TECHNICAL UNIVERSITY OF LODZ

INTERNATIONAL FACULTY OF ENGINEERING

MEASUREMENTS

<u>LABORATORY EXERCISE # 1</u>

INPUT MEASURING TRANSDUCERS

1. Aim of the exercise

The laboratory exercise is aimed at recognising:

- methods of transformation of measured quantities;
- individual elements of a measuring system, with special emphasis on measuring transducers;
- a method of practical determination of basic, static properties of measuring transducers on the basis of measurements made on a shaft's rotational frequency.

2. Introduction

Signal transformation is a basic activity carried out in the measuring process. It allows one to replace a given measurement signal with an equivalent one that is more convenient for data transmission. Measurement signal transformation allows one to:

- obtain the physical measured quantity in a chosen form (mechanical, electrical, pneumatic, optical signal, etc.) with a required amplitude or power,
- apply one standard to measure different quantities,
- use universal elements of the measuring path (amplifiers, recording instruments, etc.) in measurements of various physical quantities.

In the present exercise, the measured rotational frequency of a rotating shaft is transformed into mechanical, electrical (analogue and digital) and pneumatic signals, whose values can be read on a voltmeter, a pressure gauge, a liquid-column microgauge, and an analogue and digital frequency meter.

A recent development in methods of measurement, including automation and computerisation of measuring processes, has made fast transformation and transmission of measurement signals possible via an electrical way. Numerous electronic blocks that can be combined with suitable measurement systems have been developed and can carry out (with high accuracy in general) highly specialised measurement procedures. These systems equipped with (the so-called input) transducers of various measured physical quantities allow for the measurement of any quantity in practice. In many instances electrical input transducers (i.e. their accuracy, hysteresis, interaction of outer disturbances, dynamic properties) limit in a vital way a possibility of obtaining accurate measurements with this method.

Employing different physical phenomena, numerous input transducers have been developed. They differ in static and dynamic properties, a reaction to outer factors, etc. The knowledge of these properties in the majority of cases is indispensable to build a suitable measuring system that fulfils the requirements imposed by an experimenter.

The properties and parameters of most electronic devices are provided by its manufacturers, whereas in the case of measuring transducers this data is often incomplete. Custom made transducers produced individually or in short series have to be tested to obtain the necessary parameters.

This exercise allows one to learn how to determine basic static properties of various input transducers using rotational frequency transducers. The subsequent laboratory exercises are devoted to determination of their dynamic properties, an influence of outer factors (temperature) on the transducer operation, etc.

3. Description of the test rig

The general view of the measuring installation is presented in Fig. 3.1. The measured quantity is the rotational frequency *n* of the shaft (1) that has slide bearings and is fixed to a base by two supports. An alternating-current electric engine (2) drives the shaft. To change the engine rotational frequency an autotransformer (3) must change the engine's voltage supply.

The measuring installation is equipped with six different frequency transducers, whose input signals include: mechanical displacement, voltage (value and frequency of changes) and gas pressure. Some of these signals are in the form of discrete (digital) signals and some are analogue (continuous) signals.

During this exercise the static calibration of the frequency transducers installed will be done by comparing their indications to those of a standardised instrument. This is called the comparative method.

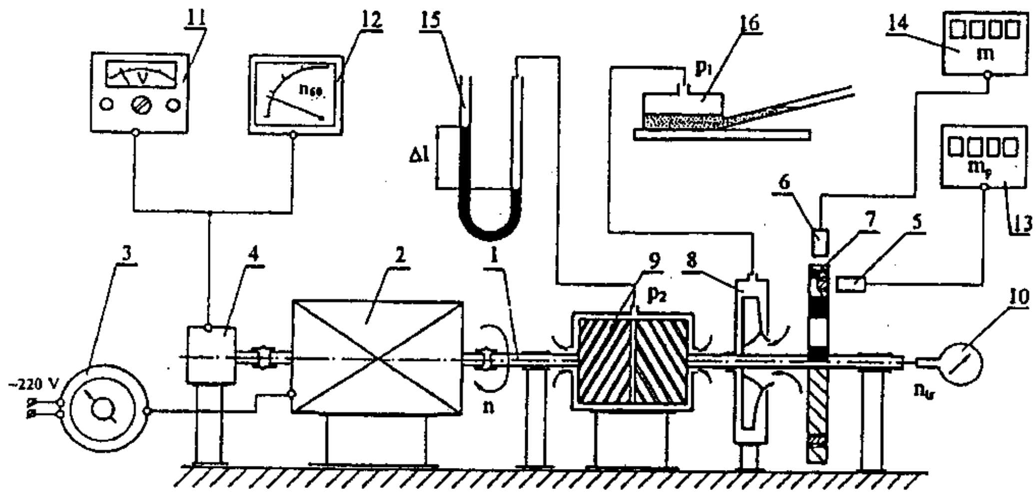

Fig. 3.1. Schematic view of the measuring installation
1 – rotating shaft; 2 – drive engine; 3 – autotransformer; 4 – rate generator; 5 – inductive converter; 6 – optical converter (laser); 7 – rotating disk (modulator); 8 – pneumatic transducer; 9 – pneumatic transducer; 10 – mechanical transducer; 11 – voltmeter; 12 - analogue frequency meter; 13,14 – digital frequency meters; 15 – U-tube manometer; 16 - micromanometer

The optical converter (laser, 6), which shows results through a digital frequency meter (14), will be assumed as standard (reference) instrument. A laser diode and a miniature receiver are mounted in the converter head. The luminous flux emitted by the laser falls on the duralumin disk fixed on shaft (1), reflects off of it, and falls on the receiver that converts it into an electrical signal. Disk (7) is a modulator of the luminous flux and twenty light and dark fields have been marked alternately on its surface. The luminous flux falling on the dark field is absorbed, whereas it reflects from the light field and falls on the receiver. Discrete electrical signals obtained from the output are counted with counter (14). The number *m* of counted impulses in a time unit is a function of the rotating frequency of disk (7) and of the number of light and dark fields marked on it, so $m=n\cdot 20$.

Moreover, the installation is equipped with:

- rate generator (4),
- two pneumatic frequency transducers (8) and (9),
- inductive frequency converter (5),
- manual tachometer (10).

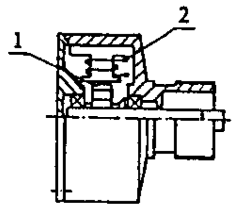

Fig. 3.2. Rate generator:
1 - permanent magnet of the rotor,
2 – windings of the stator

The rotor of the rate generator (Fig. 3.2) has been coupled with the rotor of the measuring installation drive engine. The electromotive force SEM induces in the rate generator stator windings under the influence of the displacing magnetic field generated by the rotor magnets. The value of the induced voltage is proportional to the rotational frequency of the rotor. The output signal from the rate generator can be:

- value of the voltage generated,
- frequency of changes in this voltage.

In the first case the rate generator cooperates with a voltmeter calibrated and graduated in frequency units, and in the second case with a frequency meter (rpm). A measurement signal in the form of changes in frequency has much better metrological properties – it is much more resistant to outer disturbances than a signal in the form of changes in voltage values. In the measuring installation the transducer voltage signal is used only. This signal is transmitted to two voltmeters: the first one graduated in voltage units, the second one in frequency units.

In duralumin disk (7) there are six steel inserts in holes co-operating with inductive converter (5) that has a fixed coil and a magnetic field (a change in the magnetic flux pulse is caused by a passing by steel insert). The principle of operation of the converter is presented schematically in Fig. 3.3. A discrete output signal from the converter is transmitted to digital frequency meter (13), type C 549A.

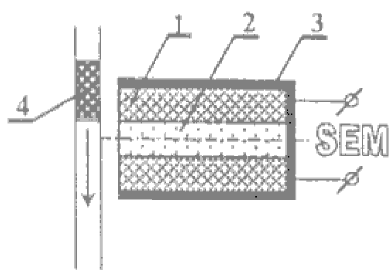

Fig. 3.3. Inductive converter
1-inductive fixed coil,
2-magnet,
3-shield,
4-moving ferromagnetic material (steel insert)

The result of the measurement with the inductive converter is the number m_{pi} of electrical impulses counted in a time unit, and thus it is a function of the rotational frequency n and the number of steel inserts placed in disk (7), $m_{pi} = n \cdot 6$.

There are also two pneumatic transducers of the rotational frequency mounted in the measuring installation. The first one is a typical transducer met in pneumatic control systems. It is made in the form of a miniature fan mounted on the shaft that is directly coupled with the rotating element whose frequency is to be measured. The air sucked from the surroundings is compressed in a small chamber. The value of the pressure p that forms in this chamber is a function of the rotor rotational frequency n – it is a non-linear relationship:

$$p = k\, n^r \tag{3.1}$$

where *k, r* are constants that depends on the design of a given transducer. At low values of the rotational frequency, the value of pressure *p* is small and difficult to be measured with high accuracy. In the measuring installation this measurement is performed with a Berlowit's micromanometer (Fig. 3.4). A detailed description of the pressure measurement with a liquid – column gauge is given in Exercise #2 (clause 2).

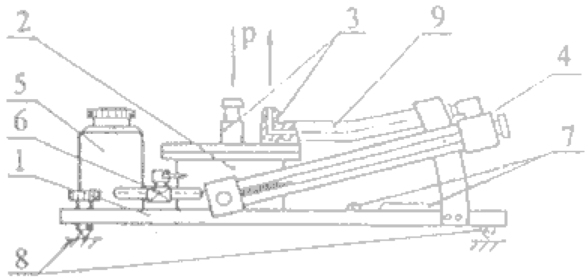

Fig. 3.4. Inclined micromanometer: 1 - base plate, 2 – vessel, 3 – connector pipes, 4 – inclined tube, 5 – manometer liquid reservoir, 6 – cut-off valve, 7 – level indicator, 8 – stems, 9 – elastic pipes

Vessel (2) with a manometer liquid has been mounted on metal plate (1). A tube positioned at an angle α with respect to the plate (1) plane is connected to this vessel. The angle α defines the position *i* of the micromanometer, which in the applied design of the manometer can assume values: 2, 5, 10, 20, and 50 (which corresponds to the position of the tube at the angle α equal to, correspondingly: 30^0, $11^0 32'$, $5^0 11'$, $2^0 52'$ and $1^0 9'$ with respect to the horizontal plane). Two level indicators mounted on the base plate allow for its positioning in the horizontal plane by means of stems (8) with adjustable height.

The measured pressure is transmitted by means of connector pipes (3), which allow for measurement of a pressure difference. The measured pressure is expressed as a difference between the liquid levels Δl in tube (4) and vessel (2).

$$p = \frac{\Delta l \rho_{cm} g}{i} \tag{3.2}$$

where: ρ_{cm} – manometer liquid density,
g – acceleration of gravity,
i – ratio of the micromanometer (inclination coefficient).

The liquid level in vessel (2) can be read from the tube when no pressure is supplied to the manometer. A proper selection of the diameters of tube (4) and vessel (2) assures a constant liquid level in vessel (2) in practice, irrespective of the value of the pressure measured. The level in vessel (2) can be changed by lifting or lowering reservoir (5) after valve (6) is opened.

The second pneumatic transducer of the rotational frequency installed in the measurement system is an original design (patent of the Institute of Turbomachinery, TUL) characterised by the linear static characteristic:

$$p = k\, n \tag{3.3}$$

It has a significantly higher value of the measurement signal (pressure *p* is measured with U-tube manometer (15)).

This transducer is made from of a rotating cylinder (with notched helical grooves) that is placed in a fixed cylinder. A selection of geometrical dimensions (width and depth of grooves, a gap between the rotor and the casing, etc.) assures a proper flow of the air sucked from the surroundings.

Manual tachometer (10) uses the property of dependence of a centrifugal force of rotating masses on the rotational frequency. A scheme of such a transducer is shown in Fig. 3.5. The centrifugal force *F* that is balanced by the spring (2) force acts on weights (1) with mass *m* located on the radius *r*

$$F = 4\, \pi^2 n^2 m\, r \tag{3.4}$$

The position of weights (1), being a function of the frequency *n*, is transferred by a lever system on sleeve (3), and next to the angular displacement of the measuring instrument hand. A change of the measuring range is carried out through the toothed gear (4) that changes the frequency of rotation of weights (1) in a step-like manner.

The tachometer used in the measuring installation has six ranges and a change in a measuring range takes place through a rotation of the tachometer head around the tachometer axis.

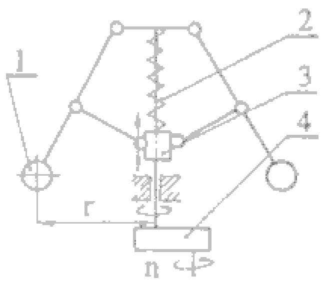

Fig. 3.5. Mechanical transducer of the rotational frequency:
1- weights,
2 - spring,
3 – sleeve,
4 – gear.

4. Description of the exercise

During this exercise the following has to be done:

- static calibration of the frequency transducers installed in the measuring installation at an increasing and decreasing rotational frequency of the shaft and to process the data obtained,
- measure a rotational frequency with the calibrated transducers.

4.1. Calibration of the rotational frequency transducers

Before the calibration, the relationships between the indications of the optical and inductive transducers and the rotational frequency *n* (output signal is a factor of the rotational frequency *n*) should be determined. The calibration is conducted at an increase in the rotational frequency *n* from 0 to n_{max} (the value provided by the instructor, at least 7 values of the rotational speed), and then at a decrease from n_{max} to 0 (at least 5 values of the rotational speed between n_{max} to 0). The values of the indications of the output devices are to be recorded in Table 1 of the report. All the transducers (except the manual tachometer) are to be calibrated simultaneously. The readings of the measuring instrument indications are to be done after the rotations become stable (simultaneously where possible).

The processing of the measurement results should comprise:

- presentation of the static characteristics obtained in a graphical form and by an analytical equation,
- determination of random uncertainties of the performed calibration and of basic parameters of the static characteristics (static sensitivity, non-linearity, hysteresis, class) for pneumatic transducer 1 (with the non-linear characteristics) – Table 2 of the report.

The characteristics of the calibrated transducers should be presented in the form of reverse transformation equation, i.e. the relation $n = f(y)$, (y - output signal of the transducer being calibrated).

For pneumatic transducer 1, an analytical equation describing changes in its sensitivity dn/dp should be determined.

Two sample static characteristics of both pneumatic transducers are presented in Fig. 4.1.

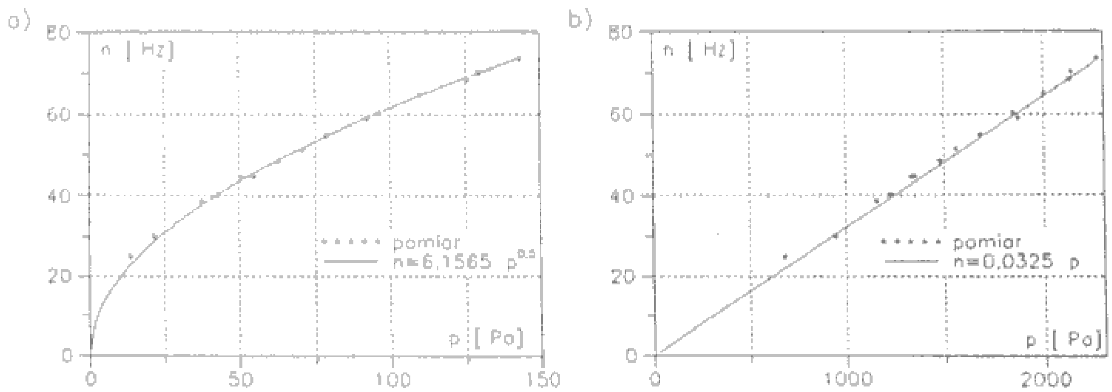

Fig. 4.1. Static characteristics of pneumatic frequency transducers (examples)

Random uncertainties, absolute Δn defined as a difference between the measured value n and the value n' calculated from the reverse transformation equation ($\Delta n = n - n'$) are to be presented graphically in the form of the relation $\Delta n = f(y)$.

4.2. Measurement of the rotational frequency

Rotational frequency measurements of the rotating shaft, for several different values, are to be performed with the calibrated transducers. The recorded values of output signals from individual transducers are to be recalculated as done in clause 4.1 to determine the shaft rotational frequency. On the basis of the results obtained, the average rotational frequency and a range of the averages are to be calculated. The results are to be presented in Table 3 and 4 of the report and conclusions are to be drawn in regards to the calibration performed.

5. Final remarks

The report should include:

- aim of the exercise,
- short description of the activities carried out,
- measurement tables,
- diagrams of static characteristics of the transducers under investigation, with the analytical equation that describes them plus calculations of the characteristic parameters for the Berlowit's micromanometer (nonlinear characteristics case)
- conclusions and remarks concerning the exercise.

Check questions:

- *static characteristics of the instrument and methods for its determination,*
- *in what form can the static characteristics of the measuring instrument be presented?*
- *parameters of the static characteristics,*
- *prove why the instrument static characteristics are needed to make measurements,*
- *influence of time-variable outer factors during the measurement on the instrument static characteristics,*
- *classification of measuring transducers,*
- *what is the difference between a generating and parametric transducer?*
- *at what angle should the inclined tubes of the micromanometer be placed to make its ratio equal 8.0?*