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Research Article

Design and production of a fixed anode x-ray tube

Mert Arslan [a,*], Tunahan Yadigaroğlu [a], Meltem Muhsuroğlu [a], and İlyas Kacar [a]

[a]*Department of Mechatronics Engineering, Nigde Omer Halisdemir University, Nigde and 51240, Turkey*

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ABSTRACT

Nowadays, *X*-ray has had a wide range of applications in nuclear imaging, medicine, and industry. In our country, *X*-rays are widely used in these fields. However, we are in dependence on foreign sources on the *X*-ray devices. In our study, it is aimed to design a fixed anode type *X*-ray tube which is essential in medical imaging techniques by using the local opportunities, to carry out production of a prototype and to observe the *X*-rays experimentally. As a result, an *X*-ray tube is designed and three *X*-ray tube prototypes are manufactured by forming of Pyrex glass. *X*-rays are measured by using dental *X*-ray film and Geiger Muller counter.

1. Introduction

Since the exploration of *X*-rays, they have been used on various and important fields in daily life by the reason of their short-wavelength and high energy. It is being used as a device for prognosis and treatment in medicine, to detect the stiffness of metals especially for cast or welded components in industry, as a researching tool in chemistry and physical science as in *XRF (X-ray fluorescence)*, *XRD (X-ray Diffraction)*, and other *X*-ray devices.

The study was started by discussing the question "Is it possible to produce *X*-ray tools with domestic resources?". After a long time of researches, some questions were answered such as what kind of ray *X*-ray was, which *X*-ray production technique could be used, and which manufacturing technologies had to be applied. Ultimately, materials to be used were determined and necessary process steps were decided to apply. If the high-voltage circuit is applied between well placed anode-cathode in a vacuum chamber, *X*-rays can be obtained and a prototype *X*-ray tube can be produced [1-2]. *X*-ray tubes are divided into two types as *fixed anode* and *rotary anode* [3]. An *X*-ray tube consists of *anode* and *cathode* elements placed inside a glass tube where its air is removed by means of high vacuum [4].

The anode material consists of a thick rod and a metal target at the end of this rod. The material of anode is very important because it determines the type and amount of electron to be released. For example, *Cu* metal can conduct *X*-rays when an electron arrives on it [5]. The cathode is made of tungsten material and called filament [6]. It releases electron when heated. When the filament is fed with an *AC* source, it starts heating. So electrons on the tungsten material reach high speed and kinetic energy. High speed electrons flow toward copper metal and collide with a copper atom. The electron may have to collide with many atoms until it is stopped. When electron stops, one percent or less of its kinetic energy is converted to some *X*-ray radiation and the remainder to heat energy [7-9].

The power of *X*-rays to penetrate into the material is called "hardness". The hardness of these rays depends on two main parameters. First one is vacuum quality. The more vacuum leads to the less number of remaining gas molecules in the tube. It results in the less impact of electron to remaining gas molecules and the less deviation from target. Second factor is the applied voltage, namely the electrical pressure. The higher voltage results in the bigger impact effect of electron flow [10].

In this study, firstly, a fixed anode *X*-ray tube was designed and prototype tubes were manufactured by

* Corresponding author. Tel.: *+90-553-987-4005*; Fax: +90-388-225-0112
E-mail address: mert.arslan.125@gmail.com
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adhering to this design. As a result, an *X*-ray tube was produced and electromagnetic *X*-ray waves ranging from 0.1 to 100 *Å* in wave length were observed experimentally.

2. Method and Material

2.1 X-Ray Tube Design

The design of the *X*-ray tube was done in Solid Works™. The *X*-ray tube consists of 6 parts in total. The tube design created by mounting of solid models of whole components is given in Figure 1.

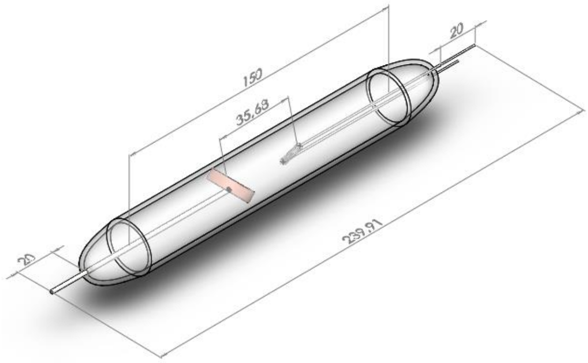

Figure 1. Designed X-ray tube

After the *X*-ray tube is designed, the bottom plate is used to accommodate the power sources and the tube together. Installation is shown in Figure 2.

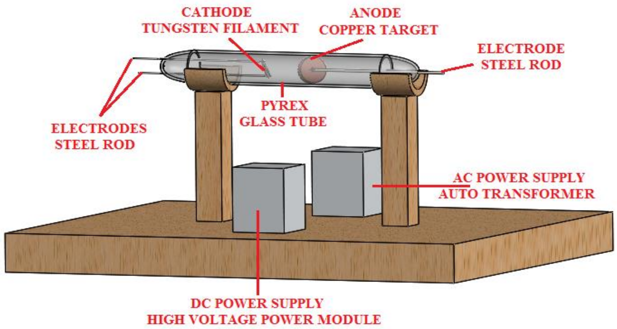

Figure 2. Montage schema of complete system

2.2 System Manufacturing

After the tube design, the manufacturing stage has been started.

Firstly, anode material is prepared. A copper bar is machined by a lathe machine to obtain *Cu* target. The copper target is brazed to steel electrode using gas welding. Besides, surface polishing is done to get more rays from the target material. The surface of the target material is gradually sanded from coarse to finer sandpapers by using 350, 500, 1000, 2200 and 4000 grids containing silicon carbide grains and magnetite powder. A produced anode material is shown in Figure 3.

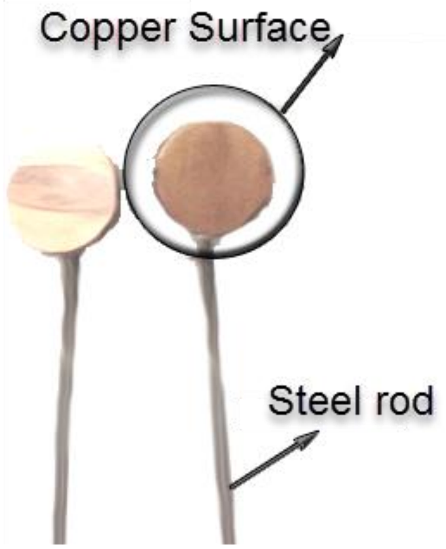

Figure 3. Anode (copper target)

Later, the cathode preparing process has been started. The cathode is negative terminal of the *X*-ray tube. The cathode is called "*filament*" too. The filament is a winding of tungsten alloy wire in cylindrical shape with outer diameter of 2 mm and a length of 1-2 cm. The reason for using tungsten is that it has high heat-resistance (up to 3410 °C) and emits more thermionic emissions. In order to allow electrons to leave filament metal in the thermionic emission, electrons must be given at least *W* energy, which is defined as a function of work applied on the filament metal. The count of electrons leaving filament metal in a unit time increases with the temperature of the filament depending on metal used. In the case of energy greater than *W*, the electrons leaving the filament surface will have some kinetic energy. Filament is heated by passing a low AC current inside in order to load kinetic energy on electrons and accelerate them and so it will be ready for high temperature shock. The applied voltage and current approximate 3 to 6 amperes result in heating of more than 2200 °C due to the high resistance of filament material. In the heated filament, electrons in the outer orbital of the tungsten atoms liberate and separate from filament surface and thermionic emission occurs.

Since the tungsten element has a brittle microstructure, filament formation is very difficult. So tungsten wire is heated by using oxy-acetylene flame and bended into cylindrical shape. Finally both ends of filament winding are brazed to steel electrodes as seen in Figure 4.

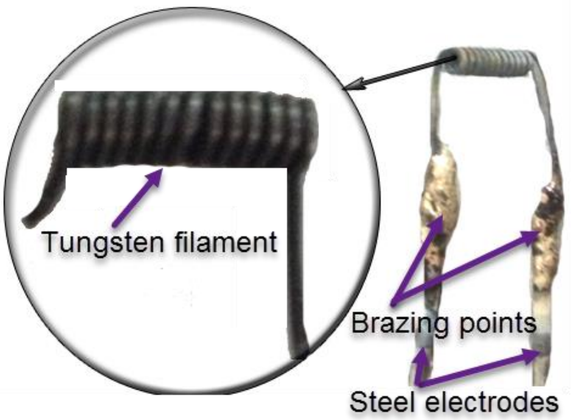

Figure 4. Cathode (tungsten filament)

After the anode and cathode elements are prepared, these two materials were appropriately inserted into a Pyrex (borosilicate) glass tube. Pyrex glass has high temperature resistance and makes rays up to 3000 Å passed through and has low heat expansion coefficients. Pyrex glass is processed at high temperature of approximate 3200 °C, by using flame, a mixture of 50% oxygen and 50% acetylene gases. Anode element is placed on one side of the Pyrex glass and after it is sealed.

Another narrower Pyrex glass tube with 2 mm inner diameter is attached to the tube as vacuuming port on the glass tube. After the implementation of the anode element and vacuum port, finally, the cathode element is assembled to glass tube. An image taken during operation is shown in Figure 5 and the assembled *X*-ray tube is given in Figure 6.

Figure 5. Stage of placement of anode-cathode elements

Figure 6. Anode-cathode elements placed in Pyrex glass tube

Inside Pyrex glass tube, anode-cathode elements and the narrower tube for vacuum are mounted properly. Later, epoxy adhesive treatment is applied to the ends of the tube for sealing precisely. Also an epoxy adhesive fills the cracks for preventing of crack propagation. The image after applying the epoxy is given in Figure 7. But epoxy breaks down at high temperature. So, epoxy will be useful unless reaching high temperatures. For commercial application of the tube, it is compulsory that a leak proof connection has to be done instead of epoxy due to high temperatures or long application times.

Figure 7. Produced X-ray tube

2.3 Experimental Setup

In our experimental rig system, vacuum is applied during working. During vacuuming, an *AC* power source is connected to the filament (cathode) side, finally, the high voltage source is connected to the *X*-ray tube.

The vacuum is applied to remove any gas molecules inside the tube, so that accelerated electrons can reach the target without colliding with the gas molecules inside the tube. When inside of tube is vacuumed perfectly, gas ionization is avoided in the *X*-ray tube completely. Besides, the vacuum of the tube is necessary for long life and effective *X*-rays. Figure 8 shows vacuum pump and *X*-ray tube used.

Figure 8. Vacuum application to the X-ray tube

It is necessary to heat the filament about 2200 °C so that electrons of the tungsten atom can break off from the filament surface. Heating can be controlled by using a variac (auto transformer or other name *AC* voltage power supply). The high voltage power supply used in the system is a *R* 179 model, *DC* 40 KV ignition coil power module. An image of the connection of the auto transformer and the power module to the *X*-ray tube is shown in Figure 9.

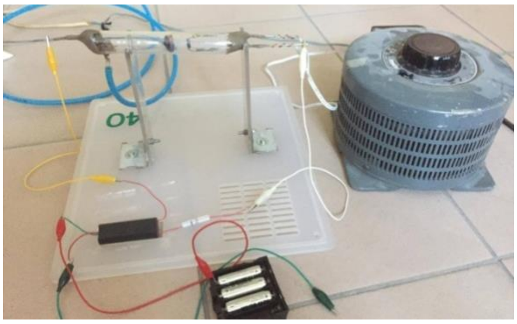

Figure 9. Connecting power supplies

The *X*-ray tube becomes ready for use after the vacuum, auto transformer (variac), and the *DC* high power module are connected to Pyrex glass tube.

2.4 Experiments

In this study, *X*-rays are applied by two different methods. First method is directing of rays to on *X*-ray film. In the experiment, self-bathroom dental *X*-ray films are used. This method is not accurate due to difficulty for calibration. Also these films are affected by temperature and humidity and not reusable but still used as a successful method for getting fast results. Figure 10 shows the experimental system with dental film.

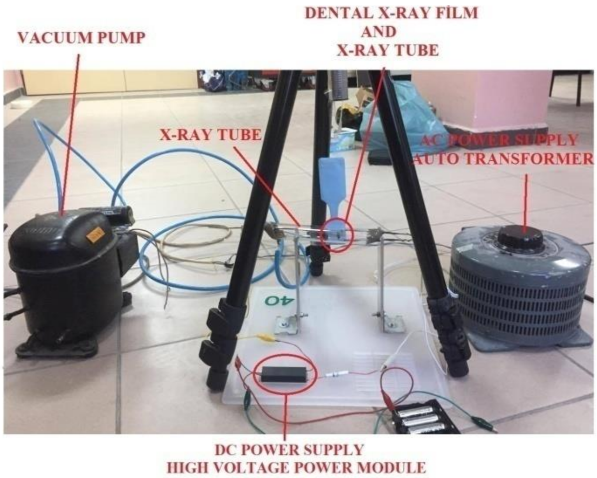

Figure 10. Experimental system

Figure 11 shows that the system is started and rays are directed on the dental film.

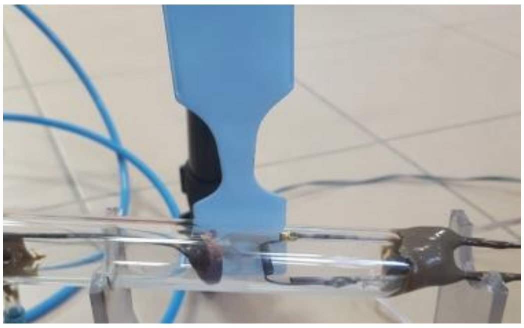

Figure 11. Dental X-ray film and X-ray tube

A Geiger-Muller counter which measures radioactivity is used in the second method. This counter detects any nuclear radiation resulting from *X*-rays by using ionization produced by the low-pressure gas (He-Ne) inside the Geiger-Muller tube which gives the name of the device. The Geiger-Muller counter used is seen in Figure 12. Experimental rig system is given in Figure 13.

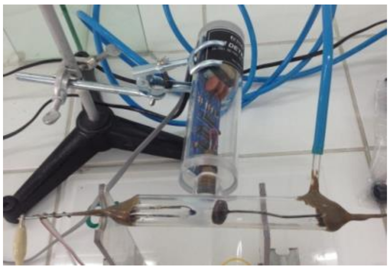

Figure 12. Geiger-Muller counter and X-ray tube

The test system shown in Figure 13 detects the nuclear radiation originated from *X*-rays. When the Geiger-Muller counter is getting closer to the *X*-ray tube, it detects the *X*-rays emitted and transfers data to software by a computer and the computer graphically displays number of counted *X*-rays with respect to time.

Figure 13. All of the experimental system of Geiger-Muller counter

3. Results and Discussions

In this work, so called fixed anode *X*-ray tube is design and produced. The design process is realized with Solid Works™ three dimensional solid modeling program. After design, glass processing for placing the anode-cathode materials is done by means of oxy-acetylene flame.

The obtained image by using dental film is given in Figure 14.

Figure 14. A flue image formed on dental film

The image couldn't be obtained clearly by that method but a flue image formed already on film proves existence of the *X*-rays. The reason why the image couldn't be obtained clearly is that the photographic film (dental film) is inefficient in absorbing *X*-rays. These films can absorb only 2% of incoming photons. To increase this ratio in commercial applications, a screen is put behind films. Our experimental system hasn't any monitoring screen.

Screen material is generally composed of fluorescent materials (Calcium-tungsten, cesium-iodide). When *X*-rays arrives at screen, rays are absorbed by screen and stimulate electrons on this screen. It causes more ionization and the absorption efficiency goes up to very high levels and a clear image is obtained.

In the Geiger-Muller counter method, Geiger-Muller counter can show number of ionization events. In other words, it can prove precisely existence of the *X*-ray. It can't determine energy and other characteristics of the ray. Figure 15 shows the results obtained.

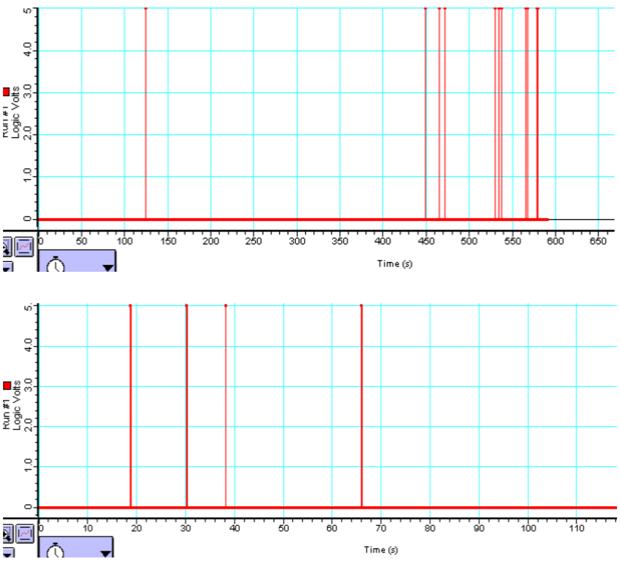

Figure 15. Logical value of X-rays counted by time

When the *X*-ray tube is started to emit *X-rays*, counter will detect and logically display a pick value on the screen.

Because Geiger-Muller counter can only determine if *X*-ray radiation occurs. Two graphics show logical values. Logic 1 value is seen as 5.0 V in the graphic.

The results of two different experiments are shown on graphics in Figure 16 as exist or not exist. In other words, graphics show ionization events occurring during test. In the first graphic, the *X*-ray tube is run for 125 seconds and in the second experiment for about 600 seconds.

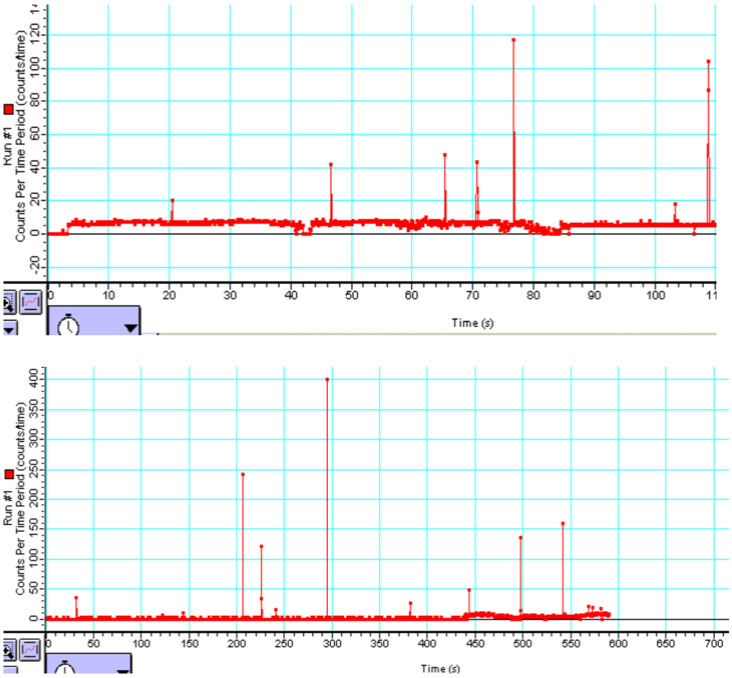

Figure 16. Geiger-Muller experiment results

4. Conclusions

With this study, an *X*-ray tube, which is basic part of an *X*-ray machine is designed and manufactured. The one of remaining two basic partitions is a *control console* that includes an on/off switch, control buttons allowing the operator to obtain the desired amount of *X*-ray, some indicators for *KV* and *mA* values, a regulator which compensates incoming current. The second partition is a *high voltage generator*. It is placed inside a tank full of oil. It also includes voltage-boosting transformers, filament transformers and rectifiers. Oil is an electrical insulator and allows these elements to be located side by side placement inside oil. When these three basic parts are come together, there will be a full *X*-ray device.

With this work, the design and manufacture of an *X*-ray tube has been realized and the prototype costs 33.5 Turkish Liras. Thus, *X*-rays can be produced at very low cost.

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Nomenclature

AC :Alternative Current
DC :Direct Current
KV :Kilovolt
Å :Ångström
W :Energy
mA :Miliampere

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