Evaluation of random errors in the measurement of pressure

This task deals with the evaluation of data and identifying various random errors of measurement readings.

Assignment

1. Accurately measure overpressure in the measured object.
2. Identify random errors of individual readings, and the arithmetic average for a set of 10, 20 and 30 measurements and compare their sizes.
3. Construct an empirical error rates curve for a given set of measurements and evaluate their progress.

Connection diagram

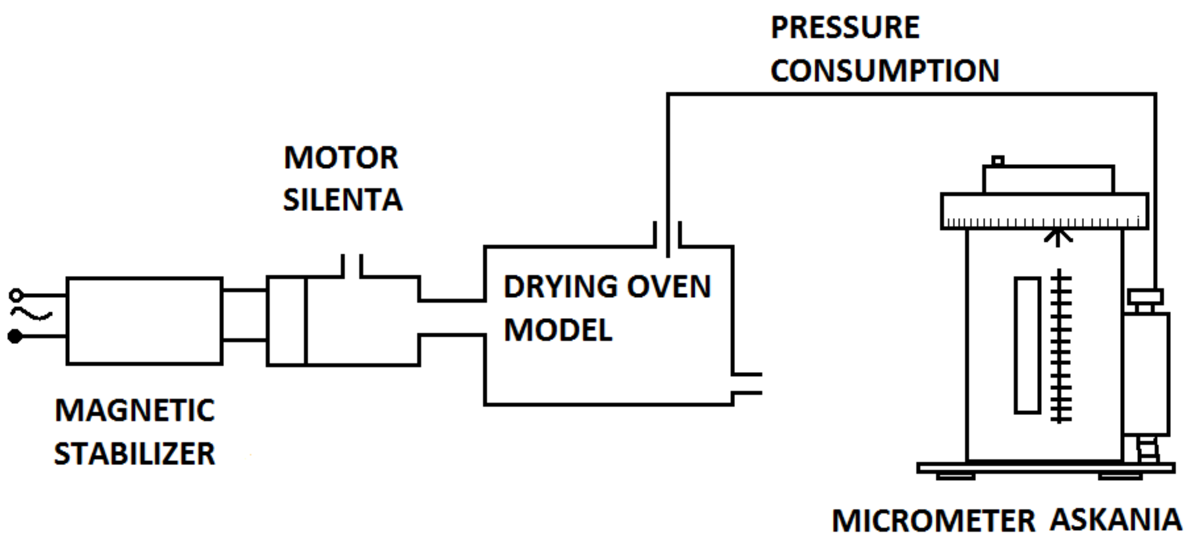

Fig. 1 Block diagram

Theoretical analysis

a) Random errors (constancy errors) of individual measurements or the arithmetic average can be determined only from multiple measurements and statistical methods. They shall calculate the arithmetic average of the n measurements and are closer to the actual value of the measured quantity. We are talking about that the arithmetic mean $\bar{x}$ is best estimate of the true value x_S :

$$\bar{x} = \frac{\sum_1^n x_i}{n} \qquad (1)$$

In practical calculations we choose the number of measurements usually quite small, eg. n = 10 or even n = 5. Gauss (normal) distribution law of random errors assumes that the relative frequency or probability density error is expressed as:

$$\varphi(\varepsilon) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{\varepsilon^2}{2\sigma^2}} \qquad (2)$$

Where $\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n} {\varepsilon_i}^2}$ is the root mean square deviation.

Progress of $\varphi(\varepsilon)$ is shown in Fig. 2.

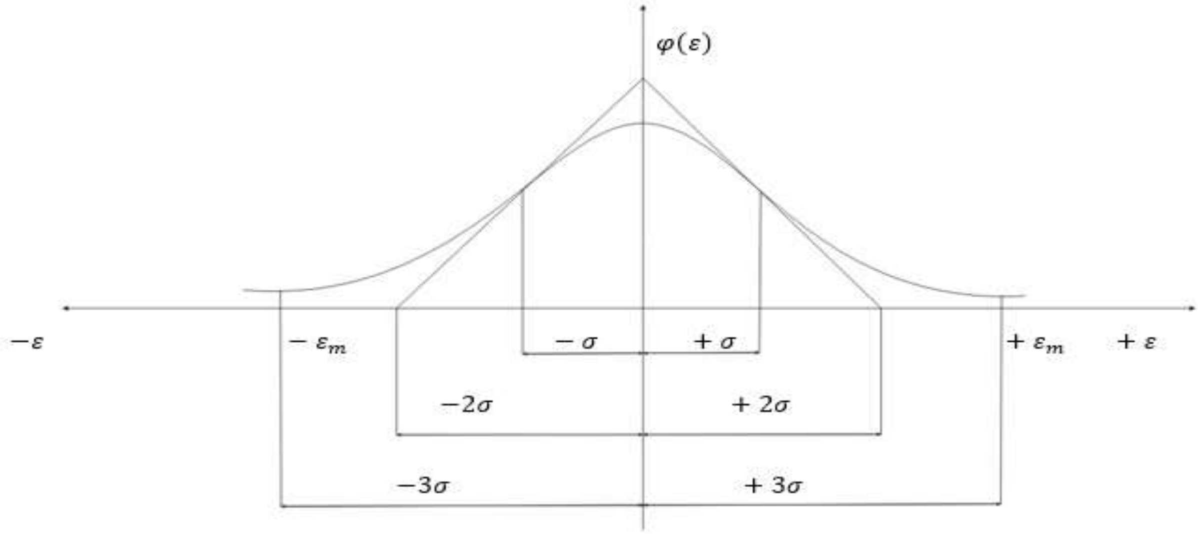

Fig. 2 Normal Gauss distribution law of random errors

For a number of measurements $n \ll \infty$ - as it is often in practice, mean square deviation can only be estimated. One measurement error estimate S_x can be expressed as:

$$S_x = \pm k\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\bar{x} - x_i)^2} \qquad (3)$$

Because it theoretically can also occur at relatively large errors (but considerably with low probability), it is possible to estimate the measurement errors also described as probability with witch there is a larger actual error in the errors less than the calculated error. Relationship between the ranges of the confidence interval $\pm\varepsilon_m$(i.e. k-multiple of the mean quadratic deviation σ) and the probability that the true value of x_S is within the limits of this interval is shown in the following table 1.

In practice, we choose the size of the confidence interval and thus the coefficient k = 3, this means that the limit (maximum) random error $\pm\varepsilon_m = \pm 3\tau = \pm 3S_x$, so the probability that the real measured value x_s is in the range $\pm 3S_X$ is 99,73%, which is a large enough value . Individual measurement error estimates S_X is the estimated error of each individual readings (regardless actually performed error) and is calculated so that we know with what error the unit continues to be measured at approximately the same conditions. More frequently used estimate of the random error of the arithmetic mean $S_{\bar{x}}$ which is given by 4.

Table 1

$\varepsilon_m = \pm k\tau = \pm kS_x$	The probability of occurrence values x_s
0,5	0,383 0
* 0,6745	0,500 0
1,0	0,682 7
* 2,0	0,954 5
* 3,0	0,997 3
4,0	0,999 937
5,0	0,999 999
* The most commonly used size of coefficient k	

$$S_{\bar{x}} = \pm k \sqrt{\frac{1}{n(n-1)} \sum_{i=1}^{n} (\bar{x} - x_i)^2} \qquad (4)$$

b) The procedure for constructing the empirical error rate curve corresponding to approximately Gauss normal distribution of random errors:

1. We bring the size of both positive and negative apparent deviations $\Delta_i = \bar{x} - x_i$ on the horizontal axis of Fig. 3. We mark each individual error on this axis with ring.

2. We bring the total number of departures Δ_i on the vertical axis.

3. We select the appropriate size of the interval I for the horizontal axis and draw it on an assistant paper (eg. $1/5 \leq \Delta max, +\Delta$ max ≥ 1 Pa)

4. We move with this interval in appropriately small steps (eg. 1/5 I) on horizontal axis from one side to the other and gradually find out the number of the deviations Δ_i in that interval I, which we bring on the vertical axis in the middle of interval I in scale (see example in Fig. 3).

5. Final stepped curve would be for a sufficiently large number of measurements n (n>100), sufficiently small interval I and step feed be close to Gauss normal distribution of errors, provided that gross and systematic errors are excluded. To thus obtained curve we plot the calculated errors$S_{\bar{x}}, S_x$.

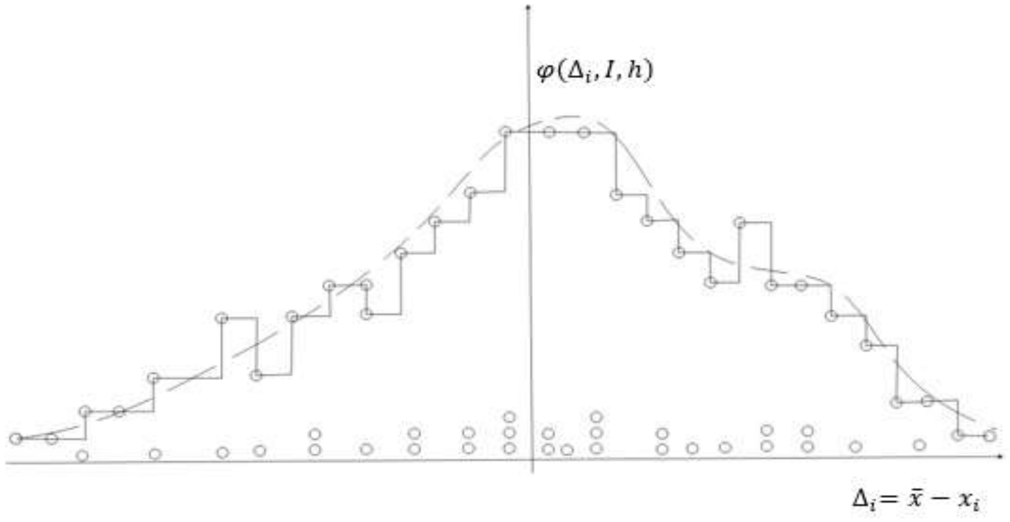

Fig. 3 Construction of the empirical distribution curve of random errors

Measurement procedure

1. Before the measurement, we perform adjustment of micromanometer Askania (Fig. 4) to zero for a given barometric pressure.
2. We will plug in fans via magnetic voltage stabilizer to eliminate errors due to voltage fluctuations. We will switch the ventilator into operation after stabilization run (about 20 minutes), then we can measure the pressure of the compressed air device - a drying oven model. The first 10 measurement test is performed to eliminate the personal error in readings of pressure from micromanometer.
3. We will measure the average static pressure at the supply point for a 30 times. For these measurements it is necessary to keep constant all the factors affecting the measurement (one observer performing reading of values, varying fan speed…)
4. Micromanometer data will be considered without systematic errors. For the first 10, 20 and 30 readings we will calculate the average, in order to evaluate differences in measurement results. For each number of measurements n = 10, n = 20, n = 30 we will calculate the estimate of the error of the arithmetic mean according to equation (4). Bring the sizes of reached errors in the table and graph and evaluate them!
5. From a total of 30 measurements and their individual deviations Δ [Pa] construct empirical Gauss curve of errors. Perform analysis of its process, evaluate the impact of systematic errors on the measurement, draw the curve of confidence intervals corresponding errors $S_{\bar{x}}, S_x$.

Table 2 Table of random measurement errors pressure

n	$S_{\bar{x}}$ [Pa]	S_x [Pa]
10		
20		
30		

Addiction on the size of random errors of measurement

Table 3 Air pressure measurements and calculations of random errors.

P_i $[mmH_2O]$	P_1 $[Pa]$	$\Delta = p_{10} - p_1$ $[Pa]$	Δ^2 $[Pa^2]$	$\Delta = p_{20} - p_1$ $[Pa]$	Δ^2 $[Pa^2]$	$\Delta = p_{30} - p_1$ $[Pa]$	Δ^2 $[Pa^2]$
P_1 P_{10}							
	$\bar{P}_{10}$	$\sum_{i=1}^{10} (\bar{P}_{10} - P_i)^2$					
P_{11} P_{20}							
	$\bar{P}_{20}$			$\sum_{i=1}^{20} (\bar{P}_{20} - P_i)^2$			
P_{21} P_{30}							
	$\bar{P}_{30}$					$\sum_{i=1}^{30} (\bar{P}_{30} - P_i)^2$	

Control questions

1. Indicate the method of calculation of random errors in the n values.
2. What is the difference between the estimate errors of the individual measurements and the estimation arithmetic mean?
3. What expresses Gauss normal distribution of errors, which is given by the equation?
4. Explain the principle of compensation micromanometer.

Answers to questions

Attachment n. 1 Compensation micromanometer "Askania"

This micromanometer measures the pressure or differential pressure of about 0,02 kp/cm^2 (200 mm v.s.) = 1961,33 Pa exact measurement of the level difference cartriges (water) in continuous containers. Resolution is half scale interval ie. 0,005 mm v.s.

Micromanometer adjustment to zero is carried out with the involvement of the source pressure. With screw Š and according to a scale with fine splitting S on the head of the screw H is container N set to zero. The entire micromanometer is set to prescribed positon with help of adjusting screws on the base. Then the level of measurement vessel M is adjusted using the adjusting nut A to zero. In this adjustment the tip must just touch its mirror image on the surface. (For very accurate measurement, the balance is set at a smaller positive value).

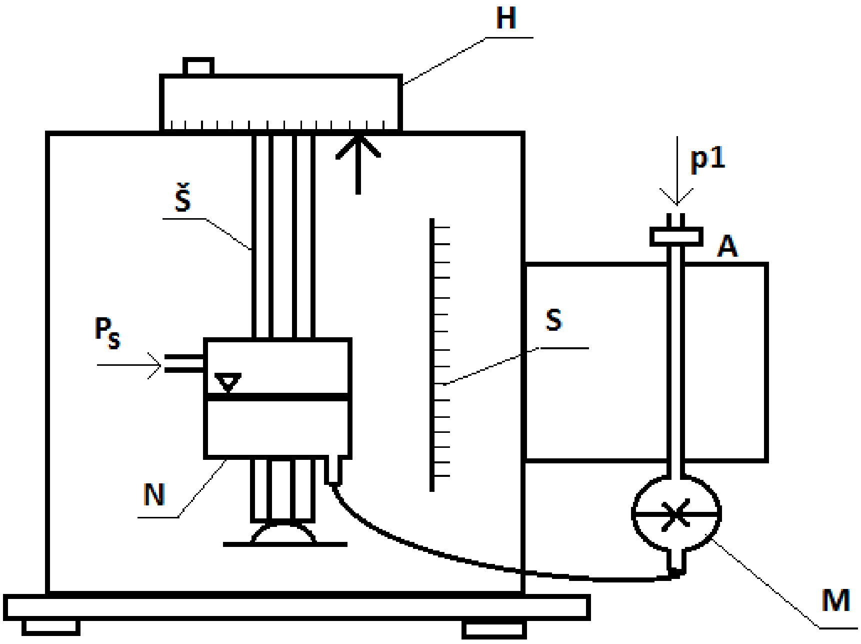

Fig. 4 Micromanometr Askania

Then screw set the estimated value of the pressure and the measured pressure or differential pressure will join. With screw H we move with vessel N so that the tip of the compensating vessel just touch the surface. In this case the pressure P_s is equal to the hydrostatic pressure of a column of liquid. We read his height from the scales S and H with accuracy of 0,01 mm (1 piece on scale H). This information is converted according the filling to pressure units according to SI.