Measurement of speed of rotation and torque

1. Aim of the measurement

The aim of measurement is

- ***to measure the losses of an electrical motor/generator and***
- ***to analyse the influence of load on the losses.***

2. Introduction

For rotating motion, power is the product of torque and angular velocity

$$P = M \cdot \omega = M \cdot 2\pi \cdot n$$

Thus, to determine the power of the rotating motion the *torque* (M) and the *revolution number* (n) must be measured.

Measurement of the revolution number

From the point of view of the *measuring concept* the instruments measuring the revolution number can be divided into three groups:

- <u>speed indicators</u> measuring the average revolution number,
- <u>tachometers</u> measuring the momentary revolution number and
- <u>stroboscopes</u> working on the principle of comparison.

a) Measurement of small revolution number can be performed simply with **stopwatch** and by <u>counting</u> revolutions with naked eye. When the mark on the rotating machine part gets to the marked position, we start the stopwatch and begin counting (with 0). Having measured the time (T) and the number of revolutions (N) the revolution number is simply n=N/T.

b) For higher speed of rotation a special counting device must be used. One of the simplest of these is the so-called **jumping-figure speed counter**. The rotating shaft of this device turns gears. One of them completes one revolution while the other rotates only 1/10, and so on. Reading the numbers uniformly painted from 0-9 on the cylinder jacket we get the number of revolutions. Such a device is used in kilowatt-hour meters, water consumption, tape recorders, speedometers of cars etc.

c) **Mechanical tachometers** count the revolutions only for a fixed time, generally for 6 seconds. The time measuring device of the instrument connects its pointer for 6 seconds with that shaft of the instrument which joints the rotating machine part. After these six seconds there is no more connection which means at the same time the end of the measurement. A widely used example of this device is the Jacquet indicator. With pressing the starting button the instrument is zeroed and after releasing it the counting and the clockwork starts.

d) **Electric tachometers** operate with the same principle (counting the number of revolutions during some period of time), but the number of revolutions is measured in an optical way.

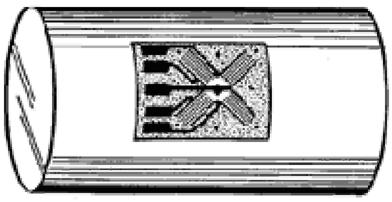
e) A **stroboscope**, also known as a strobe, is an instrument used to make a cyclically moving object appear to be slow-moving, or stationary. In its simplest form, a marker is placed to the rotating shaft and a lamp capable of emitting brief and rapid flashes of light is used. The frequency of the flash is adjusted so that it equals to the shaft's cyclic speed, at which point the object is seen to be either stationary or moving backward or forward, depending on the flash frequency.

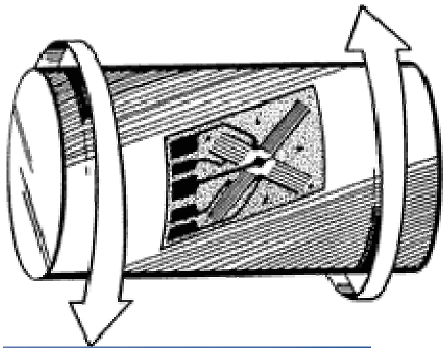
Measurement of torque

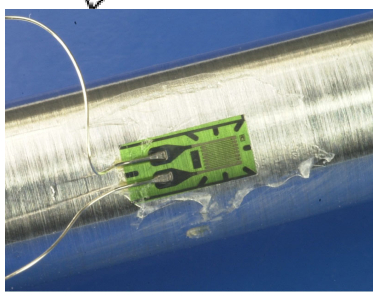
There are many ways of measuring torque, out of which the two most important ones are

- strain gauges and
- balancing motors

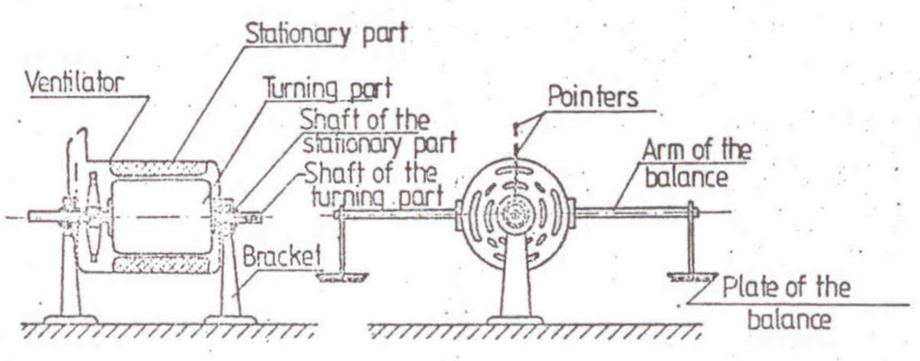
a) A **strain gauge** is a small electrical 'element' printed on a non-conductive substrate. The pattern of the element is arranged so that if the gauge is stretched (or compressed) in one direction (along operating axis of the gauge), the resistance of the element increases (or decreases) in relation to that stretch. A stretch perpendicular to the axis of the strain gauge has little effect on the resistance of the element. If a gauge is bonded to the shaft, with its axis aligned with the direction in which the shaft material stretches when a torque is applied, the strain gauge will also stretch and therefore the element will increase in resistance. By measuring the change of resistance, after appropriate calibration, one can measure the torque applied to the shaft.

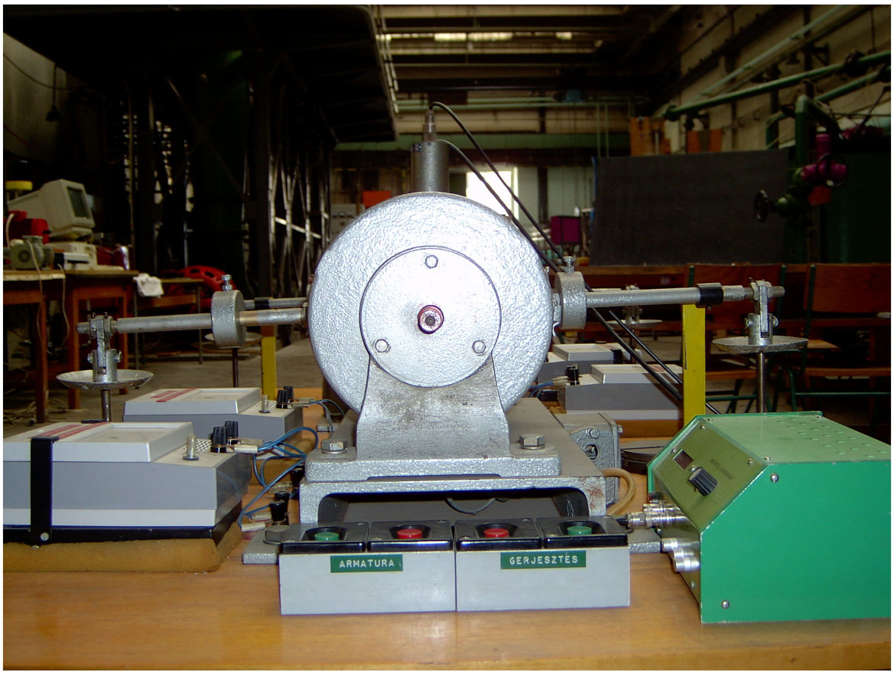




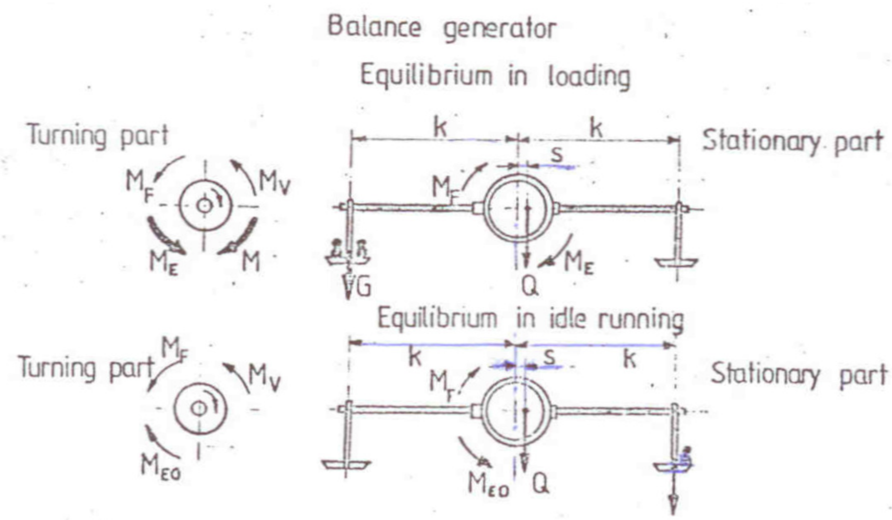


b) **Balancing machines** (motor or generator) are special machines, whose housing is free to rotate and arms are mounted onto it.





The equilibrium of the turning part is depicted below.



The balance generator is driven by the torque M. The equilibrium of the turning part (see Figure):

$$M = M_E + M_F + M_V$$

The equilibrium of the stationary part is:

$$M_E + M_F \pm Q \cdot s = G \cdot k$$

where

M is the shaft torque to be measured. This torque is produced by the power machine and is transmitted by the coupling to the rotating part of the generator,

M_E is the electromagnetically generated torque acting on the turning and stationary parts

M_F is the torque generated by bearing friction and brush friction,
M_V ventilation torque is composed of the torque caused by the friction of the air and the torque needed for the driving of ventilator delivering the cooling air.
G is the weight needed for balancing the stationary part,
k is the length of arm
Q is the weight of the stationary part
s is the distance of the centre of gravity of the stationary part from the vertical plane through the shaft.

Combining these equations result in:

$$M = G \cdot k + M_V \pm Q \cdot s$$

For determining the last two terms we have to make a measurement in idle running. In this case we operate the balance machine as a motor independently from the power machine and keeping the direction of the rotation.

Equilibrium of the turning part in idle run is

$$M_{E0} = M_V + M_F$$

And that of the stationary part is

$$M_{E0} = G_0 \cdot k + M_F \pm Q \cdot s \; .$$

From these two equations:

$$\underline{M_V \pm Q \cdot s = G_0 \cdot k}$$

*Finally, the torque is to be measured in **generator** running is*

$$M = (G + G_0) \cdot k \; .$$

With a similar train of thought, *the torque is to be measured in **motor** running is*

$$M = (G - G_0) \cdot k \; .$$

3. The measuring exercise

The test rig

The group of machines consists of a balance motor driving a balance dynamo connected by clutch.

During the measurement, the following quantities are measured at each point:

- balance mass *m*
- voltage *U*
- current *I*

Plus the balance arm length *k* has to be measured once.

The load will be increased by increasing the resistance at the output of the generator, as if the electrical consumption of the generator would be increased. Note that by increasing the load, the revolution number will decrease (just the same as the car slows down if a steep uphill is reached), thus before actually starting to measure, one has to re-set the constant revolution number of 2000 rpm.

Equations

The task is to determine the losses and the efficiency of the balance motor (student group *M*) and the balance generator (student group *G*) as a function of load at n = 2000 r.p.m. constant speed of rotation. The actual equations are as follows.

The idle measurement resulted in:

$$m_0 = 0.02kg \ , \ G_0 = m_0 \cdot g$$

The output torque of the **motor** is

$$M = (m - m_0) \cdot g \cdot k \ .$$

The input torque of the **generator** is

$$M = (m + m_0) \cdot g \cdot k \ .$$

In both equations, the arm length k is to be measured on site.
The revolution number is kept constant 2000 rpm.
The mechanical power is

$$P_m = M \, 2\pi n$$

The electric power is

$$P_e = UI \ ,$$

both of which is measured directly.

<u>For the calculation of the load</u> we need the nominal effective useful power (output):

Generator (dynamo): $P_{nom,gen} = 1540 W$

Motor: $P_{nom,motor} = 1300 W$

In the case of the generator, the input power is mechanical and the output is electrical (generators is driven by some prime mover – air or wind turbine, internal combustion engine or, as in our case, electric motor) to produce electric power, thus

$$x_{gen} = \frac{P_e}{P_{nom,gen}} \qquad \text{and} \qquad \eta_{gen} = \frac{P_e}{P_m}$$

Contrary, motors are used for producing shaft power and the input power is electrical, hence

$$x_{motor} = \frac{P_m}{P_{nom,motor}} \qquad \text{and} \qquad \eta_{motor} = \frac{P_m}{P_e}$$

Post-processing the measured data

The table on the following page will be used for calculations.

When done with the measurements, you have to fill in the table and calculate the required quantities.

Then, the curves $P_{useful}(x)$, $P_{input}(x)$, $P_{loss}(x)$ and $\eta(x)$ are to be plotted into the same graph.

# of meas. point	Measurement				Evaluation								
	n	U’	I’	M	ω	U	I	P_{el}	M	P_{mech}	x	η	P_{loss}
	1/min	div.	div.	kg	rad/s	V	A	W	Nm	W	-	-	W
1.													
2.													
3.													
4.													
5													
6													
7.													
8.													
9.													
10.													

4. Preparation questions

1. Describe at least three devices for measuring revolution number.
2. Describe two ways of measuring the torque.
3. Describe the aim and process of measurement. What quantities are to be measured? What will be the result of the measurement?
4. Make a sketch of the test rig and explain for what the different elements are used.