MEASUREMENT 2

MEASUREMENT OF TORQUE AND EFFICIENCY (BALANCE MACHINES)

Introduction:

In the everyday practice the machines (power and working machines) around a mechanical engineer are usually rotating machines. The most common power machines, like electric motors or internal combustion engines, can convert the electrical or the internal energy of the fuel into mechanical work (e.g. rotation). Working machines, on the other hand can use rotational energy for specific applications, like pumps conveying a fluid or dynamos generating electricity. Common characteristic parameters of rotating machines are the speed of revolution (or angular velocity) and the torque.

Measurement of torque:

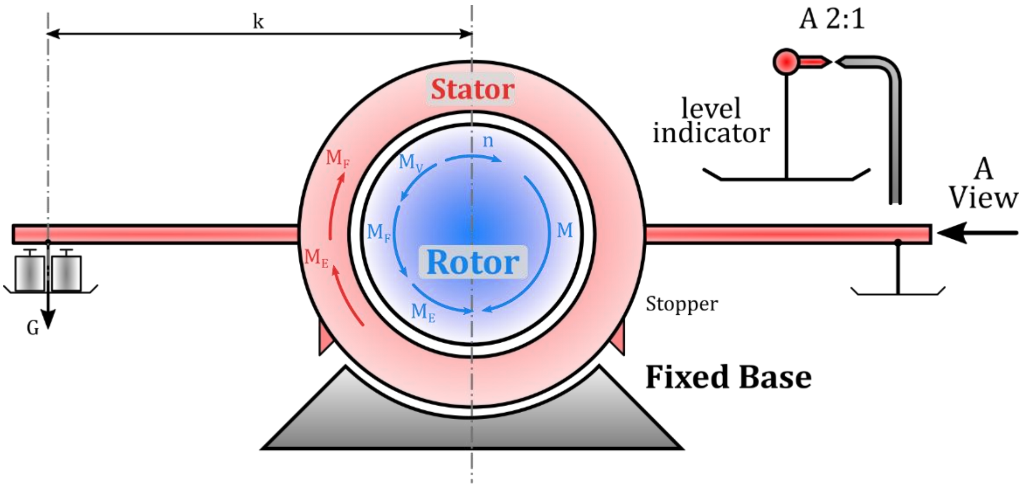
There are many ways to determine the amount of torque transmitted on a shaft. One possible way is to measure the deformation (twisting) of the axle with a strain gauge, as the deformation is proportional to the amount of torque. This is one of the most common type of measurement technique and You will learn about them in your engineering studies later-on.

In this measurement, the torque will be determined by a balancing machine (balance generator and balance motor). The **balance generator** is capable of measuring the supplied torque of a power machine and a **balancing motor** is capable of measuring the amount of torque, that a working machine can use up.

The principle of a balancing machine can be summed up as it follows. Normally, the housing of an electrical motor (or a generator) i.e., the stator should be fixed to a base, so it does not move due to the electromagnetic field interaction during a normal operation. However, when we want to measure the torque the housing is not entirely fixed to the base. The bearings allow the rotation of the stator (up to a fixed angle), and so the electromagnetic field interaction can rotate the stator.

In a generator the rotor (that’s been driven) tries to pull the stator with itself, while in a motor the rotor pushes away itself from the stator, thus generating torque in the opposing direction.

The torque generated in this way can be measured by known weights which we can put on an arm that is fixed to the stator. The amount of weight on the arm counteracts the generated torque (*Fig. 1*).



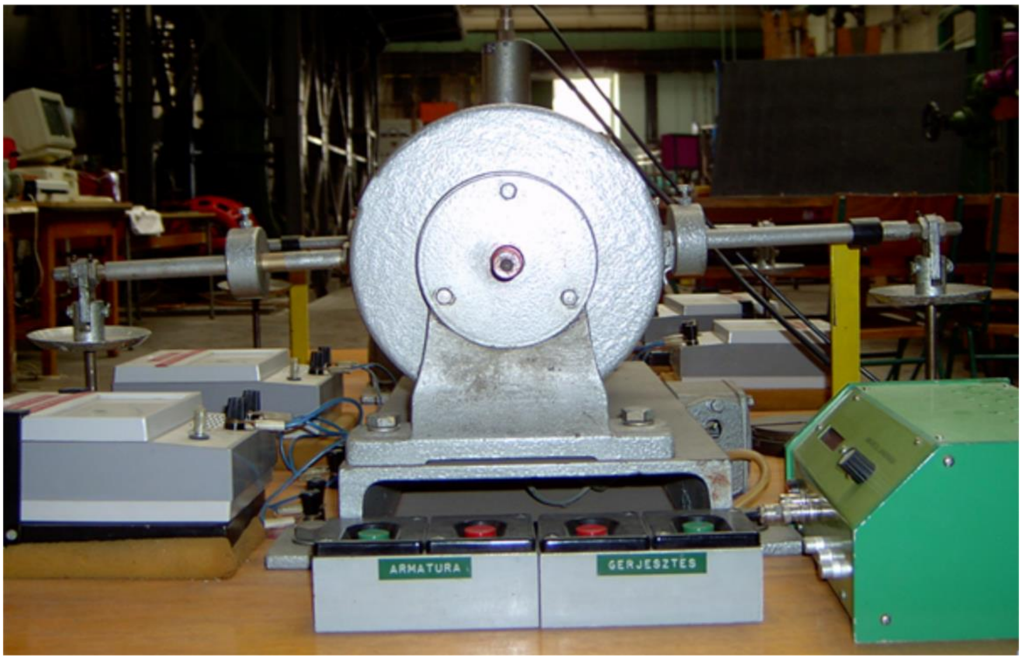


Figure 1: Torque equilibrium of the balance generator (top), image of the generator (bottom).

The torque equilibrium on the stator and rotor will be analyzed, and other – comparably small - sources of torques will be taken into consideration too. In the equation the following quantities will be used:

M is the 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 is the ventilation torque, which is composed of the torque caused by the air resistance and the torque needed for the driving of the ventilator delivering the cooling air,

G is the weight needed for balancing the stationary part,

k is the arm length, where the weight is placed.

Torque equilibrium on the **generator's rotor**:

$$M = M_E + M_F + M_V \tag{1}$$

since the measured torque is accounting for the ventilation and the friction torque.

The equilibrium on the **stator** – with the balancing weights – while the arms are horizontal:

$$M_E + M_F = G \cdot k \tag{2}$$

since the ventilation torque – unlike to the electromagnetic and friction torque – is not transmitted toward the stator.

The equilibrium of the stator is set if the indicators mounted on the stator and the base are aligned (the arms are horizontal). By substituting (2) into (1) we get:

$$M = G \cdot k + M_V \tag{3}$$

For the determination of the second term, we have to perform measurements in idle run. During the idle run measurement, the generator must be decoupled from the power machine so that the motor only encounters the inertial losses ($M_F + M_V$) (see *Fig. 2.*).

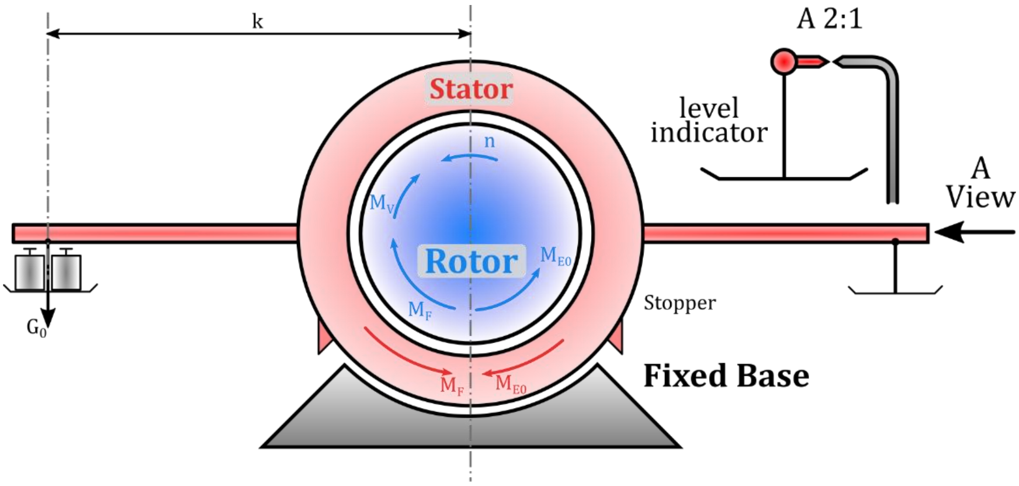


Figure 2: Equilibrium of the motor in idle run.

Torque equilibrium of the rotor in idle run:

$$M_{E0} = M_F + M_V \tag{4}$$

The stator:

$$M_{E0} = G_0 \cdot k + M_F \tag{5}$$

After substitution:

$$M_V = G_0 \cdot k \tag{6}$$

Substituting (6) into (3) we get the torque for the **generator** operation:

$$M = (G + G_0) \cdot k \tag{7}$$

After similar derivation, the torque for the **motor** operation:

$$M = (G - G_0) \cdot k \tag{8}$$

Generally, the idle run measurement should be repeated for other speeds of revolution , and a diagram should be appended to the balance machine. The **sign of G_0** depends on which side we placed the weights during the idle measurement, and how we operate the balance machine (generator or motor mode).

The measurement exercise:

The test rig consists of a DC balance motor and a generator connected with a clutch depicted in *Fig. 3*.

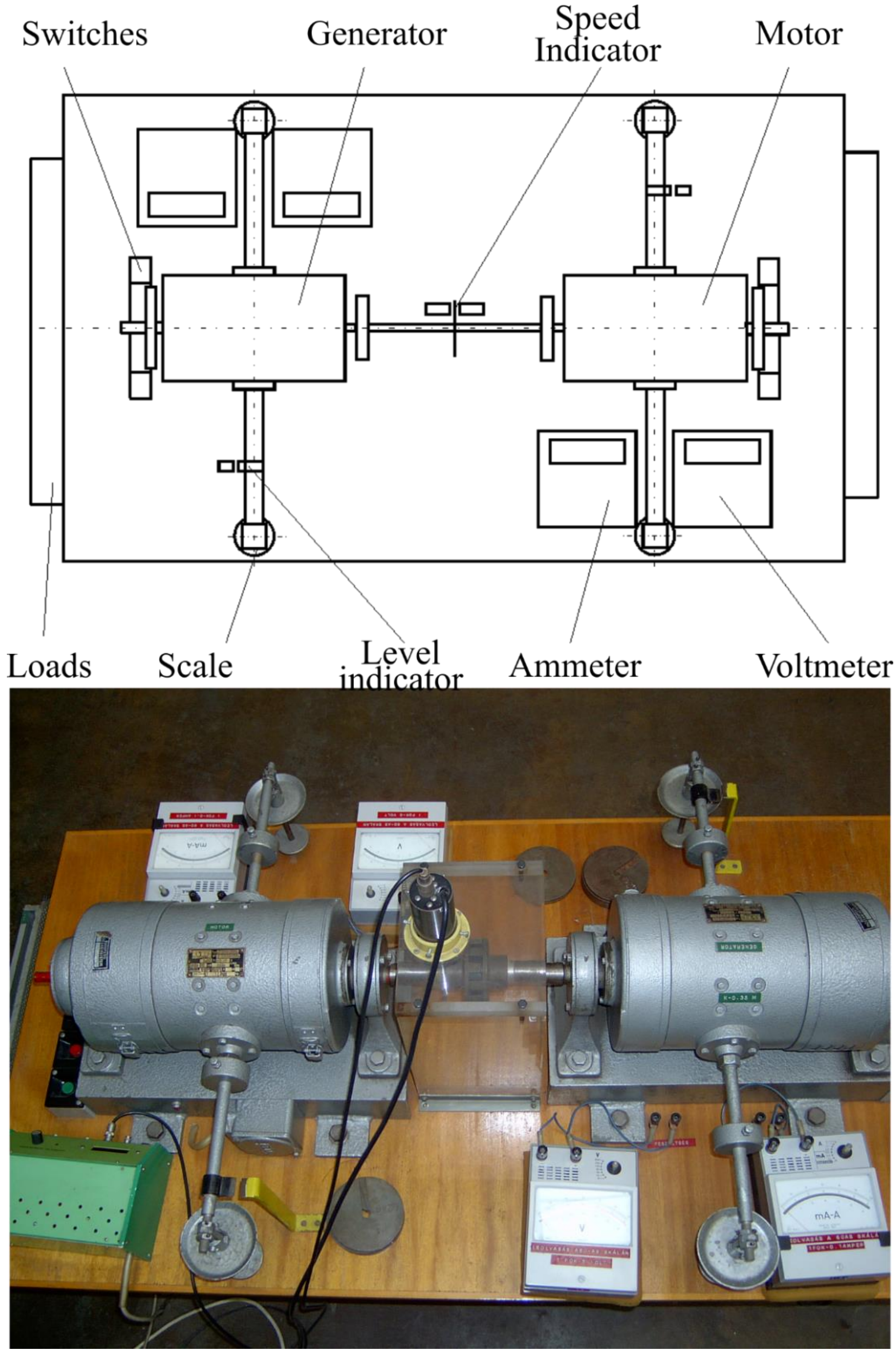


Figure 3: Sketch (top) and image (bottom) of the test rig.

The aim is to measure the efficiency of the balance machine (some groups will measure the generator side; others will measure the motor side) under different loads at $n = 2000\ RPM$.

The **load factor x** is the ratio of the useful and the nominal power:

$$x = \frac{P_u}{P_n} \tag{9}$$

The efficiency of an electric machine **(η)** is the ratio of the useful $\boldsymbol{P_u}$ and input $\boldsymbol{P_{input}}$ power:

$$\eta = \frac{P_u}{P_{input}} \tag{10}$$

The **efficiency** of the electric machine **(η)** depends on **(x)** and takes the shape as depicted in *Fig. 4*. The **useful P_u** and **input P_i** power in function of the **load factor** can be seen on the diagram as well.

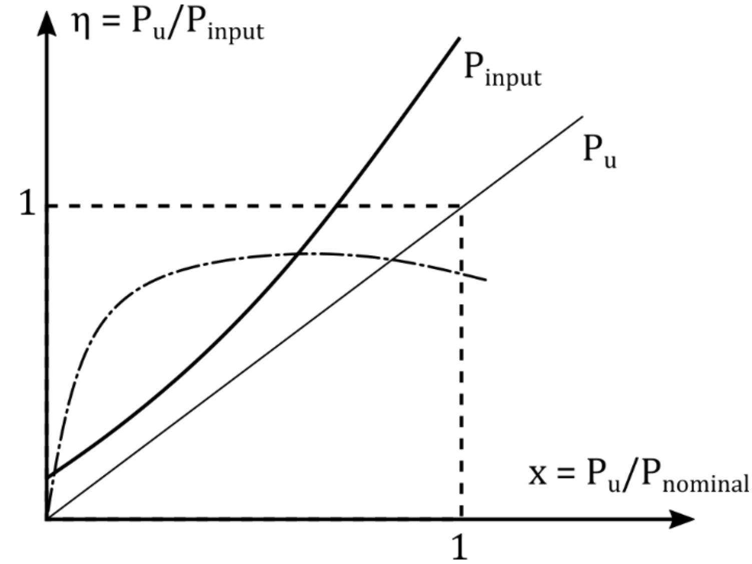


Figure 4 Characteristic curves of a balance machine.

The **electric power** – which is the input power for the motor and the useful power for the generator – will be measured by reading out the ammeter and the voltmeter for the current and the voltage, respectively. Additionally, a multiplier constant (**C_V** and **C_A**) has to be recorded, so that after the multiplication we can obtain the voltage and current in volts and amperes, respectively. (measuring regions: 6 A and 300 V) (*Fig. 5 and 6*)

Figure 5: Ammeter.

Figure 6: Voltmeter.

The mechanical power - which is the input power for the generator and the useful power for the motor – comes from the amount of torque needed to balance the machine (balancing weights times arm length) and the speed of revolution. Both of them are given: **n = 2000 RPM** and $\mathbf{m_0}$ **= 0.02 kg**.

Using these data:

$$G_0 = m_0 \cdot g$$

The produced torque by the motor:

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

By the generator:

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

The speed of rotation can be measured with the speed indicator. To calculate the load factor we need the nominal power of the electric machine. For the **generator mode** the nominal voltage and current can be found on the name plate of the machine:

$$P_{1G} = 1540\ W$$

The nominal power of the motor is the power when the machine is operated under the nominal voltage and current, and it was obtained by a precursor measurement:

$$P_{1M} = 1300\ W$$

Summary:

- The task is to measure the efficiency of the balance motor (or generator) at the constant speed of revolution of 2000 RPM. (Half of the students will measure on the generator side and the other half will measure the motor side).
- The measurement has to be repeated at 10 incrementally increased loads. At each point of operation, the students have to record the balancing weight for the generator/motor, the current and the voltage. From the obtained data, the input and useful power, then the load factor (**x**) and the efficiency (**η**) shall be calculated.

Evaluation:

The report should contain the serial numbers of the balancing machine and all of the measuring instruments used during the measurement. The rows should be filled in by increasing order of the load factor. The measurement groups should contain three or four people, and each of the students should calculate 3-4 rows, then at the end of the evaluation the group should write together all the individually calculated data. Finally, all the students should draw the η(x) diagram individually.

Equations used in the evaluation process:

Current: $I = I' \cdot C_A$

Voltage: $U = U' \cdot C_V$

Electric Power: $P_{electric} = U \cdot I$

Mechanical Power: $P_{mech} = (m \pm m_0) \cdot g \cdot k \cdot 2\pi n$

Load Factor: $x = \frac{P_u}{P_1}$

Efficiency: $\eta = \frac{P_u}{P_{input}}$

The sign before $\mathbf{m_0}$ in the equation for the mechanical power and the quantities in the equation for the load factor and efficiency depend on whether the measurements are about a generator or a motor.

The efficiency in the function of load factor diagram have to be prepared on an A4 millimeter paper. Be careful about the diagram scaling (1 unit should be either 1, 2 or 5 cm)**!** On the diagrams, the title, the revolution number, the name and Neptun code of the student have to be listed.

PREPARATION FOR THE MEASUREMENT

- Bring one A4 millimeter paper for the measurement!
- There will be a short test beforehand about the measurement. The test will be about the measurement principles and the formulas used in the evaluation. (Test questions can be found on our webpage.)
- Up to section 4. the lab report template should be done before the measurement. (The corresponding teacher will inspect the forms.)

All the questions about this measurement description should be addressed to bcsippa@hds.bme.hu