

Small-sized X-ray apparatuses for industrial defectoscopy

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Abstract. One of the main problems during designing of X-ray apparatuses for the operation in unsteady condition is the problem of designing a unit of minimal weight and dimensions. There are two key priorities: the development of pulsed X-Ray generators on the basis of explosive electron emission and the development of classic thermionic X-ray generators operating at high frequency of transformation of supply mains' voltage to voltage applied to the X-ray tube.

One of the main problems during designing of X-ray apparatuses for the operation in unsteady condition is the problem of designing a unit of minimal weight and dimensions. Although in recent years most manufacturers involved in designing the X-ray equipment have turned to the production of generating monoblocks operating at high frequency of transformation of supply mains' voltage to high voltage, however, the weight of these monoblocks is usually 15–30 kg. This fact can make the use of monoblock X-ray detecting devices under route and mounting conditions very difficult.

For this very reason, the efforts of LLC "Spectroflash" specialists have been always aimed at the development of portable X-ray generators. There were two key priorities:

1. The development of pulsed X-Ray generators on the basis of explosive electron emission;
2. The development of classic thermionic X-ray generators operating at high frequency of transformation of supply mains' voltage to voltage applied to the X-ray tube.

The phenomenon of explosive electronic emission was discovered by a group of Soviet scientists (G A Mesyats, G N Fursey, V A Zuckerman and others) in the late 20th century and since then it has been used by manufacturing of cold-cathode X-ray tubes. The nature of this phenomenon is as follows: at certain values of electric current in the tube diode as a result of warming-up of local apices of the cathode by own self-emission current, they explode and dense plasma forms, that is an intense source of electrons.

Many experimental studies showed that in the initial period of time that equals to several nanoseconds, the velocity of plasma expansion into a vacuum for most metals is $(1-3) \cdot 10^6$ cm/s, so it shall be assumed that current in this tube diode is limited by a space charge in the gap "the front of moving plasma-anode". That means that such a diode is the tube diode with a decreasing "anode-cathode" gap. Appeared cathode plasma leads to the formation at the cathode of the tube diode a liquid constituent of metal from which under the influence of electric field micro-apices are drawn and craters appear at the solid part of the cathode. In such a manner, a specific cathode micro-relief is created. With each current pulse, a certain quantity of cathode micro-apices disappears and a certain quantity of them appears again. This process is called the effect of a self-healing cathode. Explosive electronic emission is quite a complicated phenomenon and that's why it is not a subject of a detailed description in the current report.



From all has been said above, only several practical assumptions can be made:

1. The plasma cathode under certain conditions can be considered as a regular metal cathode, so at determining of the X-ray tubes' voltage–current characteristics with explosive electronic emission, it is possible to use all instruments developed for regular diodes with an incandescent cathode, taking into account that current in this case increases in comparison with Child–Langmuir equation (three-halves power law) due to the decrease of the “anode–cathode” gap by the plasma movement;

2. There is certain dependence between electric field intensity at the tube cathode, the current amplitude and the tube life duration. This refers to the realization of the mode of the “self-healing cathode”.

These assumptions define the list of requirements to output parameters of a high-voltage source, feeding the X-ray tube with an explosive cathode.

First of all, the source has to produce at the output a high-voltage pulse with amplitude that provides electric field intensity at the tube cathode about 10^6 V/cm. At that, pulse front time shall not exceed units of nanoseconds. Only under these conditions the process of explosive electronic emission is developed on the tube.

And, in the second place, the current pulse, appearing in a tube vacuum gap, on the one hand, has to be powerful enough to obtain maximal energy of the X-ray emission, and, on the other hand, its duration has to be less than the time required for plasma to cut the “anode–cathode of the tube” gap. Elsewise, there will be an electric arc in the tube, leading to a quick breakdown of the tube.

In all pulse apparatuses produced by LLC "Spectroflash", Tesla transformer as a high-voltage source is used. Due to a special construction of the transformer, the mutual-coupling coefficient between its coils is 0.65–0.7, which provides a high performance coefficient of the whole generator. The voltage pulse duration at the output of the generator is 1–2 ms depending on the type of apparatus. To obtain the duration of pulse at the X-ray tube about 1–1.5 ns between the generator and the X-ray, a special discharger-sharpener filled with hydrogen under pressure of 40–60 atm. In case of electrical breakdown of this discharger, a high-voltage pulse with front less than 1 ns on electrodes of the X-ray tube appears. With this front the explosion of cathode micro-apices with further plasma formation happens. All three elements (Tesla transformer, discharger-sharpener and X-ray tube) at such short voltage pulses have extremely low weight and dimensions.

Pulse X-ray apparatuses have been produced by LLC "Spectroflash" company for 25 years. Its first series contained 5 models and had a common name ARINA. These apparatuses are still produced. Their technical characteristics are shown in the table 1.

Table 1. Technical characteristics of ARINA pulse X-ray apparatuses.

Characteristics	ARINA-1	ARINA-3	ARINA-7	ARINA-9
X-ray tube operating voltage, kV	150	200	250	300
X-ray dose at a distance of 500 mm from focus of X-ray tube during 1.5 min, mR	500 (in 1000 p.)	600	1000	1200
Focal spot size (mm)	2.5	2.5	2.5	2.5
Ray method – directed/panoramic. Maximal thickness of X-ray steel from focal distance 700 mm during exposure period of 10 minutes with film usage:				
D7 + Pb	–	–	20	25
F8 + RCF	15	20	25	30
F8 + NDT 1200	25	30	40	50
Weight of X-ray source, kg	8.9	5.5	7.9	8.1
Dimensions of X-ray source	530×125 ×210	420×125 ×215	515×140 ×210	510×135 ×215

At the present time, a new series of pulse apparatuses named PAMIR is developed. As distinguished from the ARINA apparatus, new detecting devices have increased operational life and longer time of continuous operation. X-ray characteristics of both series are the same. The weight and dimensions of apparatuses of both series are close to each other. Pulse X-ray apparatuses are shown in figure 1.



Figure 1. Pulse X-ray apparatuses (from left to right) PAMIR-200, PAMIR-250, PAMIR-300.

A thermionic group of apparatuses is produced under MART name and consists of 2 models. Technical characteristics of both apparatuses are shown in the table 2.

Table 2. Technical characteristics of MART thermionic X-ray apparatuses.

Characteristics	MART-200	MART-250
X-ray tube operating voltage, kV	205–200	130–250
X-ray dose at a distance of 500 mm from focus of X-ray tube during 1 min, R	3	5
Max anode power, W	100	200
Ray method – directed/panoramic. Maximal thickness of X-ray steel from focal distance 700 mm during exposure period of 10 minutes with film usage:		
D7 + Pb	20	30
F8 + RCF	30	40
F8 + NDT 1200	40	50
Power supply	220 V 50 Hz	220 V 50Hz
Weight of X-ray source, kg	6	9
Dimensions of X-ray source	430×100×160	580×140×190

MART differential characteristics are: first of all – high transformation frequency of 220 V supply mains voltage to 200–250 kV voltage, required for supply to the X-ray tube, and secondly – bi-polar connection of high-voltage to X-ray tube electrodes. Both factors allowed decreasing significantly the weight and dimensions of X-ray generators. Practically, their weight is commensurate with the weight of X-ray generators but both MART apparatuses are significantly more powerful than pulse apparatuses. Each of them provides for the possibility of adjusting the anode voltage in wide range and the total operational life of each apparatus exceeds the operational life of pulse apparatuses. In both apparatuses, 0.1 BPM27 X-ray tube, with two versions, is used. The MART-250 apparatus' tube has a side output in the solid angle 50°. In the MART-200 there is a front output in the solid angle 140°.



Figure 2. Thermionic group of apparatuses MART-250, MART-200.

Summarizing all above-mentioned information, it is possible to make the following general conclusions:

1. Pulse and high-frequency apparatuses are close to each other in their dimensions and weights and X-ray characteristics, so they can be used in the same conditions;
2. Pulse apparatuses can be used both for directed and panoramic X-raying, they have extremely simple construction, and they are repairable at a customer's site, comparatively cheap in operation, undemanding in all weather conditions;
3. High-frequency apparatuses have the possibility of adjusting the X-ray tube voltage; they are more powerful in comparison with pulse apparatuses and have longer operational life.

References

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