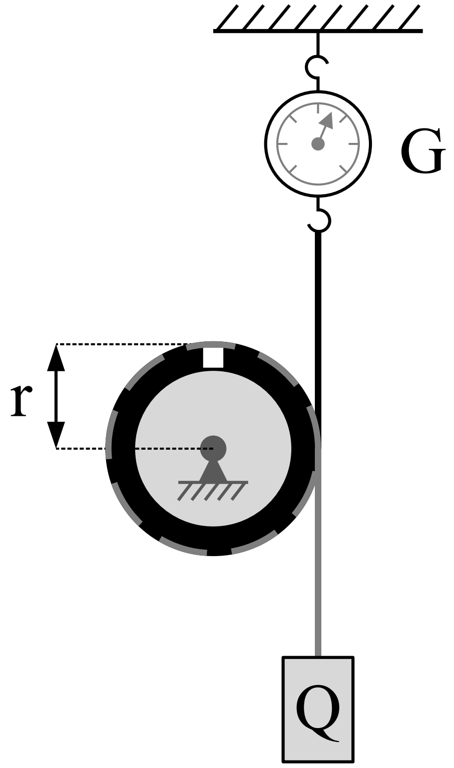

Figure 5. The band-brake

The value of torque M_1 on the brake shaft can be calculated by multiplying the band friction force on brake disc T by a radius of the brake disc r:

$$M_1 = T \cdot r \tag{7}$$

The radius of brake disc equals $r = 0{,}14\ m$.

The band friction force on brake disc T is the difference between mass indication Q and dynamometer indication G:

$$T = (Q - G) \cdot g \tag{8}$$

where g s the gravitational acceleration,

for calculations take $g = 9{,}81\ m/s^2$.

Mechanical power for the measurements by 1st method $P_{m.1}$:

$$P_{m.1} = M_1 \cdot \omega \tag{9}$$

4.3. Torque measurement using the oscillating motor suspension (2nd method)

Another method of measuring torque on the motor shaft is its oscillating suspension. In normal motor attachment torque on the shaft is transmitted electromagnetically to the body and compensated by the reactions of the body attachment. When the motor body is mounted in bearings (as shown in Figure 6), the torque M is balanced by the force F, which is measured using the lever arm pressing the weight (reactions in bearings pass through the rotation axis and do not have torque).

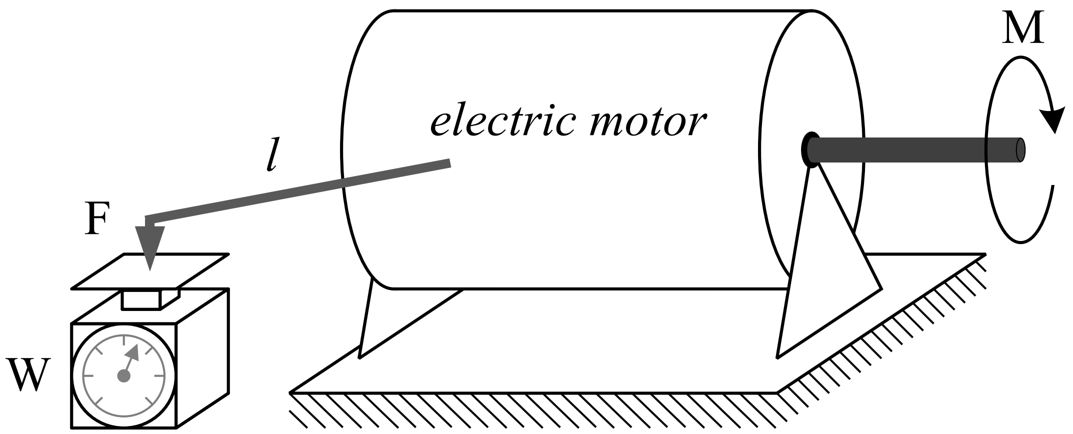

Figure 6. Torque measurement using the oscillating motor suspension

The value of torque M_2 is given by:

$$M_2 = F \cdot l \tag{10}$$

where l is the length of the lever arm from motor body, amounting $l = 0{,}635\ m$.

The force F is determined using the weight indication W:

$$F = W \cdot g \tag{11}$$

Mechanical power for the measurements by 2nd method $P_{\mathrm{m.2}}$:

$$P_{\mathrm{m.2}} = M_2 \cdot \omega \tag{12}$$

5. Course of the exercise

Table of measurements and table of results in a form prepared for printing are located on the last page of these instructions. **Two sets of tables** must be prepared - for measuring with increasing and decreasing load of the brake.

1) Measure the mass Q of all weights, which are used in subsequent steps to load the brake band (the number of weights from 1 to 5).
2) With the motor under zero load ($Q = 0$) perform a first series of measurements for: dynamometer G, the weight W, current on the ammeter I, power on watt-meters P_{W1} and P_{W2} and the rotational speed n.
3) Load the brake with one weight and make the next series of measurements.
4) Repeat step 3 for the number of weights from 2 to 5.
5) In analogy to the steps 2-4 make the measurements with offloading the brake, starting from the load of 5 weights and ending at zero load.

6. Calculations

a) For all measures shall be calculated: electric power P_{el}, angular speed ω, and for both measuring methods: torque M_1 and M_2, mechanical power $P_{\mathrm{m.1}}$, $P_{\mathrm{m.2}}$ and electric efficiency of the motor $\eta_{\mathrm{el.1}}$, $\eta_{\mathrm{el.2}}$. Summarize the results in the table of results.
b) On the basis of measurements and of the results of calculations create charts with the following characteristics of the analyzed motor:

I.	$N_{\mathrm{el}} = f(\omega)$	
II.	1. $P_{\mathrm{m.1}} = f(\omega)$	2. $P_{\mathrm{m.2}} = f(\omega)$
III.	1. $M_1 = f(\omega)$	2. $M_2 = f(\omega)$
IV.	1. $\eta_{\mathrm{el.1}} = f(\omega)$	2. $\eta_{\mathrm{el.2}} = f(\omega)$

Perform the characteristics separately for the increasing and decreasing motor load.

7. Report.

The report shall include:

1. Title page.
2. Objective of the exercise.
3. Theoretical review (short and specific)
4. Sample calculations.
5. Tables of measurements and tables of results.
6. Characteristics of analyzed motor.
7. Comments and conclusions.

Time:		**Date:**		**LAB No.:**	M-2	**Group No.:**	

TABLE OF MEASUREMENTS

No.	**Number of weights**	**Mass** Q, **kg**	**Dynamometer** G, **kg**	**The weight indication** W, **kg**	**Amperage** I, **A**	**Electric power** P_{W1}, **W**	**Electric power** P_{W2}, **W**	**Rotational speed** n, **rpm**
1								
2								
3								
4								
5								
6								
7								
8								

TABLE OF RESULTS

No.	**Electric power** P_{el}, **W**	**Angular speed** ω, **rad/s**	**Torque** M_1, **Nm**	**Mechanical power** $P_{ef.1}$, **W**	**Electric efficiency** $\eta_{el.1}$, **%**	**Torque** M_2, **Nm**	**Mechanical power** $P_{ef.2}$, **W**	**Electric efficiency** $\eta_{el.2}$, **%**
1								
2								
3								
4								
5								
6								
7								
8								