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A LOW-VOLTAGE X-RAY TUBE

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ABSTRACT

A low-voltage X-ray tube was developed to generate and transmit radiation at wavelengths longer than one angstrom. Operation is possible with target current up to 50 milliamperes and at target voltages from 0 to 12,000 volts, the target dissipation limit being 10 watts. The tube is built in a simple hard-glass bulb with a thin glass window approximately 5 microns in thickness. Preliminary performance tests indicate transmission of radiation in the region of 12 angstroms and shorter wavelengths, and in the ultraviolet. No determination has been made of possible transmission at intermediate wavelengths. It is expected that the tube will prove useful in investigations in this little-known part of the spectrum between the soft X-rays and ultraviolet radiation.

PROBLEM STATUS

This is a final report on an instrumentation development connected with research in the upper atmosphere.

AUTHORIZATION

NRL Problem P06-09R.
NR 486-090

A LOW-VOLTAGE X-RAY TUBE

INTRODUCTION

The development of the low-voltage X-ray tube described in this report was undertaken as a result of a request from the Rocket Sonde Branch of Radio Division I for a device which would emit radiation in the wavelength range from one to thirty angstroms. It was to be used for the testing and calibration of counter tubes used for the exploration of solar radiation in this range in the upper atmosphers.

The design and development problem was to produce a source of X-rays in which the minimum (or peak) wavelength could be varied throughout this range and determined with reasonable accuracy. This required that the tube operate at target voltages between 500 volts and 12,000 volts approximately, and that the window transmitting this radiation to the air have appreciable and reasonably known transmission in the wavelength range specified. Generation and transmission of X-rays of reasonable intensities at the longer wavelengths was obviously the more difficult and important requirement.

DESIGN OF THE TUBE

From a general consideration of transmission characteristics of known materials, it was apparent that anything like uniform transmission through the window over the required range would not be obtained, but that the optimum design would be the thinnest possible window composed of material of low atomic number. Since it is possible to blow glass windows about 5 microns thick strong enough to hold vacuum against atmospheric pressure, a thin glass window was chosen. It was made of Pyrex glass, which is composed mainly of boron, silicon, and oxygen.

As it was desired to produce the tube in a limited time to allow tests before a scheduled use of the detection equipment, it was decided to use initially a simple design in which all electrodes of the tube are contained within a glass bulb and cooled by radiation. This design limits the target dissipation to a level of 10 watts maximum for a target of convenient size. In order to obtain, with this dissipation limit, maximum radiation intensity throughout the voltage range of operation, the electron beam current must be adjustable from 20 milliamperes at 500 volts to about 1 milliampere at 12,000 volts. In order to provide for possible use of the tube at even lower voltages, and to provide for modulation peaks, it was considered desirable to use an electron source capable of supplying an electron beam current up to 50 milliamperes.

For convenient control of current throughout the range from 1 to 50 milliamperes, and in order to make it possible to modulate the current at a high rate, it was decided not to rely on control of filament temperature, as is usual in X-ray tube practice, but to use an electron gun having a control and an accelerator electrode, the voltage on which would control the current in the electron beam. The use of two closely spaced accelerating electrodes appeared desirable, because the electron lens formed by the potential field between these two electrodes provides some focussing of the electron beam. Focussing to a small spot was not needed, but some control of beam dispersion

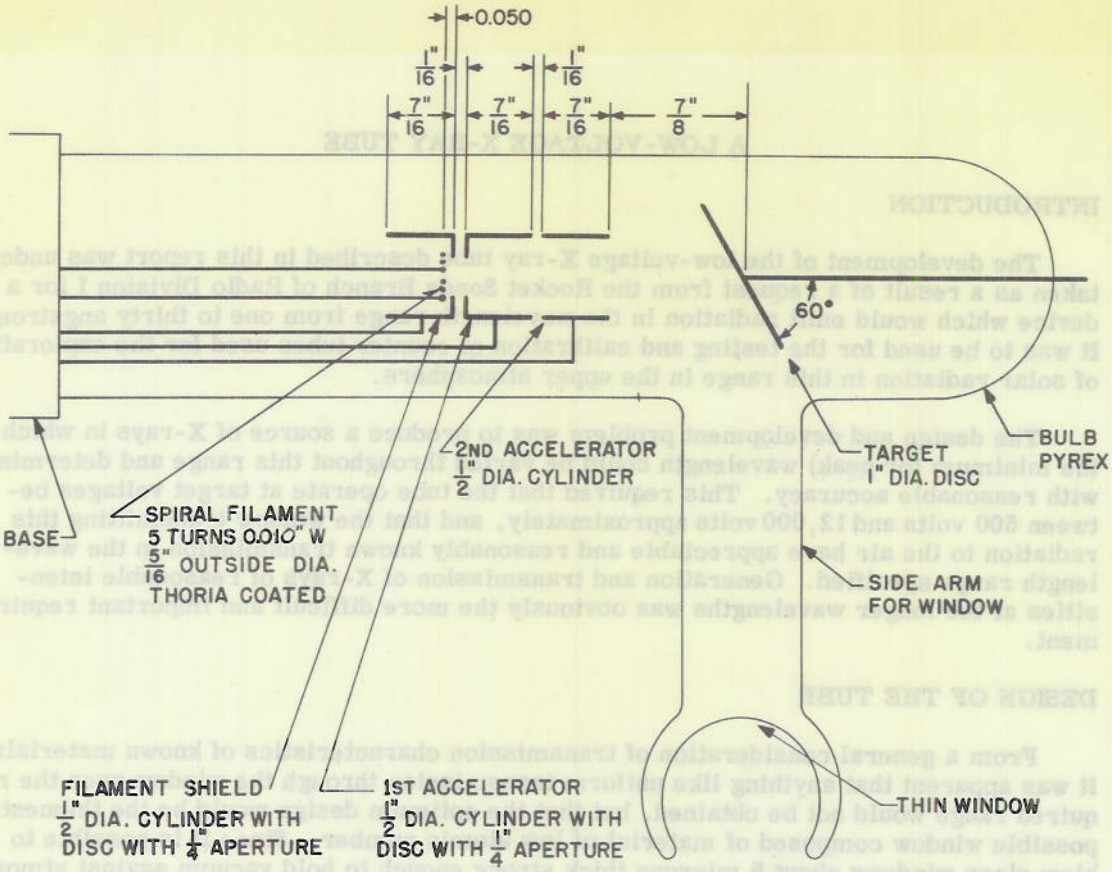

Figure 1. -- Cross-section of envelope and electrodes

was desired in order to minimize bulb bombardment possible with operation over the desired wide range of target voltage and current.

In accordance with the above considerations, and from experience with various electron beam sources for many types of devices, the structure shown in Figure 1 was adopted for trial. This made use of parts readily available and a structure easily assembled. The gun consists of a filament, a filament shield, and first and second accelerator electrodes. The filament is a thoria-coated tungsten spiral of 10-mil wire, 5/16 inch in diameter. The filament shield has a 1/4-inch hole and serves only as an aperture immediately in front of the filament. At first it had been intended to place a coarse mesh grid over this aperture to control the beam current, but because of the method of supporting the filament it was not possible to position the shield close enough to the filament to get effective grid-control action. Used as a shield, this electrode aids in beam focussing and elimination of stray bombardment.

The 1st and 2nd accelerators are cylinders, the dimensions and spacing of which are shown in Figure 1. The first tube constructed used a target of molybdenum because this material is most easily mounted on a support from the top of the bulb. In

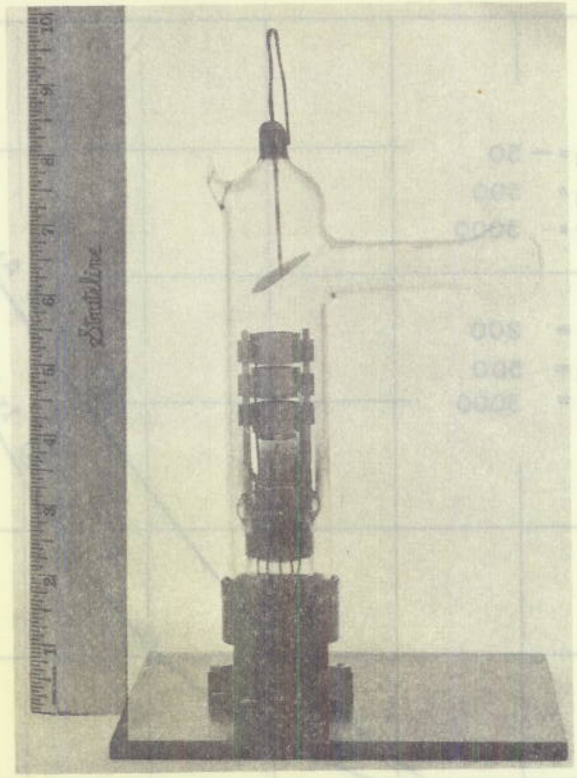

Figure 2. -- The Complete Tube

constructing a second and third tube, titanium was used as target material, as titanium has L-orbit resonance at approximately 28 Å and so should give radiation peaks in this poorly transmitted spectral region. The target is mounted at an angle of 60 degrees to the tube axis and is lined up with the window side-arm in order to permit transmission of the X-radiation through the window. Figure 2 shows the completed tube and relative positioning of the various parts.

OPERATING CONDITIONS

In operation it has been found that, for target voltage at or above 1,000 volts, best operation is obtained by setting the filament shield voltage at -50 volts, the 2nd accelerator at 500 volts, and with target voltage on, raising the voltage on the 1st accelerator to give the target current desired. Curve 1 of Figure 3 shows the variation of target current with the voltage applied to the 1st accelerator. From this curve one can determine that, if the target is to be operated at 5,000 volts, for example, and if the current (for 10 watts dissipation) is to be 2 milliamperes, the 1st accelerator voltage must be adjusted to 140 volts. If it is desired to modulate the beam current, an a-c voltage may be applied to the 1st accelerator, which draws practically no current under these conditions. Variation of voltage on the cathode shield does not very efficiently modulate the target current. This characteristic is shown in Figure 3, curve 2.

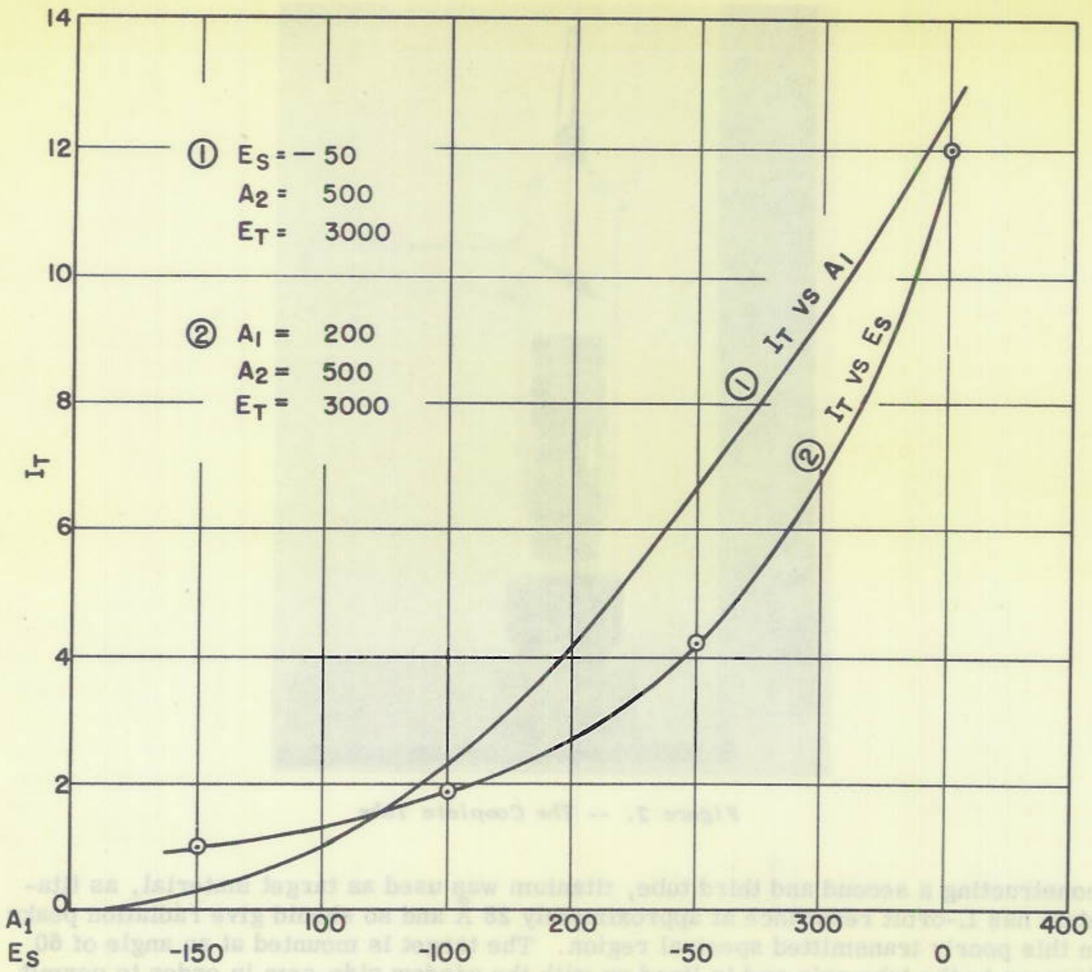

Figure 3. -- Target Current vs. Voltage on 1st Accelerator (Curve 1) and vs. Shield Voltage (Curve 2)

It should also be noted that target voltages can be changed between 1,000 and 10,000 volts with practically no effect on target current because the filament is well shielded from the target by the accelerator electrodes. At the maximum target voltage, some glow due to ionization is noticeable in the tube, but this does not affect operation nor damage the tube. It is expected that, with some aging on further use, this effect will probably disappear.

For operation below 1,000 volts and at target currents above 10 milliamperes, it is necessary to use a magnetic focussing coil around the electron gun. The type of coil used for magnetic focussing in television cathode-ray tubes is suitable. The coil is so placed that the magnetic gap is in the plane of the gap between the 1st and 2nd accelerator electrodes. With this magnetic lens, satisfactory beam operation is obtained with the following conditions:

V_{Target}	=	600 Volts	400 Volts	200 Volts
I_{Target}	=	17 ma	25 ma	25 ma
V_{Shield}	=	-10 Volts	-10 Volts	-10 Volts
V_{A1}	=	350 Volts	500 Volts	500 Volts
V_{A2}	=	350 Volts	200 Volts	100 Volts

Under these conditions no current was drawn by the shield or either of the accelerating electrodes. Operation can be obtained down to zero target voltage, but 10 watts of target power is easily obtained only at and above 400 volts potential on the target. Target current up to 50 milliamperes at low target voltages can, however, be obtained by increasing 1st accelerator voltage to a maximum of 900 volts. But in this case some current is drawn by the accelerator, probably not to exceed 5 milliamperes.

PERFORMANCE INDICATION

The radiation transmitted to the outside through the thin bubble window of the low-voltage X-ray tube has not been quantitatively measured or analyzed. When a target voltage of approximately 1,100 volts was used, strong counting has been obtained with a counter tube having a one-mil-thick aluminum window. This is believed to be good evidence of transmission in the region of 12 angstroms wavelength, just above the K-resonance cut-off of aluminum. That good transmission also exists at shorter wavelengths has been confirmed by tests made in the Rocket Sonde Branch.

Radiation has also been detected with quite low voltages on the target, even with zero target volts, when 200 to 500 volts potential was connected to the 1st accelerator electrode. In this case a counter tube with a thin glass window similar to that on the X-ray tube was used as detector, with an air path of approximately 3 cm between the transmitting areas of the two windows. This response is believed to have been due to radiation in the ultraviolet region caused by ultraviolet fluorescence under electron bombardment of the target or of the accelerator electrode. This counting was reduced to background level if the voltage was removed from the accelerator electrode, the filament of the X-ray tube remaining lighted. The radiation was stopped by a two-mil thickness of aluminum foil, and also by a one-mil thickness of mica, but was passed by a plate of fused quartz several millimeters thick. It is surmised that ultraviolet radiation emitted by the accelerator could be reflected from the target surface and pass through the bubble window. Since filters capable of isolating regions of the spectrum in the short ultraviolet or long X-ray wavelengths are not readily available, no further analysis of the transmitted radiation has been made.

It is hoped that this low-voltage X-ray tube may prove useful in further investigaation of this little-known region of transition between soft X-rays and ultraviolet radiation.

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