This invention relates to X-ray apparatus, and in particular, to a cable assembly for supplying power at high voltage to an X-ray tube in a potentially explosive atmosphere.

X-ray apparatus is often used in explosive atmospheres that are found in industry and hospitals. A typical case is the hospital surgical room where the atmosphere may contain explosive vapors that result from using volatile anesthetics such as ether and cyclopropane and from fumes of disinfecting agents. If there is a breakdown in the electrical insulation of the X-ray apparatus, there may be sparking which would ignite the vapors and cause an explosion.

The cables which carry electric power from the high voltage supply to the X-ray tube casing are especially susceptible to breakdown because their insulation regularly undergoes flexing and wear as a result of positioning the X-ray tube casing over an object or a patient being subjected to radiography or therapy.

There are two general types of cable used. The first is one that is not intended for use in hazardous atmospheres and it usually comprises conductors that are surrounded with layers of solid but fairly flexible insulation about which there is a concentric braided wire grounding sheath. The grounding sheath may also be covered with flexible insulation and with braided cotton that is covered with protective coatings that meet electrical and mechanical requirements and produce a smooth exterior. If the insulation breaks down, a spark may occur between the grounding sheath and the conductors which is apt to ignite explosive gases, if any are present.

The second type of cable is one that is intended for use in a potentially explosive atmosphere. It may comprise the basic cable described in the preceding paragraph with the addition of a concentric metallic barrier that is filled with an insulating compound like rubber. The outer side of the barrier may be covered with further solid but flexible layers to augment the thermal insulating properties and improve appearance. If the insulation between the centrally located conductors breaks down, the heat that is incident to sparking between the conductors and the braided sheath or barrier is confined by or distributed by the barrier so that any surrounding gas is not raised to its ignition temperature which is about 1800° C. for ether.

Cables that are wholly insulated with flexible solid materials have several disadvantages. Their flexibility usually suffers at the expense of obtaining dielectric strength and protection against sparking. Moreover, there is no way to anticipate failure. One cannot be certain from inspecting the cable whether its concealed insulating layers are fatigued or cracked or subject to failure during the next use. Although an insulation breakdown is likely to cause a protective circuit breaker to open as a result of current flowing through the low resistance path of the metallic sheathing, there is still too much likelihood that a hot spot on the conductors or a spark will ignite the contacting gas and set off an explosion.

The basic object of the present invention is to overcome these disadvantages and to provide X-ray apparatus cables that may be used safely in an explosion hazardous environment.

Additional objects are to provide a cable assembly that surrounds the solid insulation of the conductors with a heat and spark barrier which is in turn enclosed in a flexible tube containing a pressurized insulating gas that excludes the explosive vapors or gases from the region where a fault may occur.

A further object is to provide means for monitoring the explosion preventing capability of the cable by observation of the insulating gas pressure and by disconnecting the apparatus through the agency of a pressure responsive device in the event that there is not adequate pressure differential between the inside and outside of the cable to exclude explosive atmospheric gases.

Further specific objects are to provide for X-ray apparatus a cable assembly that is flexible, that is easy to clean and sterilize, that has a pleasing appearance, that is inexpensive and simple to fabricate, and that may be used with most standard X-ray equipment.

Achievement of these and other more specific objects will appear from time to time throughout the course of the ensuing specification.

An illustrative embodiment of the invention employs polyvinyl chloride or other flexible external tube that is sealed at its opposite ends to gas-tight X-ray cable terminations from which electrical connecting prongs extend. A conductor cable inside the tube is loosely surrounded by it. The free space is filled with an insulating gas. The conductor cable is covered with a spiral interlocked flexible metal hose that acts as a spark barrier. A metal adapter into which the gas filled tube is sealed, is provided with suitable fittings for filling the tube and for communicating with a pressure gage and a pressure sensitive switch. The switch is adapted to operate de-energizing circuitry of the X-ray apparatus if the gas pressure falls below a predetermined safe minimum value.

A more detailed description of an illustrative embodiment of the invention will now be given in conjunction with the drawings in which:

FIG. 1 shows an X-ray tube casing that is connected to an X-ray power supply and control with the new cable assemblies;

FIG. 2 is a schematic diagram of an X-ray control system in connection with which the new X-ray cables may be used; and

FIG. 3 is a view, partly in section, of the new gas filled X-ray apparatus cable assembly.

In FIG. 1, is shown an X-ray tube casing 10 connected by means of cable assemblies 11 to an X-ray tube power supply and control housing 12. In a typical case, where the housing 12 is admitted to an explosion hazardous area, it will be pressurized with an insulating non-flammable gas such as sulphur hexafluoride, dry nitrogen, Freon 12 or the like. The use of pressurized gas precludes the explosive atmosphere from coming into contact with sparks that are incident to faults or more operation of the controls within housing 12. In cases where the X-ray tube power supply and controls are not protected against explosion hazards as they are in this example, it is preferable to keep them outside of the hazardous area and to connect with casing 10 by passing cables 11 through the walls of the room which has openings that are above the danger level of six to eight feet for a heavy vapor like ether. In such a case the X-ray tube casing 10 is often pressurized interiorly with insulating liquid in order to prevent admission of explosive gases.

The usual mechanism that supports the X-ray tube casing and allows it to be positioned is omitted for the sake of brevity.

In FIG. 1 the exposure factors for the X-ray tube in casing 10 are set by a series of pushbuttons 13-18 that are mounted in the top of gas filled housing 12 and her-
metrically sealed with respect to it. This construction is schematized in Fig. 2, where there is a pushbutton 13 that is accessible to the operator for raising or lowering the voltage on the X-ray tube 14, for instance. Another hermetically sealed pushbutton assembly 15 is used to raise and lower the exposure time setting. Pushbutton 16 may be for controlling the current through the X-ray tube. Also provided is a pushbutton 17, which when depressed, initiates making an X-ray exposure. The apparatus may be energized and de-energized by a line contactor 20 under the control of an on-off pushbutton 18.

The power input to the X-ray tube power supply and control is a three-conductor cable 19 which makes connection with the internal parts of housing 12 through hermetically sealed insulated bushings 21. In Fig. 2, the X-ray controls 22 and the X-ray tube power supply 23 are shown in block form because the details of their construction are not necessary to understanding the present invention and they are understood by those versed in the X-ray art. The principal observation to be made in Fig. 2 is that current from the conductor assembly in FIG. 3 passes through the conductor to the X-ray transformer 19 and thence to the X-ray tube 14. This transformer is hermetically sealed with respect to it. This construction is schematized in Fig. 2, where there is a pushbutton 13 that is accessible to the operator for raising or lowering the voltage on the X-ray tube 14, for instance. Another hermetically sealed pushbutton assembly 15 is used to raise and lower the exposure time setting. Pushbutton 16 may be for controlling the current through the X-ray tube. Also provided is a pushbutton 17, which when depressed, initiates making an X-ray exposure. The apparatus may be energized and de-energized by a line contactor 20 under the control of an on-off pushbutton 18.

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tion is made, the valves are urged open so that there is free gas exchange between connected parts.

When it is desired to maintain gas communication between the pressurized cable assembly and a gas reservoir, connector 69 is manually coupled by means of a collar 50 to a mating part which is not shown in Fig. 3. Self-sealing disconnects such as 69 are available from various hardware suppliers. The one here used is a Hansen Connector, Catalog #WB1-111.

The termination of the cable that is remote from the end just described is shown in the left half of Fig. 3. Like parts are assigned the same reference numerals in this portion of the drawing. Modified parts have primed numbers. It will be noted in Fig. 3 that a portion of the left half of the drawing will receive gas under pressure by flowing through tubing 39 when gas is admitted to the other end of the cable assembly as described above.

The termination which appears in the left half of Fig. 3 is that one that is admitted to X-ray tube casing 10 in Fig. 1. It will be observed in Fig. 1 that where cable assembly 11 is socketed into casing 10 there is a strain relief 51. This assembly consists of a short piece of interlocking metal hose 52 which terminates in a ferrule at each end, the upper one of which is visible in Fig. 1. In Fig. 3, the ferrule 54 at the end opposite from 53 is admitted to a concentric centerbore in nut 42 circumjacent the pressurized polyvinyl tubing. The short metal hose 52 may be secured to the ferrule with epoxy resin. One purpose of the strain relief is to preclude bending the cable assembly 11 too sharply and another is to take the force off the cables in the event the operator moves tube casing 10 by gripping the cables instead of the casing itself.

The only other notable modification in the left cable termination in Fig. 3 is that the adapter 40 has no fill connector 46. Of course, the cable ends are interchangeable so as to allow filling and maintaining gas pressure from either end of the cable assembly as a matter of choice.

In the instant example, as illustrated in Fig. 1, the gas in the cable assembly 11 is common with the gas within X-ray power supply housing 12. This results from the fact that nylon tubes 47, which communicate with pressurized interior of cable 11, are connected with the tank through the agency of couplings 49 as described above. Connection is made with housing 12 through a pipe-cross 55 whose bottom branch connects with the housing and whose top branch is provided with a pressure gage 56. The two side branches connect with tubes 47. With this arrangement, gage 56 indicates the pressure that is common to the interior of housing 12 and the cable assembly 11. This construction has the advantage of permitting use of a common pressure sensitive switch 25, see Fig. 2, for monitoring both the pressure in the housing 12 and the cable assembly 11. The latter and housing 12 may be filled jointly with insulating gas through the agency of a self-sealing coupling 57 which communicates through the top of the housing 12.

It is not necessary that the interior of cable assemblies be connected with a pressure reservoir such as housing 12. For example, pipe cross 55 may be removed from housing 12 and the bottom branch of the pipe cross may have screwed into it a pressure sensitive switch assembly such as 24 which is symbolized in Fig. 2. For this arrangement, gage 56 would read the pressure on the cable assemblies 11 independently, that is, without regard to the pressure in any reservoir. Of course, a separate reservoir may be used and the gage may be omitted if desired. The pressure sensitive switch assembly may be adapted to control a circuit that disconnects the power supply in the event pressure is lost in the cable assemblies 11. An arrangement such as this is used in situations where the X-ray tube casing 10 and the cable assemblies 11 are in an explosion hazardous atmosphere but the power supply and other electrical parts are out of it.

Consideration of the way in which the cable assembly is constructed will confirm its multifold advantages. If the layer insulation 30 on the conductors deteriorates or cracks, the dielectric strength of the cable will be restored by virtue of the insulating gas occupying any voids that might be created. If the breakdown is sufficient to cause sparking between the conductors and metal braid 35, for example, the heat incident of sparking encounters a barrier in the form of flexible metal pipe 38 which confines and distributes it and prevents heating of the surrounding explosive atmosphere to a dangerous level. The pressurized non-combustible insulating gas further inhibits sparking and prevents admission of explosive gases to the insulted region. Cables were intentionally faulted in the laboratory while carrying their rated current and voltage but the temperature of the barrier never exceeded 180° C., at which ether ignites within the time specified for operation of the overload device on the X-ray apparatus. Dual protection is provided. During occurrence of a fault a protective circuit breaker, not shown, will open and isolate it immediately. Concurrently, loss of pressure in the cable assembly causes a pressure sensitive switch 25 to be actuated and it may open a line contactor such as 20 or other protective device. Moreover, loss of the safe qualities of the cable assembly can be anticipated. The operator may detect leaks by observing a loss of pressure on gage 56, in which case appropriate maintenance procedures may be instituted, and if the loss of gas pressure is unobserved, the pressure sensitive switch 25 will act to prohibit energization of the apparatus. Operating under conditions of maximum safety is thereby assured.

Although one embodiment of the invention has been described in considerable detail, such description is to be considered illustrative rather than limiting, for the invention may be variously embodied and its true spirit and scope are to be determined only by interpreting the claims which follow.

It is claimed:

1. A cable assembly for use with X-ray apparatus in an explosion hazardous area comprising:
   (a) an electrical conductor cable having an insulating coating and adapted to transmit power between components of X-ray apparatus, (b) an insulating body that is sealed to the cable at an end thereof, (c) said body having sealed terminals extending from it for making connection between the conductor cable and a component of X-ray apparatus, (d) an external flexible tube means that is gas impervious and surrounds the conductor cable substantially coextensive with its length, (e) means joining the outside of the flexible tube means and the body in gas tight relation with each other, (f) a gas pervious flexible barrier means separate from and surrounding said conductor cable in the intervening space between the conductor cable and the inside of the flexible tube means, (g) means effecting a gas communication path with the interior of the flexible tube means, (h) said gas communication path with the interior of the flexible tube including a coupling device connected with the interior of said means that joins the flexible tube and said insulating body, (i) a pressure responsive switch means that is connected in pressure exchange relation with the pressure inside the tube by way of said coupling device, and (j) a switch means that is in electric circuit with said pressure responsive switch means and X-ray apparatus and is operable in response to a predetermined drop in pressure on the pressure responsive switch means to de-energize the X-ray apparatus.

2. A cable assembly for use with X-ray apparatus in an explosion hazardous area comprising:
(a) an insulation coated electrical conductor cable for carrying electric power between components of X-ray apparatus,
(b) insulating bushings receiving opposite ends of the conductor cable within them,
(c) said bushings having conductive external prongs that connect with the conductors of the cable interiorly of the bushings,
(d) said bushings being filled with an insulating material that encapsulates the cable ends,
(e) a metal shield through which the conductor cable is admitted to the respective bushings,
(f) a braided metal covering over the insulated conductor cable that terminates near and is electrically connected to the shield,
(g) a hollow cylinder means sealed to the shield concentrically about said cable,
(h) a spiral wound interlocking metal hose that is concentric with the conductor cable and extends into the cylinder means,
(i) an outer flexible tube of non-metallic gas impermeable material surrounding said metal hose,

(j) a gasket surrounding said tube,
(k) a nut that is screwed onto the cylinder means to thereby exert component forces that press the gasket against the cylinder means and the tube to make a gas tight seal,
(l) a smooth ring interposed between the inside of the tube and the outside of the metal hose to provide a regular bearing surface for the gasket, and
(m) means effecting a gas communication path with the interior of the tube.

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