Modernization of radiation detectors thickness gauge

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Abstract. Currently, there is a tendency in the industry by refusing isotopic radiation sources in favor of the X-ray machines. This is due to several factors, main among them radiation safety and maintenance problems, movement and disposal of gamma-ray sources. Compared to the gamma ray-source these devices have a number of disadvantages. The spectral energy distribution and therefore change in the spectrum as the radiation passes through the controlled material. Instability of radiation compared with gamma sources. All this complicates the use of X-ray sources for the materials thickness measurement with different chemical compositions.

1. Introduction

In metallurgical factories in Russia to address the problem of measuring the thickness of the rolled metal produced by widely used non-contact X-ray and isotope or radiation thickness gauges. The widespread use of these devices is justified their high metrological characteristics, performance and the lack of contact transducer with a moving surface in the metal rolling. Radiation thickness measurement – radiometric method for non-destructive testing for measuring thickness or surface density of the material and is based on the measurement of the parameters of ionizing radiation resulting from the interaction of the primary ionizing radiation controlled material according GOST 24034-80 "Non-destructive testing radiation" [1]. Park radiation thickness gauges requires constant maintenance, repairs and modernization. Currently, the problem of maintenance of the operated equipment in steel mills added a new task set by the leadership of our country – import substitution. To solve these problems at the same time the company "VIZ-Stal" Ekaterinburg decided to make work on the modernization of import FMM thickness gauges manufactured by "Messelektronik" German Democratic Republic (development of the '80s).

2. Formulation of the problem

The thickness meter is used the absolute measuring method (figure 1). Measuring clearance – 160 mm. Measured thickness for the steel from 0.1 to 2.0 mm. Random error (RE) measurements on a fixed sample thickness of 0.3 mm was 0.1 % compared to the measured thickness of hire. The equipment in the radiation source used isotope Americium²⁴¹, with the following main parameters:

- energy gamma rays of 60 keV;
- photon flux density at a distance of 1 m from the center of working surface (7.0 ± 2.1)·10⁴ s⁻¹·cm⁻²;
- Am²⁴¹ maximum activity at the source 2.24 Ku (8.3·10¹⁰ Bq);
- half-life 432.6 years;
– energy $\gamma$-quanta $E = 59.5$ keV (35.8%).

Sources “IGIA-5 M-1” produced by the Russian "Isotope" and can be purchased on the territory of Russia in the required amount without any problems. As a radiation detector in thickness meter used gas-filled argon-xenon ionization chamber (IC) (figure 1).

The main parameters of the IC (figure 2).
– diameter of 165 mm;
– height 80 mm (with electrodes 110 mm);
– case material aluminum thickness 2 mm;
– input window aluminum 0.5 mm thick;
– supply voltage 500 V.

![Figure 1. Diagram of the radiation measuring chain gauge FMM-24004.](image)

In the operation of the camera thickness gauges have been exposed to corrosive media and vibration, impact resistance, with time, cameras leak disrupted as a consequence of the pressure of the gas mixture is beginning to subside. Reducing the pressure leads to reduced density and efficiency of the chamber. The number of photons interacted falls, and statistical error increases with a simultaneous decrease in the output level of the camera. Increasing the intensity of the source is not desirable because the lead to overexposure of personnel or require the installation of additional protective shields in the design of devices.

![Figure 2. Gas-filled argon-xenon ionization chamber.](image)

Replacing the camera to a more efficient, it is the most simple and secure as well as cost-effective way to solve the problem. As a prototype of heterogeneous camera developed earlier in JSC Scientific-Research Institute of Introscopy "Spectrum" was used for the X-ray thickness gauge RIT10.6 [2–4]. IC design [5] required significant improvement, because effective energy flux in the case of the isotopic source (Americium) instead of the previously used X-ray is increased by 30 %. The dose rate $P$ will be equal to:

$$P = N\cdot E\cdot \mu b \cdot 1/a \left[\text{R}\cdot\text{m}^2/\text{s}\right] = 7\cdot10^4 \cdot 60 \cdot 0.028 \cdot 1/5.5 \cdot 10^{10} = 2.1 \cdot 10^{-6} \left[\text{R}\cdot\text{m}^2/\text{s}\right],$$

where $N$ – number of photons incident on 1 cm$^2$ per second at a distance of 1 m from the source; $E$ – energy $\gamma$ rays in keV; $\mu b$ – mass emission rate of energy conversion in the air cm$^2$/g.
When the distance from the source to the center of the chamber 230 mm the dose rate camera geometric center is 40.4·10⁻⁶ R/s. Current ionization chamber with a volume of 1 cm³ will make up

\[ I_k = 3.3 \cdot 10^{-10} \cdot 40.4 \cdot 10^{-6} = 1.33 \cdot 10^{-14} \text{ A}. \]

Taking into account the absorption of rolled materials (0.05±3 mm Fe)

\[ I_{k_{\text{min}}} = I_k \cdot \exp(-\mu \cdot d) = 8 \cdot 10^{-16} \text{ A}/\text{cm}^3, \]

where \( d \) – maximum thickness of the tape 0.3 cm; \( \mu \) – linear attenuation coefficient of the material rolled at a photon energy of 60 keV is 9.42 cm⁻¹ at its density 7.86 g/cm³.

Given that modern operational amplifiers don’t work well with such small current value, so it is necessary either to increase the source activity, which is unacceptable from the viewpoint of radiation, or substantially no less than 2·10⁸ to increase the sensitivity of the ionization chamber.

The sensitivity of the ionization chamber can be increased in two ways – increase in the area of the input window and the height of the camera. From the design requirements (TR) the amount of not more than 150.

where \( Z \) – electron photon energy conversion factor for the material chamber electrode with an atomic number \( Z \); \( \mu_{\text{air}} \) – electronic power conversion coefficient of photons in the air.

In view of the not full of electrons from the electrodes, the attenuation of the radiation due to the distance and absorption in the electrode chamber, we assume \( n = 30 \% \) and Cu = 45 we obtain:

\[ I_{k_{\text{min}}} = 4.5 \cdot 10^{-11} \text{ A (3mm Fe)}; \quad I_{k_{\text{max}}} = 7.6 \cdot 10^{-10} \text{ A (0.1 mm Fe)}. \]

To convert the current camera to a digital signal designed electronic circuit measurements with ADC with the integration of the camera signal on the vessel > 50·10⁻¹² F. The time constant \( \tau \) discharge circuit based on its own chamber of the bottle and the ADC input resistance is <50 ms, which is perfectly technical project. Technical demands made by the customer to the ionization chamber and the values obtained from the tests made camera, are shown in table 1.

### 3. Results and discussion

The camera (figure 3) comprises a body in the form of a hollow metal cylinder with radiolucent conductive caps at the ends, symmetrically placed between the covers along the longitudinal axis of the camera body and parallel plates radiotransparent dielectric material, alternating high and collecting electrodes. Which are formed as coatings of a material with a high \( Z \) and insulated from the housing and outer plates forming surfaces rigidly fixed to the housing seals the end planes. The distances between the coatings and high-collecting electrodes respectively and the cavity are sealed, and the chamber is filled with air. Two metal rods, one of which is electrically connected to the high voltage coating electrode, but is insulated from the collecting electrode coatings and other coatings electrically connected to the collecting electrodes, but insulated from high voltage electrode coatings. The rods are arranged parallel to the longitudinal axis of the camera body and rigidly attached to the plates. As a result, high vibration resistance cells were obtained by providing an increased mechanical rigidity of the plates and sensitivity. Reducing inter-electrode distances which increased tension in the chamber at
a constant voltage power supply high-voltage electrodes and the same external dimensions of the chamber, which generally improves the dynamic and metrological performance of the camera.

| Parameter                          | Presentation of the value | Value     | Obtained technical requirements |
|-----------------------------------|---------------------------|-----------|---------------------------------|
| Sensitivity, A·s/Gy               | 9.5·10^{-5}               | 2·10^{-3} | Yes                             |
| Dynamic range, rel. un.           | 10^3                      | 10^3      | Yes                             |
| Supply voltage, V                 | 400                       | 150÷500   | Yes                             |
| Overall dimensions, mm            | Diameter 165, Height 125 | Diameter 165, Height 125 | Yes |

**Figure 3.** Heterogeneous ionization chamber.

**Table 1.** The main parameters of the IC.

4. Conclusions
Depending on the current dose rate were obtained during testing chamber for two focal lengths (figure 4). Thus it is shown that dose rates in the range of 0.1 to 100 P/min, which corresponds to a dynamic range of 10^3, the sensitivity of the camera is constant and equal to 2·10^{-3} A·s/Gy. Changing the camera voltage range from 150 to 500 insignificantly affects the sensitivity (figure 5).

**Figure 4.** Dependence of the current of the ionization chamber of the dose rate for the focal length of a 0.2 m (a) and 2 m (b).

Developed by the camera can successfully replace regular detectors on all thickness gauges series FMM-24004, which will increase the metrological characteristics of meters thick and extend their life at work.
Figure 5. The dependence of the sensitivity of the ionization chamber from the supply voltage.

References

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