Advanced materials and technologies for high-pressure krypton detectors in industrial use

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A new approach to design of high-pressure Kripton (HPKr) cylindrical ionization chambers is investigated. The measurement of the thickness of sheets made of different materials, e. g. metal, plastic, paper, cellulose, rubber, etc., is one of many industrial applications of nuclear techniques. The ionizing radiation detectors of ionization chamber type are based on measuring the variations in either exposure rate (for gamma radiation) or absorbed dose rate (for beta radiation) occurring in materials of different thickness, placed between the radiation source and the detector. The variations in exposure rate and absorbed dose rate can be traced by using radiation detectors of the ionization chamber type, which convert the exposure rate $\dot{X}$, or the absorbed dose rate, $\dot{D}$, into a proportional electric current. The more stable the ionization current of the chambers (keeping a constant exposure rate or absorbed dose rate), the slighter the variations that can be detected in either exposure rate or absorbed dose rate, hence in the absorbing material placed between the radiation source and the detector. Based on these facts, several variants of such detectors, including the ionization chambers: CISP5M, CISP2M and CISP8M, have been done.

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1. Introduction

Although proposed more than two decades ago [1], high-pressure xenon and kripton ionization chambers received their long-deserved acknowledgement [2] only recently. Growing interest in Xe and Kr detectors has been stimulated by the need for large-area, high-sensitivity, and robust detectors for non-destructive testing, nuclear treaty verification and safeguards, geological exploration and other industrial applications. To date, Xe and Kr detectors represent a well-developed technique in gamma-ray detection [3].

Nuclear techniques are used in industry for, among other things: the measurement of: thickness of rolled metal sheets (metallurgic industry); fluid levels in industrial containers (chemical and petrochemical industry); the thickness of material deposited on textile supports (textile and materials industries); fluid and solution density (chemical industry); ore concentration (mining industry); thickness of plastic, cellulose and paper sheets (cellulose and paper industry); uranyl nitrate concentration (industry of nuclear products and materials); the separation of petroleum derivatives (oil industry); the checking of: drilling sludge (mining industry); density in acid production, as well as of reactions and polymerizations (chemical industry) etc.

All these applications and many others are based on the measurement of the variations in exposure rate (in the case of gamma radiation) and absorbed dose rate (for beta radiation) resulting from the different thickness of layers or materials placed between the radiation source and the detector. The variations in exposure rate or absorbed dose rate can be traced by using radiation detectors of the ionization chamber type, which convert the exposure rate $\dot{X}$, or the absorbed dose rate, $\dot{D}$, into a proportional electric current. The more stable the ionization current of the chambers (keeping a constant exposure rate or absorbed dose rate), the slighter the variations, in either exposure rate or absorbed dose rate, hence in the absorbing material placed between the radiation source and the detector, may be detected [4], [5], [6].

2. Materials and methods

2.1 The pressurized ionization chamber CISP5M

This ionization chamber (Figure 1) was designed for the measurement of the thickness and thickness variation of rolled metal sheets in the metallurgic industry.

The operating principle consists in the measurement of the exposure rate variations caused by layers of different thickness of various materials (ferrous, nonferrous), placed between the radiation source and the detector. The structural features of the ionization chamber are as follows: Case - a metallic cylinder, connected at the top, made of nickel - coated 3 mm-thick brass; Insulator - polystyrene (or Teflon/PTFE) with very good electric properties ($\rho \geq 10^{16}$ $\Omega \times$cm).

A guard ring is placed on the insulator; Collecting electrode - of hexagonal, branched form, also made of brass; Window - phosphatized brass sheet, 100 μm thick, cadmium coated.

2.2 The pressurised ionisation chamber CISP2M

This detector (see Figure 1) was designed for the measurement of the thickness and thickness variation of plastic sheets, rubbers, paper, cellulose, aluminum strips, etc. The operating principle consists in the measurement of the absorbed dose rate variations caused by layers of different thickness of the above materials, placed between the radiation source and the detector.

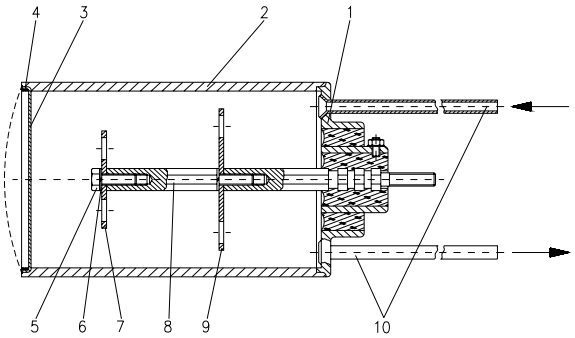

Fig. 1. Ion Chamber with pressure code CISP5M-detector design. 1 - Collecting electrode; 2 - Voltage electrode; 3 – Insulation; 4 - Guard ring; 5 – Window; 6 - Mounting piece; 7 - Scaling ring; 8 - Base plate; 9 - Filling hole.

The structural features are the same as in the Ionization Chamber CIS-P5M, namely the same case, collecting electrode, insulator, etc., by excepting the window is made of aluminum sheet, 44 μm thick (99.99 % purity), and the filling gas pressure is as low as 2 atm. The chamber converts the variations in absorbed beta dose rate, caused by radiation absorption into sheets of different thickness and material, into ionization current variations.

2.3 The pressurized ionization chamber CISP8M

In an ionization chamber operating in saturation mode, the ionization current is proportional with the exposure rate (or the absorbed dose rate, respectively). Its response is proportional with the amount of gas in the sensitive volume and strongly depends on the nature of the gas. So, an ionization chamber with 70 cm^3 sensitive volume, filled with a noble gas (Kr) at 8 atm. has an average response of about 0.73×10^{-10} $A/R\times h^{-1}$ for the gamma radiation of the ^{241}Am radioactive source having $\Lambda = 2.22\times10^{10}$ Bq $\pm$ 20% (600 mCi $\pm$ 20%).

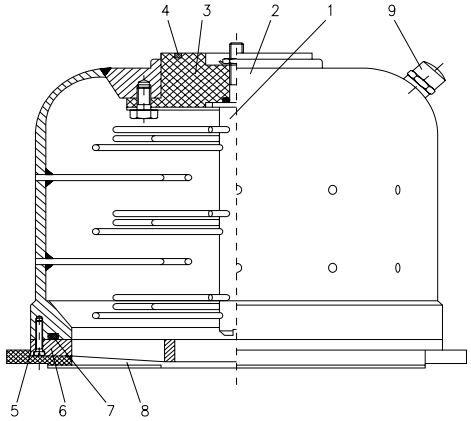

Fig. 2. Ion Chamber with pressure code CISP8M-detector design Insulation; 2 - Voltage electrode; 3 – Window; 4 – Ring; 5 – Screw; 6 - Washer Grower N 2.5; 7 - Collecting electrode I; 8 - Distance piece; 9 - Collecting electrode II; 10 - Filling hole.

This detector (Fig. 2) was designed for checking the thickness and thickness variation of plastic sheets and rubbers.

3. Experimental results and discussion

3.1 The ionization chamber converts the variations in gamma radiation exposure rates, caused by radiation absorption into sheets of different thickness and materials, into ionization current variations.

The main technical and functional characteristics of the detector are:

- Rated working voltage: - 600 V;
- Leakage current: $I_{leak} \le 10^{-13}$ A;
- Characteristic I-V curve plateau: -400 V ÷ -1000 V;
- Plateau slope: $\left(\frac{\Delta I}{\Delta U}\right)_{\dot{X}=ct.} < 4\cdot10^{-14}$ A/V;
- Relative variation in ionization current within the range - 400 V ÷ -1000 V: $\Delta I/I_0 = 1.1\%$;
- Average ionization current in the presence of a ^{241}Am radiation source having Λ= 600 mCi $\pm$ 20% (2.22×10^{10} Bq $\pm$ 20%) at 0.350 m distance: $I_0 = 3\times10^{-9}$ A $\pm$ 10%.
- Ionization current stability in time: $\Delta I/I_1 = 0.5$ % for a time interval ΔT = 30 days.

3.2 For CISP2M detector, the main technical and functional features are:

- Rated working voltage: - 600 V;
- Leakage current: $I_{leak} \le 2.5\times10^{-13}$ A;
- Characteristic I-V curve plateau: - 400 V ÷ - 1000 V;
- Plateau slope: $\left(\frac{\Delta I}{\Delta U}\right)_{\dot{D}=ct.} < 1.7\times10^{-13}$ A/V;

- Relative variation in ionization current within the range - 400 V ÷
- 1000 V: $\Delta I/I_0 = 0.22$ %;
- Average ionization current in the presence of a ^{90}(Sr-Y) radiation source having $\Lambda = 1.85 \cdot 10^9$ Bq ± 25% (50 mCi ± 25%) at 0.350 m ± 0.005 m distance: $I_0 = 2 \times 10^{-9}$ A;
- Ionization current stability in time: $\Delta I/I_1 \leq 0.5$ % for a time interval

$\Delta T = 30$ days.

The assembled and sealed detectors was baked under a vacuum of $<10^{-6}$ Tor, for several days before filling with Kr.

3.3 In an ionization chamber operating in saturation mode, the ionization current is proportional with the exposure rate (or the absorbed dose rate, respectively). Its response is proportional with the amount of gas in the sensitive volume and strongly depends on the nature of the gas. So, an ionization chamber with 70 cm^3 sensitive volume, filled with a noble gas (Kr) at 8 atm. has an average response of about 0.73×10^{-10} A/R×h^{-1} for the gamma radiation of the ^{241}Am radioactive source having $\Lambda = 2.22 \times 10^{10}$ Bq ± 20% (600 mCi ± 20%) [4], [5], [6].

This detector (see Fig. 2), was designed for checking the thickness and thickness variation of plastic sheets and rubbers. The chamber response was averaged over three different values of exposure rate (at d_1=15 cm and $\dot{X}$ =2 R/h; d_2=25 cm and $\dot{X}$ =800 mR/h; and d_3=35 cm and $\dot{X}$ =50 mR/h). In order to improve the chamber response with the exposure rate, the gas amount in the sensitive volume was increased by raising pressure to 8 atm.

The filling gas was Krypton. The averaged response under exposure to the beta radiation of the ^{90}(Sr-Y) radioactive source with Λ= 10 mCi, was approx. 0.68×10^{-10} A/rad×h^{-1}. The chamber response was again averaged over three different values of absorbed dose rate: at d_1=132 mm and D = 0.14 rad/h; d_2 = 232 mm and D =0 .06 rad/h; and d_3= 332 mm and D=0.036 rad/h.

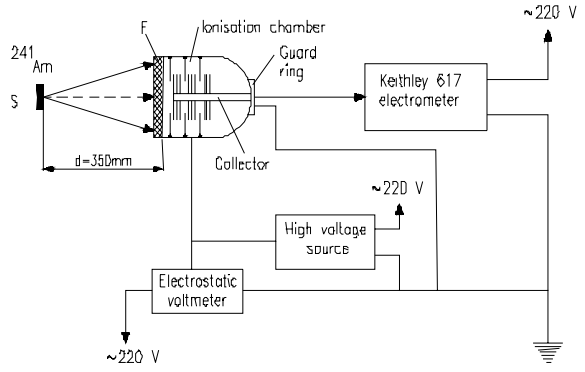

Fig. 3. Block-scheme used for the measurement of characteristic parameters

In light of the above, we developed a pressurised, metal-walled ionization chamber, filled with a noble gas at 8 atm. pressure (Fig. 2) and using frit glass as insulator. The cylindrical case, 60 mm long and 40 mm in diameter, was made of stainless steel 2 mm thick. A window made of 100 μm stainless steel (or titanium) sheet, with good elasticity and strength under high pressure (up to 10÷12 atm.), was electron-beam welded at one end of the case. A stainless steel metal holder, into which the chamber's radiation absorption into sheets of different thickness and material, into ionization current variations guard-ring-and-insulator assembly had been cast beforehand, was electron-beam welded at the other end.

The collecting shaft (i.e. the collecting electrode) came out through the middle of the insulator assembly. The electrode was so designed and made as to ensure an optimum electric charge collection from the sensitive volume and an evenness as high as possible of the electric field arising as a result of detector polarisation.

The block-scheme used for the measurement of characteristic parameters for these detectors, is shown in Fig. 3.

4. Conclusions

Based on our experience of making such ionizing radiation transducers and on our experimental results, we concluded that:

Detectors thus developed can be used successfully in various industries, nuclear medicine, dosimetric measurements, etc. The parameters and features obtained with these detectors perfectly meet the requirements that are generally related to detector use and those imposed by individual users. The ionization chambers were designed and made in such way that they could be easily fixed, reconditioned and reused. Depending on the target use, the detectors are easily customized by changing gas type and pressure, windows, insulators, etc. The results provided by these detectors are in agreement with literature data and similar devices by leading companies in the area. Further researches will allow to build these detectors in a broader range of structural options and to expand their application range.

Acknowledgments

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