T2: Measurements with an analogue instruments

 Purpose: Learning measurements with analogue instruments, learning the principles of calculating uncertainty of a direct measurement with a single reading, i. e. type B uncertainty.

1. **Basic ideas**

**absolute error** – the difference between measured value X and correct (real) Xp; it is expressed in units of measured quantity; the following entry is adopted:

 

**relative (percentage) error –** absolute error related to corrected or measured value, usually Xp≈X; it is presented in percentages; the following entry is adopted:



1. **Errors in direct measurements performer with analog (pointer) devices**

The accuracy of the measurements is mainly influenced by:

* + **aparatus error**
	+ **reading error**
	+ **method error**

The apparatus error (basic) results from the accuracy class of the device. For electric analogue instruments, there are five accuracy classes: 0.2; 0.5; 1; 1.5; 2.5.

If the measurements are made in **the reference conditions**, i.e. in the external conditions mentioned in the standard or in the manual, the accuracy of the device is characterized by the **basic limit error** allowed by its accuracy class. The maximum posible error ΔgX results from the definition of the accuracy class:

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where: **-** nominal range of the device.

A calculation formula for determining the boundary error, the absolute measure is acquired by transforming above formula



 It is worth mentioning, that absolute limit error takes constant value, independent from measured value

 Relative limit error is calculated from the equation:

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where X is measured value.

 Equations above shows, that relative limit error is increases rapidly as the pointer deflection decreases, hence the criterion of making accurate measurements does not recommend measurements when the pointer is below the middle of the scale range.

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| **Rememeber!****Readings of analogue instruments should be done carefully without parallax error and with accuracy to the tenth part of elementary scale** **(np. α=63,1 div ; 67,0 div ; 122,7 div).** |

**Example 1:** Ammeter with range In = 5A and accuracy class 1, was used to measure 0,5A; 2,5A; 5A currents. What are the limit errors of the device in this measurement.

 Absolute error value possible does not depend on the measured value:

= const

 Values of relative possible error for individual currents are as follows:

 for I = 5A (full measureing range): = 1 cl.

 for I = 2,5A (half of measuring range): = 2 cl.

 for I= 0,5A (one tenth of measuring range): = 10 cl.

Measurement with analog devices requires careful readings of the position of the pointer relative to the scale. It consists of intentional proportional division of **elementary scale**, i. e. the distance between adjacent lines. Depending on the class, readings of the pointer should be made with accuracy of 0.1 or 0.2 of the **elementary scale** – for laboratory class devices, and 0.5 scale – for technical class devices (class 1 and worse). Measurements done the following way make it impossible to include **reading errors** in the calculation.

**Example 2:** The reading of α = 50,4(scale) with the accuracy of 0.1 div was obtained with a device of class 0.5 and αm = 75 div . Compare the reading error with limit error of the device. (działki – scale?)

 ; Δoα = 0,1div

Reading error is about 4 times smaller that limit error and can be ommited.

**Example 3:** Taking device as in example 2, measurements with accuracy of 1 elementary scale has been done with reading of α=50 div. Compare the errors

Now:  i Δoα = 1 div

Reading error is higher that limit error (2.5 times). Reading error is dominating and it decreases accuracy of the measurements. It also comes from the comparison of relative errors.



**Method error** occurs when applied measurement method does not allow measuring the exact value. In direct measurements with analogue instruments, the source of the method error is power consumption from the object of measurement by the meters. The result of this can be i. e. voltmeter not measuring source voltage but only the voltage of the source loaded with internal resistance of the device. Evaluation of method errors will be the subject of further excercices.

Readings of the analogue instruments are made directly in units of measured value or indirectly, by reading the number division of the pointer. The first method is implemented in technical class and universal meters. Thanks to the scales that are described with measured value, measurements are relatively quick.

On the other hand, scale of laboratory devices or multi-range ones, allow to make readings in divisions, which are then converted to the value of measured quantity using the **range** **constant c** of the meter.

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Range constants are calculated using parameters of the meter:

 - voltmeter constant ,

 - ammeter constant 

 - wattmeter constant 

**Example 4**: With the voltmeter of given paramters: cl. 0.2, αm = 150 div, Uz = 15V, voltage was measured with the reading of α = 122,6 div. Calculate the value of the measured voltage.



# 3. Estimation of uncertainty of direct measurements

The final uncertainty of the direct measurement is determined by basic and additional errors. However, if the measurement is performed carefully, in reference conditions, and the device has been selected, so the method error is neglected, then only the basic error of the meter will affect the uncertainty of the measurement.

 **Uncertainty theory** of measurement, assumes that every reading, even the single one, has the features of random event, and therefore is the subject of laws of the statistics. In other words, it can be assigned statistical properties, defined as eg .probability of its occurrence.

 The most basic feature of random events is the ability to describe the using probability distribution function of the event. In measurements, event is single reading or error of this reading.

For measuring devices the most suitable function is uniform distribution, also called rectangular distribution, shown on fig. 1

f(ΔX)

0)

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 The general rules of creating distribution function show that for an uniform distribution it is bounded by maximum possible limit, and is constant with the value of 1/(2 ΔgX) (the area below the function has a unit value). Taking it into account means that in the single measurement, the meter has real error that is in range of ±ΔgX, assuming that occurrence of each error has the same probability.

Rys. 1. Fig. 1. Uniform (rectengular) distribution function

1/(2ΔgX)

+ΔgX

-ΔgX

0

Reffering to the measured value, range of values  is obtained in which there is a real value with a probability equal to certainty.

 Parameter that describes any distribution of probability is the **standard devation**, which in case of uniform distribution is:.

For the measuring purpose standard deviation was assumed to be called **standard uncertainty** and should be denoted as the lowercase u(x), and its relative value – ur(x):

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The standard uncertainty of unifrom distribution bounds the range of probable errors to about 58% of the limit error of the meter. Therefore the adoption of the standard uncertainty for evaluation of the accuracy of measurements gives too little confidence about measurement result. For this reason, the final result of the measurement takes into account **expanded uncertainty** – resulting from multiplying standard uncertainty by **the expansion factor k**. Expanded uncertainty is denoted as uppercase letter U:

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For direct measurements, the expanstion factor value can be assumed as:

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where p – is accepted level of confidence in the result of measurement

 **Example 5**: The voltage has been measured with the voltmeter of given parameters: cl. 0.5 and range of 100V. The result of measurement is U=80.2V. What is the measurement result taking into account the uncertainty of p=0.95

Answer:

* standard uncertainty of the meter: 
* extended uncertainty : , where k =, then

  *(presenting the uncertainty with 1 significant digit is justified by the reading resolution!)*

* final result of measurement: , 
* relative uncertainty of the measurement: .

# Properties of measuring with analog devices

The measuring activities are made up of:

* theoretical and practical preparation to the measurement,
* technical measurement,
* elaboration and evaluation of the result.

Measurements should always be preceded by the recognition of measuring object, as carefully as it is needed to select appropriate measuring method and tools. Measuring method should be selected based on an estimate of the order of magnitude of the measuring value as well as desired accuracy. Measuring

 Direct measuring method carried out with the use of analog devices guarantees a moderate level of accuracy, in best case scenario about 0.5% for meter with class 0.2. Due to simple and fast measurements analogue instruments are widely used in measuring many electrical and non-electrical quantities with average value, while taking into account full range of measurability of a quantity.

 The selection of pointer meter must take into account type, range, and accuracy class. In case of volt- and ammeters, especially when the object is of low power – it is also necessary to evaluate internal resistances.

 Before starting measurements, with analogue instrument, always check the zero position of the pointer and if necessary carry out zeroing operation

 In multi-range and multi-functional devices (multimeters), before connecting them to the circuit, proper measuring function and range should be selected.

## **Laboratory program**

1. Familiarize yourself with the instruments on the laboratory stand, make a list of instruments.
2. Measure the voltages generated by the indicated objects.
3. Develop and evaluate the results of measurements.

## **Measuring tables**

 Tab. 1. Voltage measurement Un=const, source type:………………….

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| Instrument type | Readings | Measurement result |
| UnV | αdz | cvV/dz | UV | U±U(U), p=....V | Ur(U)% |
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