July 2, 1974 E. B. TILLES ET AL 3,822,146

APPLICATION OF ELECTRICALLY CONDUCTIVE COATINGS TO INSULATING TUBES OF SWITCHING MAGNETS FOR PARTICLE ACCELERATORS

Filed July 5, 1972 2 Sheets-Sheet 1

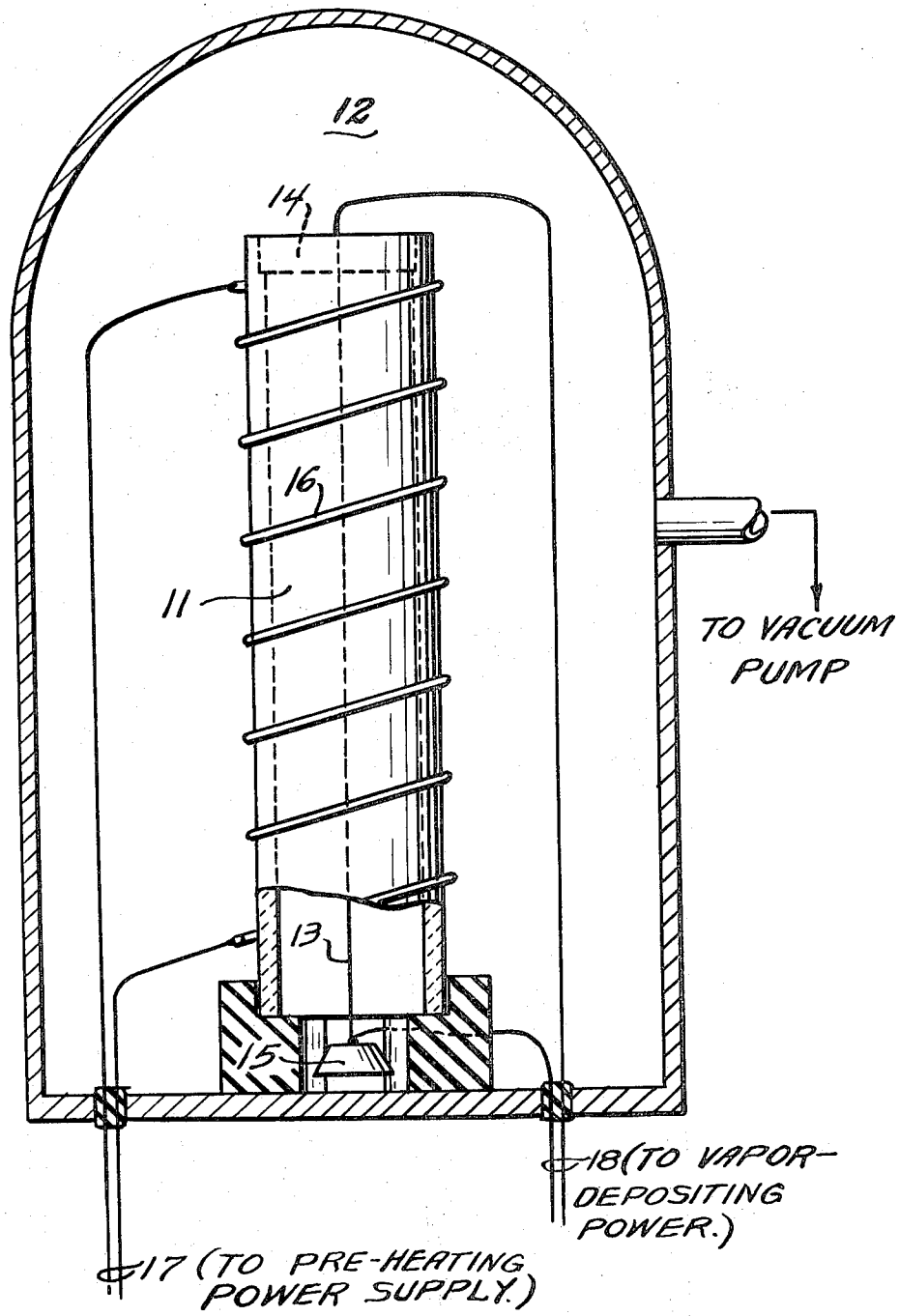


Fig. 1

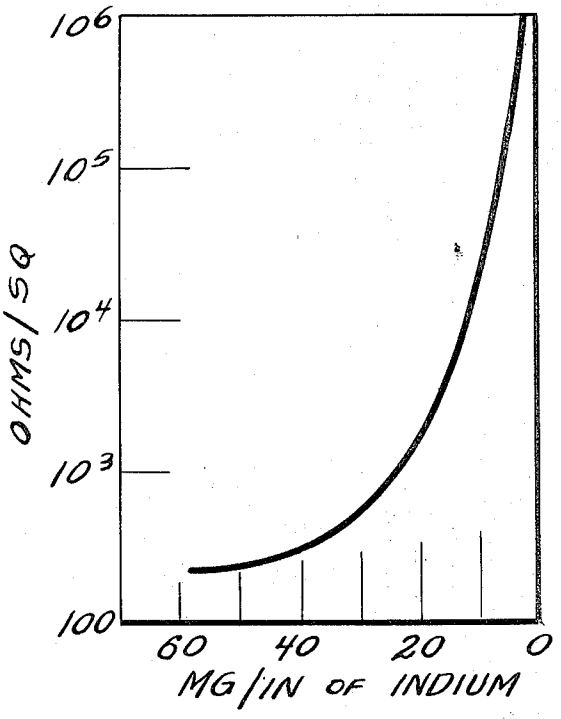
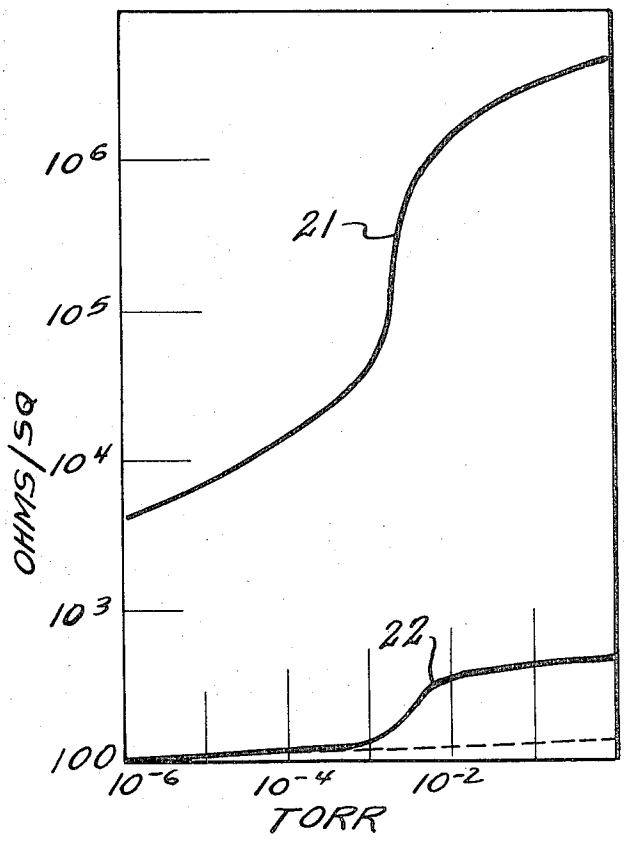

10^6
10^5
10^4
10^3
100
OHMS/SQ
60
40
20
0
MG/IN OF INDIUM

Fig-2

Fig-3


10^6
10^5
10^4
10^3
100
OHMS/SQ
21
22
10^-6
10^-4
10^-2
TORR

United States Patent Office 3,822,146
Patented July 2, 1974

3,822,146

APPLICATION OF ELECTRICALLY CONDUCTIVE COATINGS TO INSULATING TUBES OF SWITCHING MAGNETS FOR PARTICLE ACCELERATORS

Edward B. Tilles, Aurora, and Rudolf F. Nissen, Batavia, Ill., assignors to the United States of America as represented by the United States Atomic Energy Commission

Filed July 5, 1972, Ser. No. 269,005
Int. Cl. B05b 13/06; B44d 1/20
U.S. Cl. 117—213 1 Claim

ABSTRACT OF THE DISCLOSURE

Indium is applied in controlled amounts to the interior of an insulating tube used in a switching magnet for a high-energy particle accelerator. The indium is then oxidized to form indium sesquioxide. Electrical resistance of the indium sesquioxide is controlled by varying the thickness of the coating. The invention is of especial utility in preventing the buildup of surface on such tubes.

CONTRACTUAL ORIGIN OF THE INVENTION

The invention described herein was made in the course of, or under, a contract with the United States Atomic Energy Commission.

This application is related to application S.N. 269,003 (70), filed June 30, 1972, now Pat. No. 3,747,410.

BACKGROUND OF THE INVENTION

The present invention relates to a method of applying a thin conductive coating to an interior surface of a tube formed of a material that has high electrical resistivity. Such tubes, when placed in the presence of electrically charged particles in a vacuum environment, tend to accumulate surface charge and to retain the charge due to the high electrical resistivity. This results in a distortion of electric-field patterns compared to the field patterns about an uncharged surface. It is often desirable to place on the high-resistance surface a coating having controlled resistance to permit charge to be conducted away from the surface. In particular use are such conductors as graphite and evaporated layers of noble metals. Graphite is often used to control charge accumulation on the inside of a cathode-ray tube.

The methods and materials described above were inadequate for a number of reasons when applied to ceramic beam tubes used in the fast kicker magnets at the National Accelerator Laboratory. A fast kicker magnet is a switching magnet that is used to make a very fast application of a magnetic field to deflect a beam of charged particles to path different from the one they have previously been following. Such magnets are used at energy levels of the order of 6–8 GeV. and possibily higher to switch the fully accelerated beam to various target areas. Operating requirements make it necessary to switch the kicker magnets on and off in times of the order of 15 nanoseconds. The resulting time rate of change of the magnetic field makes it essential that any electrical conductors within such a field be as high in resistance as is consistent with other aspects of operation, such as minimizing charge buildup.

There are other requirements that influence the choice of a conductive coating for tubes for fast kicker magnets. Tune-up and switching often result in impacts of accelerated particles with the walls of the tubes. The coating must withstand such bombardment without change in its electrical properties and without physical distortion. The coating must also withstand the vacuum associated with accelerator operation, and it must have a low outgassing rate after pumpdown so as to minimize adverse effects upon the accelerator vacuum. It must be capable

of application to tubes of rectangular as well as round cross section with adequate adherence and uniformity of thickness.

It is an object of the present invention to provide a method of coating portions of interior surfaces of ceramic tubes used in switching magnets for particle accelerators.

It is a further object of the present invention to provide a method of producing on a ceramic tube a conductive coating of controlled thickness and hence of controlled resistance having the capability of withstanding radiation and of operating in a high vacuum.

SUMMARY OF THE INVENTION

The present invention is a method of applying an electrically conductive coating of indium sesquioxide to the interior of an insulating tube made of a material such as alumina used in a switching magnet for a high-energy particle accelerator. Indium is deposited in a layer of controlled thickness, and is then oxidized to leave a layer of indium sesquioxide. The result is a conductive coating of a predetermined resistance across two sides of a unit square that is capable of withstanding the conditions of high vacuum and radiation typical of the interior of a particle accelerator.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partial sectional view of an apparatus used in the application of a conductive coating to a nonconducting tube according to the principles of the present invention.

FIG. 2 is a curve showing the variation in the resistance across two sides of a unit square of a surface containing deposited indium sesquioxide plotted as a function of the weight of indium per inch of wire placed on the heater wire.

FIG. 3 is a curve showing resistance across two sides of a unit square of a coating of deposited indium sesquioxide plotted as a function of environmental pressure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIG. 1, ceramic tube **11** is disposed vertically in vacuum environment **12**. Heater wire **13** is suspended from plug **14** and is maintained in tension by weight **15**. Preheater **16** is disposed about ceramic tube **11**. A source of preheating power is connected to preheater **16** by preheater electrical leads **17**, and a source of vapor-depositing power is connected to heater wire **13** by heater wire electrical leads **18**.

Ceramic tube **11** is selected for its electrical and mechanical properties. It must be an electrical insulator that is capable of withstanding processing temperatures to 500° C. The shape of the internal cross section is typically round or rectangular, and the length of the tube is immaterial. This invention has been practiced upon tubes of 99.5% pure alumina (Al_2O_3) with metallized ends and having flanges brazed to the ends. Tubes ranged in length from 40 to 45 inches; their shapes include circular cylinders of diameters 1⅞ inches and 2¾ inches and a tube having a rectangular cross section 2½ inches by 4½ inches. The latter tube was processed with two heater wires **13**. An increase in the ratio of width to thickness might necessitate the use of more of such heater wires.

Application of the coating begins with a thorough cleaning and preparation of the interior surface of ceramic tube **11**. This can be done by any conventional cleaning and smoothing methods. The smoothing methods actually used were sandblasting of tubes up to 10 inches in length with 80-grit alumina. Longer tubes were dry-ball-milled with #4 glass balls and 80-grit alumina, using

the tube as its own ball mill. The tubes were then cleaned with a chromic-acid solution, washed in tap water, then distilled water, and finally rinsed in ethanol.

Several types of material were used for heater wire **13**. The best results were achieved with three strands of tungsten wire, loose-lay twisted, each strand being 0.020 inch in diameter. Adequate results were achieved using three strands of 0.020-inch tungsten in a standard tight twist and a single strand of tungsten of 0.060-inch diameter. Similar results were obtained using a resistance wire of a nickel-chromium alloy sold under the trademark Nichrome in a single strand of 0.040-inch diameter and a double strand of two wires of 0.020-inch diameter. Indium metal was affixed to the heater by wetting it with a soldering iron where precise control of weight was of minimal concern. The standard method of attaching clips of indium can equally as well be used if the tube is placed in a horizontal position. However, a vertical position was used since it is thus possible to maintain the heater wire **13** taut by attaching weight 15 to the bottom thereof. Where precise control of the amount and hence the coating thickness of indium was desired, indium was electroplated on the filament, using standard techniques. By plating on only the amount to be deposited and vaporizing the filament clean, very close control of the deposited layer is obtained. A sample wire of known length and weight was electroplated along with the desired wire, and the amount of deposited indium was determine by comparative weighing.

To coat the interior of tube **13**, the tube was cleaned as described and the coated heater wire **13** was installed as indicated in FIG. 1. Vacuum environment **12** was pumped to 10^{-6} Torr and maintained at this pressure for an hour to outgas the system. Preheater **16** was used to heat ceramic tube **11** to a temperature in a range between 25° C. and 150° C., both to outgas tube **11** and to prepare tube **11** for vaporization. Best results were achieved at a temperature of 93° C. Heater wire **13** was energized to vaporize the indium. Following cooling, ceramic tube **11** was transferred to a standard oven operating at a temperature in a range between 450° C. and 800° C. to oxidize the indium. Best results were achieved at an oven temperature of 500° C., maintained for 24 hours. An oxygen atmosphere was used but did not appear to be necessary, as adequate results were also achieved using air.

The results of application of the method described above are shown in FIGS. 2 and 3. FIG. 2 is a curve taken at atmospheric pressure showing the variation in resistance across two sides of a unit square of a coating of indium sesquioxide with the lineal density of indium placed on the heater wire **13**, which in turn determines the thickness of the coating. Knowledge of the desired resistance across two sides of a unit square, as determined by operating conditions, enables selection from FIG. 2 of the necessary amount of indium to be deposited on heater wire **13**. It is also possible to associate the resistance with the pressure to which the surface containing indium sesquioxide is subjected. FIG. 3 is a plot of the variation of resistance across two sides of a unit square on an insulating surface containing deposited indium sesquioxide as a function of ambient vacuum for two different coating thickness. First curve **21** indicates a resistance of 35 Megohms per square at atmospheric pressure, a value associated through FIG. 2 with a lineal coating density of less than 10 milligrams per inch of indium on heater wire **13**. Second curve **22** indicates a resistance of 3700 ohms per square at atmospheric pressure, which corresponds to a lineal density of approximately 25 milligrams per inch of indium on heater wire **13**. Both curves show the variation in resistance across two sides of a unit square as the ambient pressure changes.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method of applying to the interior surface of a cylindrical alumina beam tube of a switching magnet for a particle accelerator a radiation-resistant uniform coating of controlled conductivity to prevent charge buildup while leaving the magnetic field of the switching magnet substantially undisturbed, said method comprising the following steps:

(a) cleaning and smoothing said interior surface by mechanical abrasion;
(b) cleaning said interior surface with chromic acid;
(c) washing said interior surface with water and ethanol;
(d) attaching a predetermined quantity of indium to a tungsten heater wire;
(e) disposing said heater wire in a vacuum environment of 10^{-6} Torr along the axis of said cylindrical beam tube in the interior of said cylindrical beam tube, said heater wire and said beam tube being disposed vertically;
(f) heating said beam tube in said vacuum environment to a temperature in the range between 25° C. and 150° C. for one hour to outgas said tube and to prepare said interior of said tube to receive indium;
(g) delivering electrical energy to said heater wire to vaporize said indium and transfer to said heated interior surface a layer of indium of controlled thickness; and
(h) heating said beam tube in air to a temperature in the range between 450° C. and 800° C. to oxidize said layer of indium to form a layer of indium sesquioxide.

References Cited

UNITED STATES PATENTS

3,729,335	4/1973	Domrachev	117—95
3,544,832	12/1970	Brous	315—3.5
3,400,149	9/1968	Blumberg	117—217
3,356,529	12/1967	Kiser	117—201
2,932,590	4/1960	Barrett	117—201

RALPH S. KENDALL, Primary Examiner

M. F. ESPOSITO, Assistant Examiner

U.S. Cl. X.R.

117—47 R, 62, 93, 93.2, 95, 106 R, 106 A, 201