New Detectors for X-Ray Metal Thickness Measuring

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Abstract. X-ray thickness measuring instruments provide efficient in-service measurement of metal-roll thickness for metals with atomic numbers Z=12…72, i.e. no changes of technological procedures are required. This method is suitable for use (contactless, does not affect ecology in contrast to isotope one) but is indirect and hence impose certain limitations on the measurement results accuracy especially in case of metal chemical composition and density variations. As isotope sources feature high stability the same characteristics are expected from X-ray based systems. To achieve measurement accuracy that satisfies the demands of industry it was necessary to implement X-ray thickness measurement systems with new type of ionizing radiation detectors – multilayer heterogeneous chambers sensitive to energy. Such a solution provides not only the extension of measured thickness dynamic range but also to correct measurement errors occurred due to X-ray radiation instability as well as to avoid influence of mechanical vibration (so called microphone phenomena) and radiation spectra changes (anode grain recovery and metal atoms deposition on the X-ray tube window) on the measurement accuracy.
Practical statistic data obtained during one year remote operation of X-ray thickness measuring system without involvement of staff at production facility manufacturing nonferrous metal rolled products is presented in the paper. As well as experience of this type detectors use for monitoring of pulse X-ray generators' radiation and exposure metering in the process of on-site object examination by means of a.m. X-ray system.

Currently it is rather difficult to split roentgenometric and fluoroscopic techniques [1] as in both all newly developed instruments the initial signal processing is based on digital conversion while to simplify the presentation of results obtained by radiometric examination used not only digital values of measured parameter but its graphic presentation that make understanding of obtained results much better. The thickness metering based on X-ray implementation is a typical application of roentgenometric technique. X-ray thickness metering –provides on-line efficient measurement of rolled metals thickness in the range from hundredth of microns (for cupper) up to several centimeters for materials with material effective atomic number Z = 12….72 and does not require changes in technology. This method is suitable for use (contactless, does not affect ecology in contrast to isotope use) but is indirect and hence impose certain limitations on the measurement results accuracy especially in case of metal chemical composition and density variations. As isotope sources feature high stability the same characteristics are expected from X-ray based systems. To achieve required measurement accuracy of the X-ray thickness measurement system the new type ionizing radiation detectors were developed, i.e. sensitive to energy multilayer heterogeneous chambers. Such a solution provides not only the extension of measured thickness dynamic range but also to correct measurement errors occurred due to X-ray radiation instability as well as to avoid influence of radiation spectra changes (anode grain recovery and metal atoms deposition on the X-ray tube window) on the measurement accuracy [2]. Similar problems arise in case of reontgenographic examinations even when X-ray film is used as information storage mean; though due to

film heterogeneity and rather long exposition time, in comparison with X-ray TV installations, the problem of necessity to achieve X-ray flux stabilization is not so dramatic. Thereby to obtain maximal possible dynamic measuring range and improve the measurements accuracy it is required to have accurate data about used radiation flux parameters.

The X-ray thickness metering is widely used in metallurgy. The main problem facing the engineers when developing X-ray thickness measuring systems is the necessity to provide hard stability of sounding radiation flux both for flux spectra and intensity [3] points of view. At the same time, it is required to make spectral distribution of flow of energy as narrow as possible as in the process of radiation flow propagation through the tested object its spectral distribution is changed and as a result of this it is required to change correlation practice factors dependent on the chemical composition of the object material, see Fig. 1.

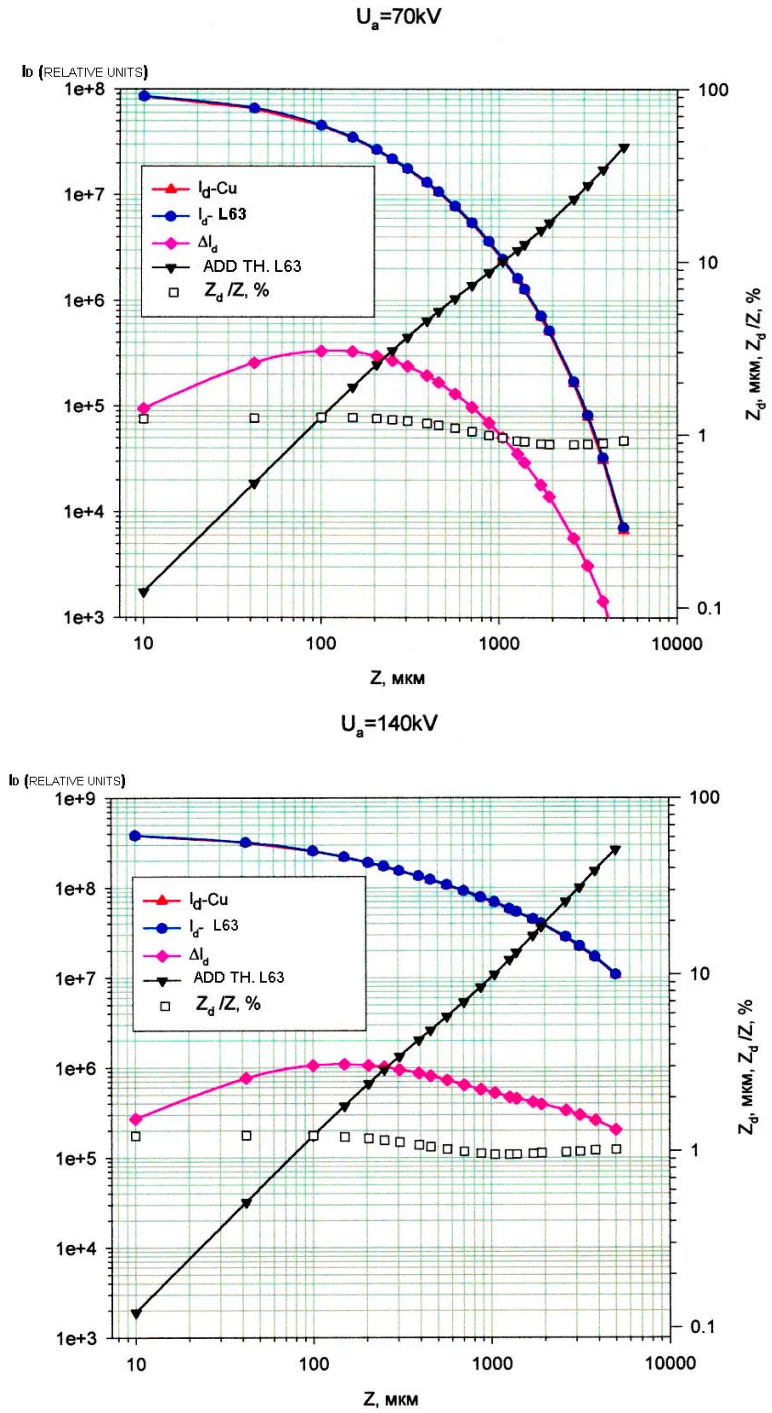

Fig.1. Dependence of correction value on variations of chemical composition and thickness of examined material for L63 brass when anode voltage is 70kV and 140kV.

In thickness meters, as a rule, used are metal-ceramic X-ray tubes. They are powered from highly stabilized constant-voltage sources. Today the practical tasks of metallurgy require accuracy of thickness measurements less than 0.1 ... 0.05%. To ensure such measurements accuracy during long period of time (during 24 hours and more) it is necessary not only to provide X-ray generator powering from highly stable source but also consistency of radiation flow independent of existing change of X-ray generator' electrodes geometry due to temperature variation as well as vibration and other shock impacts inherent to normal working conditions at rolling mills. The alteration of electron beam focusing inside the generator caused by redistribution of static charge on dielectric structure elements and cathode emission drop has a strong impact on long-term radiation parameters instability. The active radiation energy is as well changed due to the target material evaporation with further heavy metal atoms, as a rule wolfram, precipitation on glass or beryllium radiation window. The problem described above can be efficiently solved if for radiation transformation the detectors possessing energy resolution are used.

For some applications (for instance, X-ray thickness metering) very important is to avoid not only flow intensity alteration but alteration of its active energy as well. Sufficient for X-ray applications compensation can be achieved due to introduction into sounding flow of single-layer radiotransparent reference detector which properties are similar to the main one. The signal from main detector is normalized relevant to signal picked up from reference detector. Such an approach helps to reduce the measurement error caused by instability of anode current and is convenient in cases when there is no need to take into consideration the active flow energy alterations. When nonferrous rolled metal thickness changes, i.e. in case where the total mass attenuation coefficient of gamma quantum absorption depends on energy, to obtain minimal measurement errors it is important to know accurate value of actual energy flow. This task requires different approach. To solve this task the presented system of automatic correction of instability of spectra and source of sounding radiation flow was developed.

Two sectioned combined heterogeneous radiotransparent chamber 1 (Fig. 2) is the core of the system. This chamber is installed directly on the anode window of X-ray generator.

Both chamber sections have emissive coatings one with atomic number Z=13 and the other one – Z=83. Due to difference of emissive coatings atomic numbers the chamber has energy resolution. The function of radiation attenuation in the examined object material (1) is independent of radiation flow value but depends on active energy value:

$$f(Ei) = K\, I_1/I_2 \qquad (1),$$

where: Ei – radiation flow active energy value;

K – aspect ratio;

I_1/I_2 – current in first and second sections of reference radiotransparent chamber.

Chamber 2 (Fig. 2) is installed behind calibration samples and examined object; it also has emissive coating with atomic number Z = 83, i.e. identical to one in second section of chamber 1. It means that these two units are matched from the point of absorbed radiation spectra.

The signal from the second chamber is normalized relevant to signal registered at the output of the second section of first chamber that provides compensation of final signal variation caused by the primary radiation flow intensity alteration. If the alteration of primary flow active energy occurs the normalization is made relative to value f(Ei). In such a manner the alterations of sounding radiation flow caused by variation of examined object thickness are differentiated from radiation flow alterations caused by radiation source instability. To improve the measurements accuracy the signals coming out from all chambers are clock-actuated readout by means of three-channel integrating ADC. And in spite of the fact that both chambers are installed within the radiation flow, oriented in parallel to the flow normal axes planes and cover the same space angle – received from them signals will differ as the radiation spectra (see Fig. 3) varies due to filtration occurring in the material of

examined object.

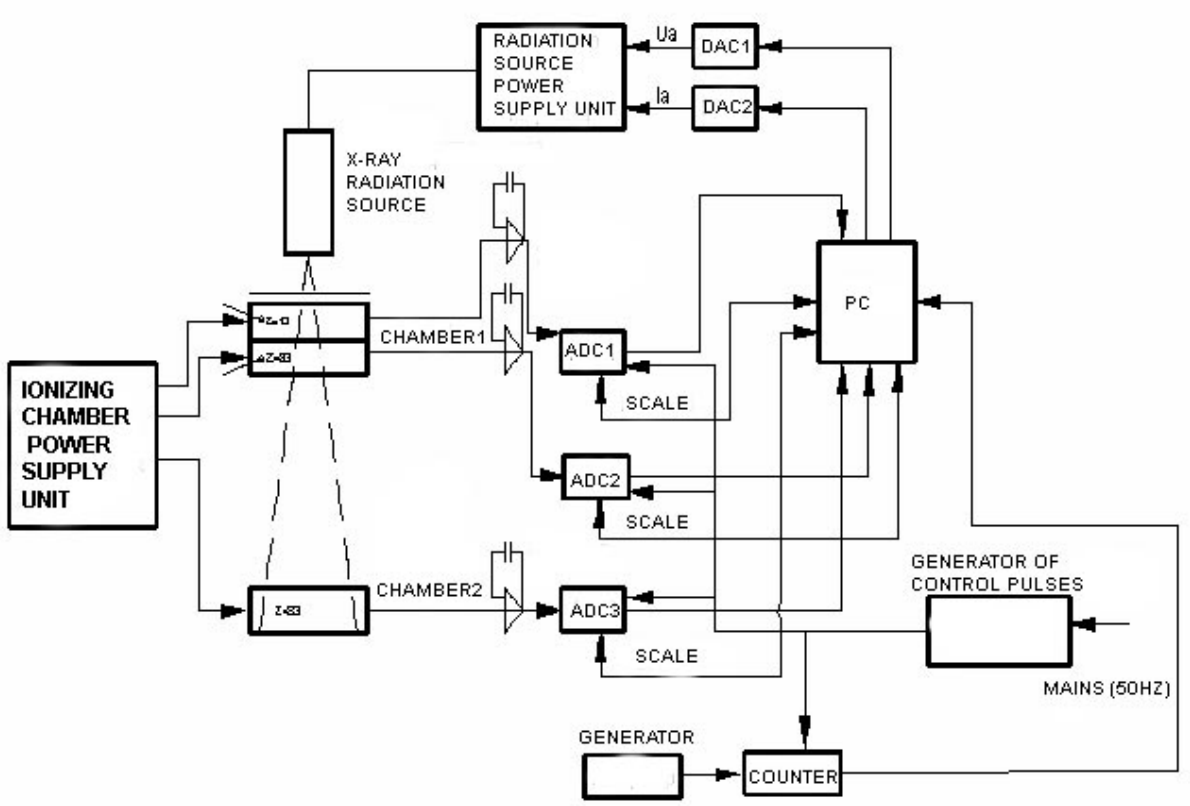

Fig. 2. Complete measuring circuit diagram of system for automatic correction of instability of spectra and flow from sounding radiation source.

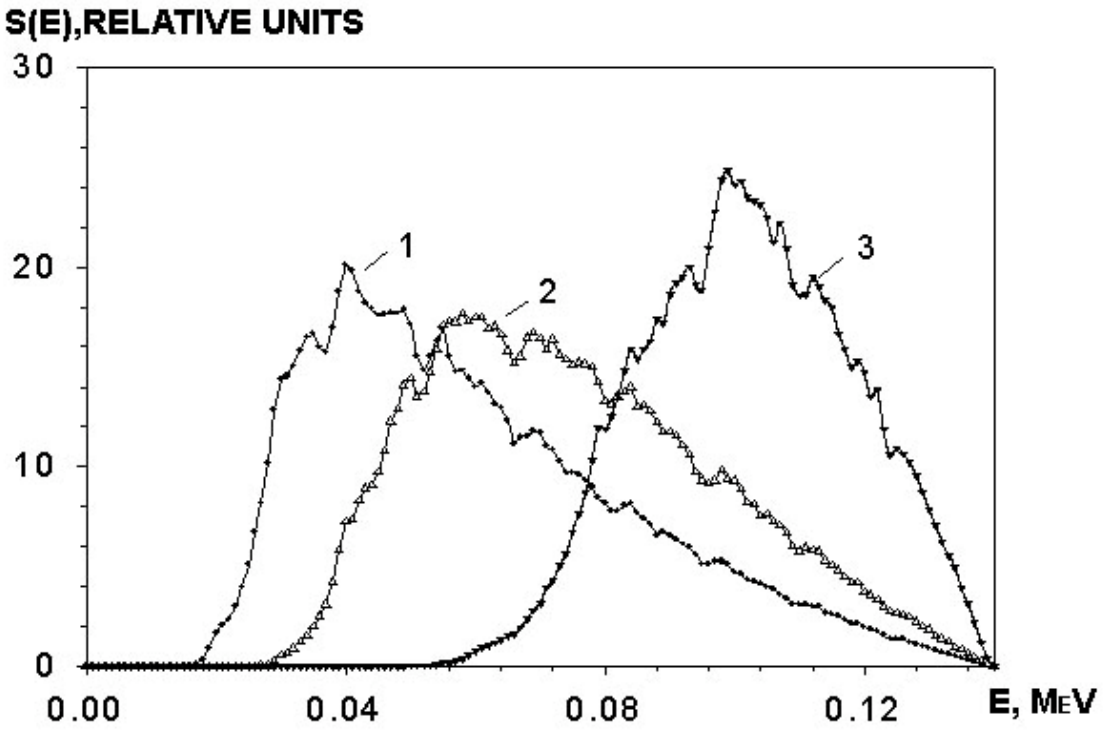

Fig. 3. Spectral distributions of X-ray radiation behind cupper sheet with different thicknesses. Anode voltage – 140 kV. Thickness of examined sheet: 1–50μm; 2 – 500μm; 3 – 5000μm

From diagrams shown in Fig. 4 it is clear that independently of the radiation spectra filtration level and current in the X-ray tube the function f(Ei) is unambiguously defined and depends only on active energy E_{acv}.

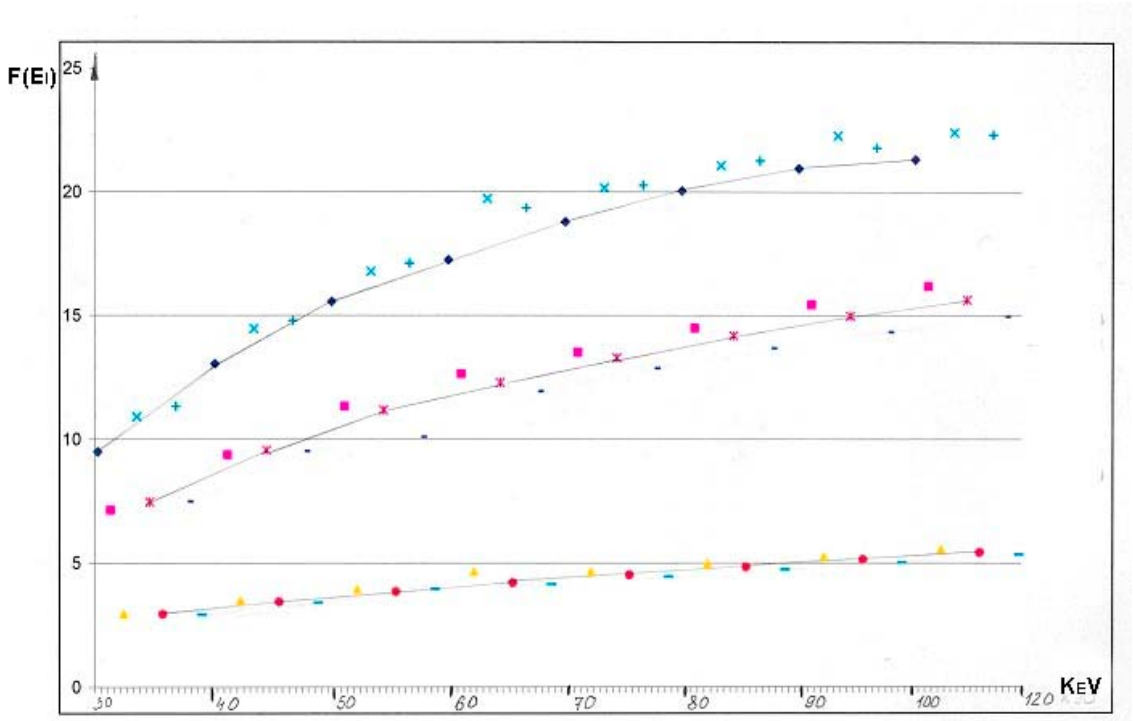

Fig. 4. Graphs of f(Ei) function dependence on X-ray tube anode voltage for three samples of chambers and various thicknesses of radiation primary filter. Series 4, 1, 7 – direct beam;
series 2, 5, 8 – 50μm (Cu); series 3, 6, 9 – 500μm (Cu).

Variation of value of individual chambers absolute sensitivity is less than 5%, the chambers' parameters are stable in time and do not deteriorate under influence of X-radiation. The curves presented in Fig. 4 do not have extremum points and areas with negative differential pattern within the wide range of active energies. All these features make it possible to reach sensitivity towards active energy alteration not less than 1% in the energy range 30 to 120keV. Experiments proved that level of influence of power and current instability of sounding radiation source on the nonferrous metal products thickness measurements carried out by X-ray thickness metering system was reduced 10 times and became practically negligible against the background of quantum fluctuations in detectors when multilayer chambers are used as detectors, see Fig. 6, 7.

Internal chamber space Fig. 5 [4,5] is sealed and filled with inert gas that provides constant humidity inside of it as well as pressure and environment humidity variations independence. Such a design provides keeping constant geometrical dimensions of chamber electrodes and interelectrode gaps that, in its turn, provide stability of free path of electrons emitted by electrodes at given X-radiation energy within interelectrode gaps. Total number of high voltage and collecting electrodes equal to N. More is N – higher is the chamber sensitivity. Nevertheless the value N is selected with taking into consideration the chamber dimensions along its longitudinal axis and value h – the air gap between electrodes defined by X-radiation quantum energy and proportional to electrons free path. When defining value h the requirement to improve the chamber sensitivity is taken into consideration as well. For instance, if the voltage of generated X-radiation is U=100kV the optimal value h equals approx. 10mm; for this specific conditions the rational number of high voltage electrodes is 4 (i.e. six coating) and collecting electrodes – 3 (six coatings). The chamber power supply applied to high voltage electrodes does not exceed 300V. Coatings 4, 5 are plated on plates 3 by method of chemical deposition or other. In drawing, Fig. 5, presented is configuration of radiotransparent ionizing chamber. The chamber comprises protective electrode 1 fabricated as metal ring and acting as chamber housing at the same time, first and second high voltage electrodes 2 & 3, collecting electrodes 4 placed between high voltage electrodes 2, 3 in the middle part of cross-section of protective electrode 1 and

radiotransparent electrostatic screens 8 & 9. Use of such detectors in the instruments and installations is especially efficient when the examination of objects that do not have limitations on minimal radiation exposure is performed.

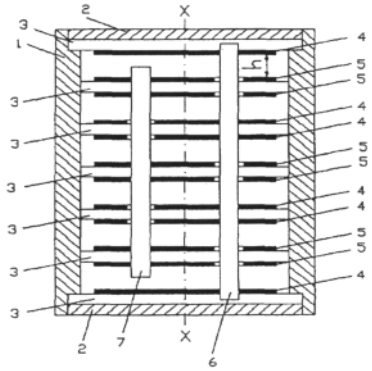

Fig. 5. Multi electrode heterogeneous ionizing chamber.

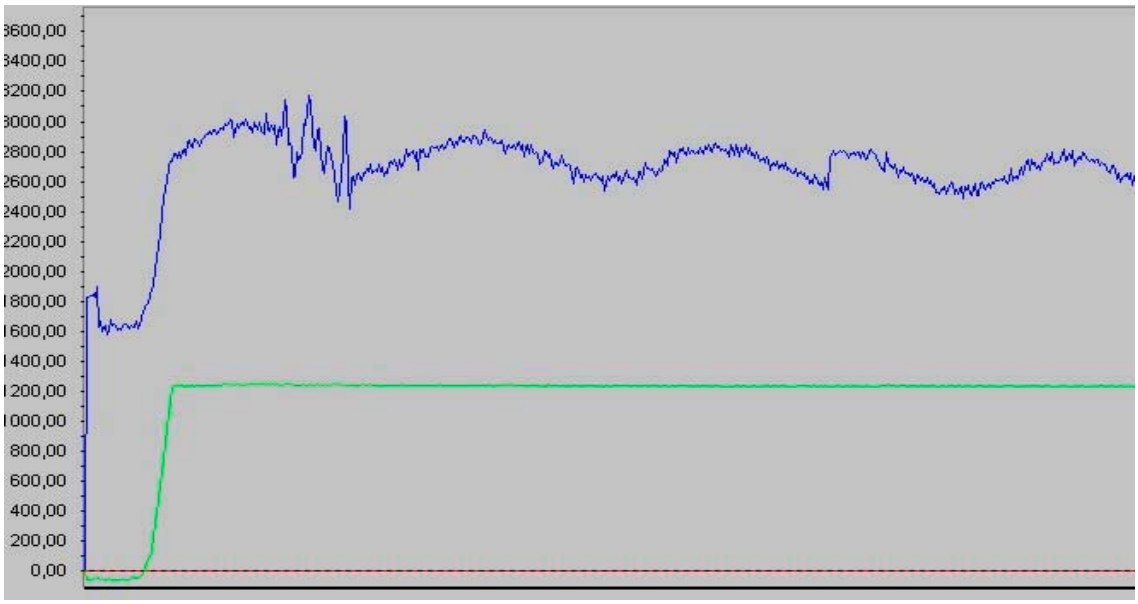

Fig. 6. Transient process of output from direct beam to measurement when examined object thickness 1200μm (material Cu alloy M1); anode voltage – 100 kV. Upper curve – without normalization (H=H+1500μm) (blue); lower curve (green) – measurement results normalization relevant to signal from reference chamber.

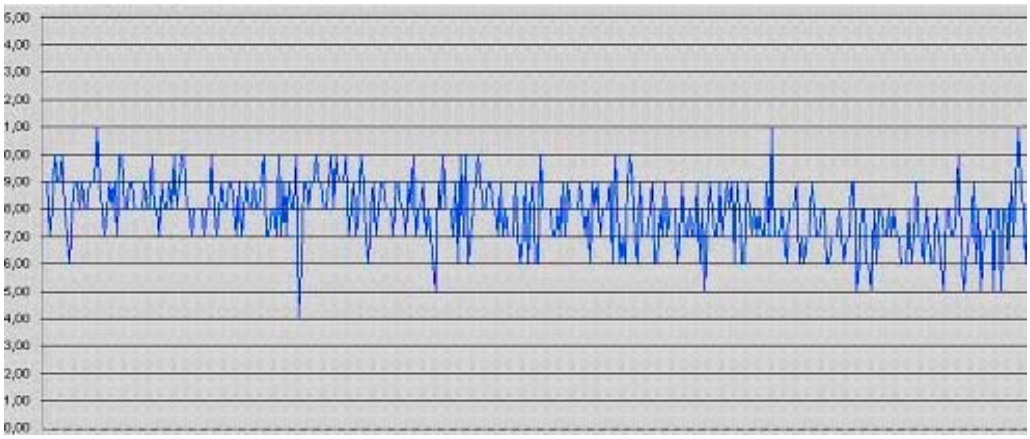

Fig. 7. Measurement uncertainty for examined object thickness 1200μm (material Cu alloy M1); anode voltage – 100 kV (range 16μm).

References

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