HIGH POTENTIAL X-RAY TUBE

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Abstract

An account is given of further development work on the high potential x-ray tube at the California Institute of Technology. Details of the construction of the tube and its housing are presented. The housing, which is a concrete structure erected on the floor of the high potential laboratory, makes it possible to operate and make observations at close range. The tube has been equipped with a hot cathode and a tungsten target, thus rendering it more suitable for spectrographic work. High speed cathode rays outside of the tube have been obtained by replacing the target by thin windows of mica or metal. Continuous operation is possible over a period of several hours at six hundred kilovolts and with a space current of three to four milliamperes. A comparison between different types of high potential x-ray tubes and of different methods of operation is contained in the discussion.

Introduction

A PRELIMINARY report describing an attempt to develop apparatus for generating x-rays of short wave-length was presented some time ago by Lauritsen and Bennett.[1] The investigation showed that it is possible to obtain satisfactory operation up to 750 kilovolts by means of apparatus constructed along the general lines described, i.e. apparatus which cannot be baked out, but in which the electrode distance is small and the glass is shielded against bombardment.

Since then the x-ray tube has been rebuilt in a more permanent form and further development work has been carried on. Satisfactory operation has been obtained at somewhat higher potentials, still using the same method of operation, i.e. making use of cold emission as the sole source of electrons and operating intermittently so that the maximum potential is applied only one second out of eight, the potential during the interval being about one half of the maximum potential. In addition, satisfactory continuous operation up to 600 kilovolts has been obtained when a hot cathode was used for furnishing the electrons.

The Tube

The x-ray tube was rebuilt primarily to allow operation and observation at close range. For this purpose a concrete housing was constructed, the general plan of which is shown in Fig. 1 whereas Fig. 2 is a cross-section through the tube and housing.

As may be seen, this housing is divided into two compartments by a concrete partition which is two feet thick. The glass section of the tube is

[1] C. C. Lauritsen and R. D. Bennett, Phys. Rev. **32,** 850 (1928).

mounted on top of the housing and the base, which consists of a steel tube one meter long, forty centimeters in diameter and of six millimeter wall thickness, protrudes down through the ceiling into one of the compartments.

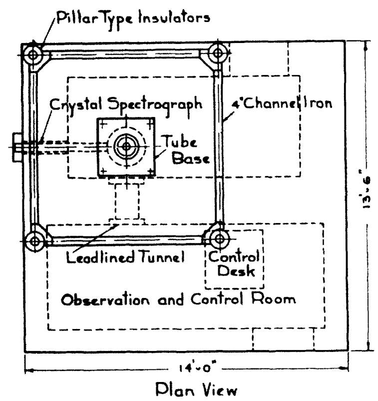

Fig. 1. General plan of apparatus.

This compartment also contains the liquid air trap and the vacuum pumps described in the previous paper.

The second compartment contains the control desk for operating the high potential transformers as well as the vacuum gauge and various meters for measuring current and potential, etc. A lead-lined opening in the concrete

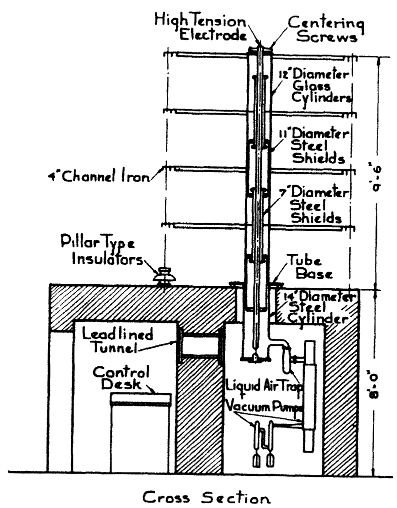

Fig. 2. Cross-section through tube and housing.

partition is provided for making absorption measurements and other observations on the radiation.

Sheets of galvanized iron are placed under all the walls, and the top of the housing is completely covered with sheets of the same material, carefully soldered together and connected at all four corners to the bottom sheets by means of copper conductors. A heavy copper conductor makes connection to the station ground. The tube base is insulated from the housing and connected to ground through two milliammeters, one for reading alternating current and the other for reading the unidirectional current through the tube.

The upper section of the tube is as previously described with the exception that the four torus-shaped corona shields have been replaced by horizontal plates of galvanized iron sheets, eight feet square. These are supported on frames of four-inch channel iron carried on insulators of the pillar type. These plates produce a very uniform field along the glass and provide a considerable capacity across each section, thus effectively preventing punctures and flashovers due to surges.

Hot Cathode

For many purposes it is desirable to have a well-defined focal spot rather than the somewhat erratic source inherent in cold emission. For this reason the upper electrode was constructed with a recess at its lower extremity into which a small spiral filament was placed. Fig. 3 shows in detail the construction and relative position of the electrodes The filament is a small spiral

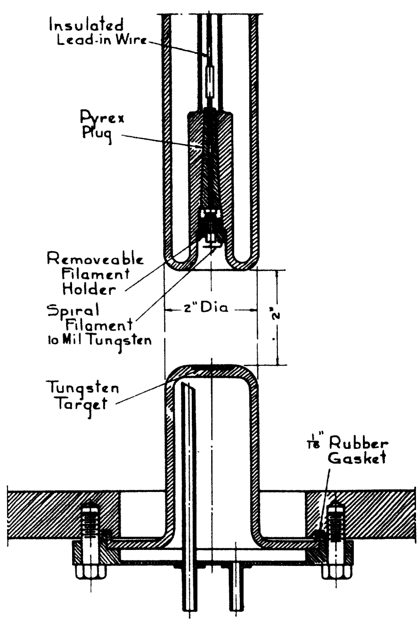

Fig. 3. Detail of construction and relative positions of electrodes.

of ten mil tungsten wire mounted in a removable holder to facilitate replacement. It is accessible through the opening in the bottom plate when the lower electrode is removed. One end of the filament is connected to an insulated central terminal of the filament holder. This terminal makes contact with an insulated lead-in wire sealed in through a tapered Pyrex plug. The other end of the filament is connected through the holder to the electrode proper. The filament is heated by means of a six-volt storage battery placed on top of the tube structure. The heating current is controlled by means of a slide wire operated through long cords.

The target consists of a tungsten disk, two millimeters thick and two centimeters in diameter, embedded in the steel electrode The distance between the electrodes is approximately five centimeters and both are water cooled by means of the cooling system previously described.

With this arrangement continuous operation is possible up to somewhat over 600 kilovolts with a unidirectional current of three to four milliamperes through the tube. The diameter of the focal spot is approximately five millimeters. The current is, of course, limited only by the heat dissipating ability of the target. Under these conditions the cold emission is usually negligible so that the radiation originates almost entirely in the focal spot and is confined to the concrete housing. This is very essential, both on account of the safety of the operators and of the shielding of the sensitive instruments required especially for absorption measurements.

Cathode Rays

In order to test the possibility of obtaining high speed electrons outside of the tube, the target was temporarily replaced by a thin window. A mica window was found to be satisfactory provided the current was limited to a very small value by keeping the filament at low temperature. Metal foils of two to three mil thickness permit the use of considerably larger currents. A very intense and concentrated beam was obtained and the usual phenomena such as glowing of crystals etc. could be observed.

Discussion

The greatest difficulty in connection with the construction and operation of vacuum tubes for high potentials is caused by cold emission. This must therefore be minimized as far as possible or else rendered harmless. The first is best accomplished by thorough outgassing or, if this is not possible, by keeping the potential gradients between the different parts below a safe limit. The second is accomplished by shielding the glass against bombardment by stray electrons.

Two principal types of high potential tubes have been developed so far, each having its advantages and disadvantages and each being best suited for a particular purpose.

The most important feature of the first type is that the tube is constructed in sections in such a manner that only a fraction of the potential across the tube is applied between any two adjacent metal parts within the tube. The first tube of this type was developed by Coolidge[2] who described successful experiments with cathode rays up to 900 kilovolts. Excellent progress with tubes of this type has been made by Tuve, Hafstad and Dahl,[3] who have

[2] W. D. Coolidge, J. Frank. Inst. **202,** 639 (1926).

[3] Tuve, Hafstad and Dahl, Phys. Rev. **35,** 1407 (1930).

constructed tubes which they report are capable of withstanding as much as 1900 kilovolts.

These tubes were carefully cleaned and pumped to a high vacuum. This is essential with this type since the electrons must travel the full length of the tube in order to get from the filament to the target. This distance is necessarily great even if the tube is designed for use under oil. If the mean free path is insufficient the electrons will collide with the gas molecules and thus not reach the target with maximum velocity. Furthermore, unless the tube has been well outgassed, many of the electrons will undoubtedly strike the walls and shields on their way through the tube and thus liberate large quantities of gas. It is doubtful if a well-defined focal spot can be obtained with this construction

The second type, which has been developed at the California Institute, is characterized by the fact that the full potential is applied directly between two electrodes which are comparatively close together. This increases the difficulties due to cold emission, but the vacuum requirements are not nearly as severe as in the case of the first type because the distance between the filament and the target is only a few centimeters instead of a meter or more

This type is well suited for producing x-rays of great intensity, but is presumably not capable of development for as high potentials as are certain other types. It seems likely that a combination of the two types here described offers advantages over any of the tubes now in use.

Our experience so far with alternating current operation indicates that the method is practical for investigating the x-ray region up to at least 600 kilovolts and there is every reason for believing that it will be possible to extend this range considerably. The advantage of the method lies in the great intensity available with continuous operation. This is extremely important for many investigations.

There can be little doubt, however, that other methods of operation will prove more suitable for much higher potentials. This has been beautifully demonstrated by the recent work of Breit, Tuve and Dahl[4] in their work with resonance coils. The instantaneous value of the energy may in this case be enormous although the average is quite small. This, of course, solves not only the problem of power source, but also the difficulty of dissipating the heat in the target.

In conclusion, we wish to express our thanks to Dr. R. A. Millikan for his interest in the work and the Carnegie Corporation of New York for financial support.

[4] Breit, Tuve and Dahl, Phys. Rev. **35**, 51 (1930).