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Pulsed X-ray source based on photo X-ray tube

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Abstract. The purpose of this paper is to present main parameters of high frequency X-ray source based on the photo X-tube with photocathode in compare with other tube types. Attention is paid to physical processes that influence such factors as minimum impulse duration and tube current. In the second part of the article the main parameters of designed pulsed X-ray source is given.

1. Introduction

X-ray tube is used for generating X-ray radiation. Such kind of radiation in conjunction with special screens, X-ray sensitive films and other detectors is used for non-destructive testing of objects structural defects or for fluorescent analysis. If object while it is being radiographed is stationary, the problem with studying of its volume does not arise. In cases when the investigated object is moving, its exposure time is directly related to the quality of the resulting image. In other cases, for example while the investigation of the scintillator “relax time” is carrying out, it is required to have a modulation of the exciting radiation faster than the object “relax time”. Thus, there are tasks when the frequency characteristic of the X-ray source is very important.

An ordinary X-ray tube consists of an anode, a thermo cathode and a glass envelope. The heated filament emits electrons by thermionic emission. It means that if it is needed to change the tube current the cathode temperature has to be changed. That process takes some milliseconds. That’s why such tube construction is not suitable for taking x-ray photos of movable objects.

2. Impulse X-ray tubes

As it was mentioned earlier, radiographing the moving object requires a source of pulsed X-ray radiation. The main rule is that the pulse time should be much shorter than the moving times of the object. To solve this problem, it began to look for a way to create impulse X-ray tubes. Nowadays, there are several major ones that should be considered.

The main type of impulse X-ray tube is an X-tube with cold cathode. The action principle of a tube with a cold cathode is based on the phenomenon of field emission and not on thermo-emission as in conventional tubes. The first samples of field emission tubes used a cathode in the form of a metal needle. A high potential between a cathode and anode produces a strong electric field at the tip of the needle sufficient to pull electrons out of the cold cathode. Then the electrons are accelerated towards an anode as in standard X-ray tubes. Generally, a vacuum of 10^{-8} Torr or better is required because bombardment of the cathode by positive ions of the rest gas deteriorates its sharp tip and reduces drastically the electron emission. The great advantage of such X-tube construction is opportunity to obtain impulses of tube current up to 10^3 A and lasting several tens ns. But current vary greatly from one impulse to other due to bombardment by positive ions "smooth" sharp tips and edges. The cathode lifetime limits by several thousands of impulse.

The latest developments use carbon-based cathodes in the form of graphite nanotubes or so-called "bucky paper". The main advantage of the carbon cathodes results from the fact that their bombardment by positive ions does not "smooth" sharp tips and edges. On the contrary, such a bombardment creates new sharp tips and edges due to the graphite structure. Therefore, the lifetime of carbon-based cathodes is significantly larger. Besides, one can work with lower vacuum (approx. 10^{-6} Torr). Operating frequencies of such tube constructions are in range up to several tens of kHz. Tube current may reach amount of several mA [2].

However, the standard x-ray tube with filament cathode can also provide a pulse X-ray. For example, for radiography in the pulsed mode periodically opening and closing the main circuit on the high voltage side are typically used. For this purpose it can be used either a three-electrode X-ray tube with a control grid or high-voltage triodes. The first variant used, for example, by Siemens is simpler. However, it requires a special X-ray tube, which able to limit the tube electron flow. In moment of fast limiting tube current the overvoltage is applying to the tube. But overvoltage is applying to the tube in moment of the fast current limiting. The second option is used, for example, by Phillips, is more complex. However, it allows conventional X-ray tube to be operated in conditions which are more relieved in comparison with the first embodiment. The opening and closing are performed here by HV triodes, x-ray tube does not suffer to overvoltage while current limiting. Such opening and closing the tube current circuit allows to reduce exposure to several ms. The tube current can reach several hundred of mA. Nowadays, a pulsed X-ray tube of the company Hamamatsu Photonics exists. The main difference is that the source of electrons is a photocathode. Such construction of X-ray tubes has a very small output intensity of X-ray radiation, but it is able to provide the modulation frequencies up to 10 MHz. It is used for determining fluorescence lifetimes between 20 ps and 1 ms.

3. Photo X-ray tube

Photo X-tube is the combination of photomultiplier tube and an ordinary X-ray tube. The schematic diagram of the photo X-tube is given in figure 1. The tube has a photo cathode to generate primary photo electron flow, which is proportional to the falling light intensity. But the amount of primary electrons is not enough for creating intensive current flow. A dynode system is used to multiply its quantity. Amplification ranging from 10^3 to as much as 10^6 provides output electron flow, which is enough for generating medium-intensity X-ray beam. After dynode system electrons get into the accelerating anode field, being accelerated, then collide with anode and generate an X-ray beam.

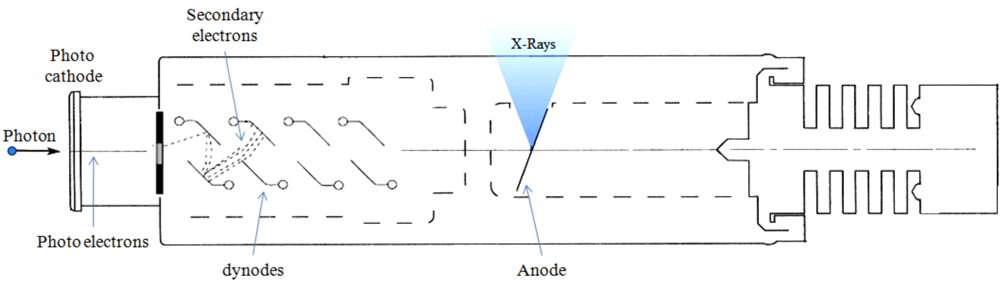

Figure 1. Photo X-ray tube construction.

It is considered, that the frequency characteristic of such kind systems depends only on electron flight time. The tube current control is carried out by modulating the intensity of the input optical radiation incident on the photocathode. For this purpose may be used either conventional LEDs or special lasers. It provides simplicity and stability of current control tube current from one pulse to the other, depending on the stability of the light emitter. According to the product datasheet [1], the tube is able to provide full frequency modulation in range up to 1 MHz with impulse current up to 1 mA.

Operating frequency range allows its use both as a source of modulated X-ray and to obtain a constant emission. Thus, the photo X-tube may be used for the similar purpose, which conventional directly heated tubes are used for. However, the tube has enlarged size and is more expensive, that features limit its application area to range, where its frequency characteristic in couple with operating current will be crucial.

4. Pulsed X-ray source based on photo X-ray tube characteristics

To investigate the frequency response of the X-ray tube with the photocathode, a special detector based on PMT and a plastic scintillator was used. The source of optical radiation for the photocathode was LED and a laser diode. As can be seen from figure 2 LED allow to provide the rise time of the out radiation front of 50 ns. Using a laser diode, it was possible to achieve a time of 20 ns.

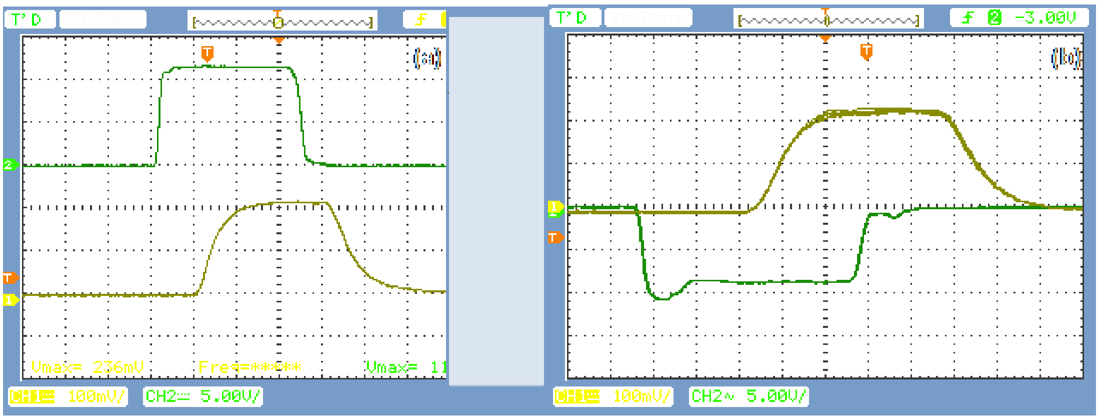

Figure 2. Oscillograms of the out radiation formed by LED (**a**) and the laser diode (**b**).

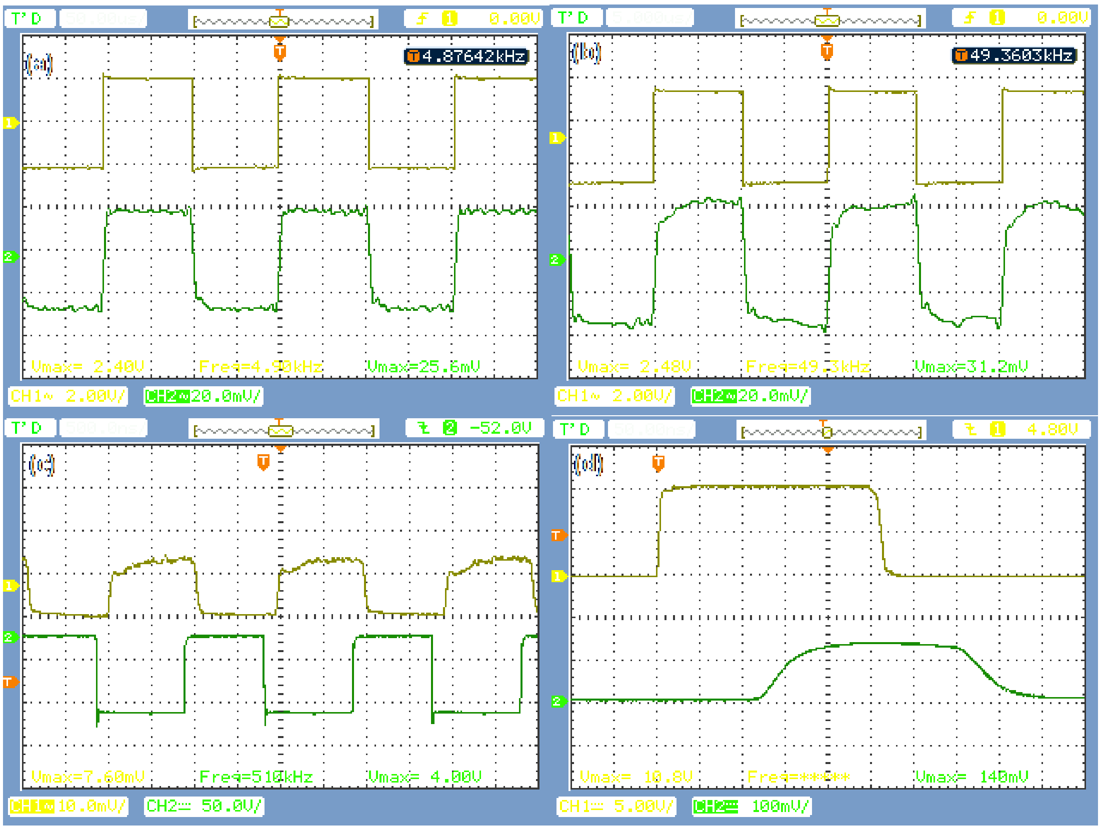

Figure 3. Oscillograms of the frequency response of the X-ray tube at frequencies of 5 kHz (**a**), 50 kHz (**b**) and 500 GHz (**c**), and also for single pulse with repetition 25 kHz (**d**).

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The frequency response of the X-ray tube with a photocathode was estimated with a duty cycle of 50% to a frequency of 500 kHz. Further experiments were carried out with pulses duration of several hundred ns and a repetition frequency of several tens of kHz. The results are shown in figure 3. The oscillograms of Fig. 5a-c illustrate the operation of the out radiation under study at frequencies of 5, 50 and 500 kHz. The oscillograms in figures 3(a)–(c) illustrate the out X-ray pulses at frequencies of 5, 50 and 500 kHz. The oscillogram shown in figure 3(d), demonstrates the passage of a single pulse. The repetition frequency is 25 kHz, the average current is 100 μA. The peak current is 30 mA.

From figure 3(d), it is possible to measure the rise time of the output pulse equal to 20 ns. The impulse current in this experiment was 30 mA. The cathode assembly of the tube is designed on the basis of PMT-84, which is capable to provide a pulsed current of up to 500 mA according to technical documentation. During the experiments, it was found that to provide such high pulsed current values, it is necessary to modify the divider of dynode system of the photo X-ray tube.

5. Conclusion

Based on the results, achived during testing developed sources of pulsed X-ray radiation, one can state the suitability of such source for generating X-ray pulses over a wide frequency range. The advantage of such X-ray source is the possibility of its use both for generation of pulsed X-ray and for long exposures. The source provides output radiation rise and fall fronts about 20 ns. The average current can vary up to 1 mA. The impulse current reaches a value of 30 mA. However, in theory, it is possible to increase this value up to 500 mA.

References

[1] *X-Ray Tube with photo cathode datasheet*. URL: http://www.electron.spb.ru/data/%D0%A4%D0%A0%D0%A2%20datasheet.pdf

[2] *Handbook of Practical X-Ray Fluorescence Analysis*

[3] *Advances in X-ray Analysis, International Centre for Diffraction Data* 2005 **48**

[4] Reyes-Mena A, Jensen Charles, Bard Erik, Clark Turner D and Erdmann K G *Miniature X-Ray tubes utilizing carbon-nanotubebased cold cathodes* (MOXTEK Inc., Orem)