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X-ray pulse apparatus based on explosive electron emission

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Abstract:

One of the basic problems of the design of the portable x-ray devices for the works under the field conditions is to get smallest possible weight and the overall sizes.

The classical apparatuses, which contain thermo-emission X-ray tube and source of constant high voltage as a rule have weight about 15-30 kg, which strongly impedes their use in the nonstationary conditions.

In the proposed work are described pulse X-ray machines containing tube with the cold cathode on the base of explosive electron emission. It explains the essence of explosive electron emission and the basic principles of the construction of the pulse X-ray emitters containing the cold cathode tube and the source of its power, capable to form the pulses of high voltage with an amplitude of 100-300 kV and with the duration of 10^{-9} s. Specifically with this duration and this voltage appears the effect of explosive electron emission, which is accompanied by the intensive flash of X-radiation.

In this work are also given the technical characteristics of pulse flaw detectors with general name of “ARINA” serially produced by “Spectroflash Ltd”, the major advantages of which are small overall sizes and weight, about 5-8 kgs.

Keywords: pulse x-ray apparatus

One of the main problems, while designing the X-ray equipment for operation under non-stationary conditions, is a problem to create the emission unit with minimum overall dimensions and weight[1]. Although, in recent years most developers of X-ray equipment have turned to manufacturing the generating single blocks with a high conversion frequency of the supply voltage to high voltage with its further multiplication and rectification; nevertheless, the weight of these single blocks is usually 15 to 30 kg. This fact makes it very difficult to use the single-block X-ray flaw detectors in pipeline routes mounting conditions.

The largest Russian pipeline systems are constructed in the East of the country. There is no infrastructure there and the prime measure for quality inspection of the pipeline welding joints is X-ray pulse apparatus, due to their small dimensions and weight and ability to obtain their power supply from batteries allowing performance of effective monitoring under difficult field conditions.

The operation principle of X-ray pulse apparatus is based on the effect of explosive electronic emission that has been thoroughly studied and described by the group of scientists with their leader, G.A.Mesyatz[2]. Its main idea is the following: when the electric field of the tube diode has certain values of intensity, the strong heating of local areas of the cathode by its own autoemission current will cause their explosion and formation of dense plasma being an intensive source of electrons. Many experimental researches show that at initial time period equal to a few nanoseconds the spread velocity of the newly formed plasma into vacuum constitutes $(1\text{-}3)10^6$ cm/sec for the majority of metals. Therefore, it can be expected that the current in the given tube diode will be limited by the space charge within the so-called interval "front of the moving plasma-anode". Consequently, this diode is a tube diode with a reducing interval "anode-cathode”. Plasma formed on the cathode will create a liquid component of metal on the cathode of the tube diode, and microspikes will extend from this liquid under the action of the electric field; some cavities appear on the hard area of the cathode. Hence, specific micro relief of the cathode is created. Some micro spikes of the cathode disappear with each current pulse, and some spikes emerge again. This procedure was called an effect of the self-regenerating cathode. Explosive electron emission is a pretty complicated phenomenon, and therefore, it is not subject to the detailed description herein.

From the abovementioned, only a few practical assumptions can be made:

1. Under certain conditions the plasma cathode can be considered as a standard metal one; that is, any means designed for standard diodes with the thermo emission cathode, can be used to determine the volt-ampere curves of the X-ray tubes with explosive electron emission only taking into account the fact, that in this case the current will increase as compared to «3/2» law due to reducing the gap "anode-cathode", while plasma moves.

2. There is a certain dependence of electric field intensity on the tube cathode, peak current and lifetime of tube cathode that determines the "self-regenerating cathode" mode.

These assumptions determine a list of requirements to the output parameters of a high voltage source which is feeding X-ray tube with explosion cathode:

Firstly, the source should generate the high voltage output pulse with the amplitude that provides the electric field intensity on the tube cathode of about 10^6 V/cm. In this case the duration of the pulse front should not exceed several nanoseconds. The explosive emission effect occurs in the tube only under these conditions.

And, secondly, the current pulse apperaing in the vacuum gap of the tube, on the one hand, should be strong enough to receive maximum X-ray radiation power, but, on the other hand, the pulse duration should be less than the time of overlapping the interval "anode-tube cathode" by plasma. Otherwise, the electric arc appears in the tube that leads to the early failure of the tube.

Few types of high voltage nanosecond generators are known. The most common among them are Arkadyev-Marx generators, in which quick successive linkage of several capacitive storages takes place, which are preliminary charged rather slow in parallel connection mode, and Tesla resonance transformers, which consist of the system with two oscillation circuits coupled, are the most common among them. The main component of these both generators is a gaseous switch that provides a startup of the high voltage circuits.

The Tesla transformer as a high voltage source is used in X-ray pulse apparatus, which are developed and manufactured by the company Spectroflash Ltd. The power of the transformer is accumulated in the primary circuit will be latter transmitted to the secondary circuit, when the gaseous switch actuates. In this case, the output voltage becomes maximum under some constant values of coupling coefficient of oscillation circuits

$$\kappa = 1 \qquad 0.6 \qquad 0.386$$

As a rule, developers of Tesla transformers use the coupling coefficient κ = 0,6, that provides the maximum power transmission from the first circuit to the second circuit during the first one-half period of free oscillation pulses and the structure is the simplest one. The coupling coefficient 0.6 is easily provided by the ordinary air transformer.

In the equipment of Spectroflash Ltd. a transformer specially developed for portable X-ray emitters is used, with ferromagnetic core and coupling coefficient that is close to 1. This essentially reduces a resistive loss in the transformer, improves operation of the switch and increases the strength of dielectric liquid within the volume of a high-voltage module. Time of voltage build-up on resonant transformer output is determined by inductance value of oscillation circuits and generally it does not provide the necessary electric field intensity to create the plasma cathode in the X-ray tube. To reduce the time of a high-voltage pulse front, the discharge circuit of the described source, contains switch K_1 and peaking switch K_2, inserted between the output capacitor C_2 and X-ray tube P_T (Fig. 1). This peacking switch is a double-electrode switch filled with hydrogen under high pressure providing its switching time equal to 10^{-9} sec. Such time of high-voltage pulse front creates a necessary overvoltage on X-ray tube electrodes to develop the explosive emission of the cathode.

Equivalent circuit of X-ray emitter presented in Fig. 1 allows the most complete demonstration of physical principles of its operation and calculation of the main parameters of all components. Coupling coefficient of oscillation circuits of transformer is $\kappa \approx 1\text{-}1/2(L_s/L_\mu)$, where L_s is a leackage inductance of both circuits and L_μ is a magnetizing inductance. Efficiency of power transmission from the primary capacitor C_1 to the output capacitor C_2 is $\eta = 1\text{-}\pi^2/8(L_s/L_\mu)$. It is obvious that at both maximum coupling coefficient between circuits, as well as peak efficiency of a high voltage source shall be provided only at $L_\mu \geq L_s$. Inductance coil L that shunts the X-ray tube prevents breakdown of P_T tube until the moment of full charge of output capacitor C_2 and actuation of peaking switch K_2.

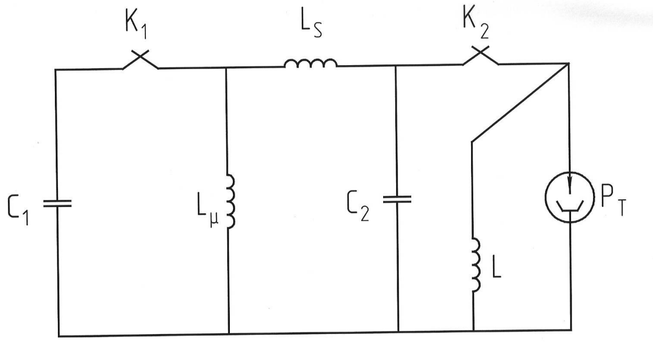

Figure 1. Equivalent electric circuit of X-ray emitter of the pulse apparatus on the tube of explosive electron emission

Experience of designing the pulse apparatus with application of this circuit of emitter shows, that despite the presence of reasonably complicated technological component - the peaking discharger, the X-ray tube overall dimensions and, therefore, overall dimernsions of the whole generator are essentially less than overall dimesions of the classic single-block generators with DC voltage owing to a very short time of a high-voltage pulse on X-ray tube electrodes.

By design, the main components of oscillator[3] the X-ray tube (3), a peaking switch (2) and pulse transformer (1) are placed into a single casing (4) filled with the transformer oil (Fig. 2).

The X-ray tube is made in the form of a glass bottle, inside which the spired tungsten core (as anode of the tube) is placed. Tungsten disk with a hole is used as a cathode, and the spired end of the anode is placed in the center of the disk. The inner edge of the disk 20 microns thick is the emitting part of the cathode. The peaking switch is a metal cylinder containing two electrodes made out of a high-melting metal. One electrode is soldered to the cylinder cover, and the other electrode is soldered to the conic ceramic insulator. Inner volume of the switch is filled with hydrogen under pressure about 40 atm. The pulse transformer includes a ferrite rod on which the secondary winding is wound; each turn of the winding is isolated from each other by the insulating layer. The transformer primary winding is made of 0.1 thick copper foil; it is wound around the secondary winding. Metal housing of the peaking switch and the housing (4) will form a structural capacitor C_2 (see Fig. 1).

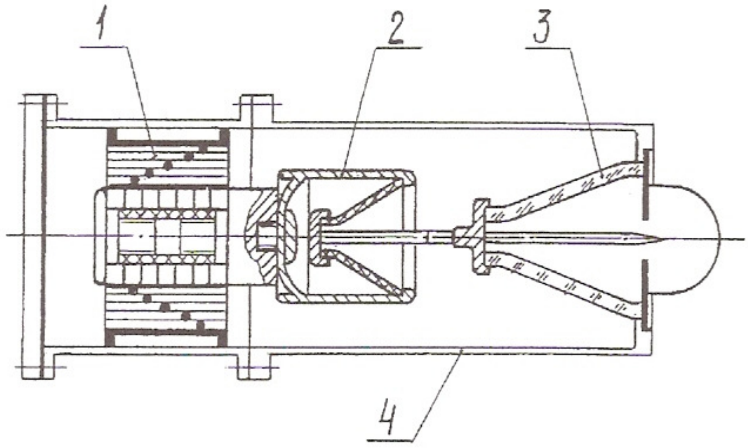

Figure 2. Structure of a high-voltage unit

It is assumed to name the structure described above as a high-voltage module of apparatus. The primary switch K_1, capacitor C_1 and a high-voltage module will form an X-ray emitter.

Except for the emitter, each X-ray apparatus has a standard remote control panel, where the control and monitoring circuits are located. Emitter and control panel are connected with 25 m cable long that provides safe position of the operator during operation.

Currently Spectroflash Ltd. manufactures four models of pulse apparatus with common name ARINA that differ from each other by the operating voltage on the X-ray tube. Their parameters are given in Table[4].

Parameters	ARINA-1	ARINA-3	ARINA-5	ARINA-7
Operating voltage on the X-ray tube, kV	150	200	220	250
Diameter of focal spot, mm	2.5	2.5	2.5	2.5
Thickness of steel examined with X-rays, mm - using the lead foil, - using fluorescent X-ray intensifying screens,	15 30	20 40	30 60	40 80
Radiation dose per pulse at a distance of 0.5 m from the focal spot, mR	0,5	0,8	1	1,5
Repetition rate of X-ray pulses, Hz	8	10	12	10

Power consumption, W	120	150	200	250
Weight of emitter, kg	6,5	5,5	6,0	8,5

Finally we'd like to say a few words specifically on how to use the pulse apparatus of ARINA[5] type.

First of all the apparatus of this type with the substantially small overall dimensions and weight compared to the continuous operation apparatus, has less average radiation power.

And, secondly, they allow neither control of the current nor of voltage. These circumstances determine the most optimal conditions for their use.

As already mentioned above, the main purpose of pulse flaw detector is a weld quality inspection of industrial facilities under non-stationary conditions. At that it is very important to select the conditions of X-ray investigation using them. Application of a high-speed film, for example, STRUKTURIX F8 type and fluorometal screens of RCF type of AGFA GEVAERT or HS 800 film of KODAK company with Kyokko SMP308 Japanese fluorometal screens, allows to obtain the high-quality images during a relatively short time of exposure. At the same time application of the high-contrast film together with the lead foil does not provide the essential advantage for the quality of X-ray pictures, but increases the time of exposure in dozens of times, thereby reducing the lifetime of the apparatus.

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