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Kuti et al.

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[54] **ENCASED FLUID FILLED TRANSFORMER**

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[51] **Int. Cl.**.....**H05k 7/00**

[58] **Field of Search** .....174/17 R, 17 LF, 37; 204/196, 204/197; 336/94

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[57] **ABSTRACT**

Fluid filled electrical apparatus, such as transformers, and methods of constructing same, suitable for underground or vault mounting. The electrical apparatus includes a metallic tank or casing formed of mild or plain carbon steel, which has a sprayed metallic coating of corrosion-resistant material disposed on the external surfaces thereof.

7 Claims, 3 Drawing Figures

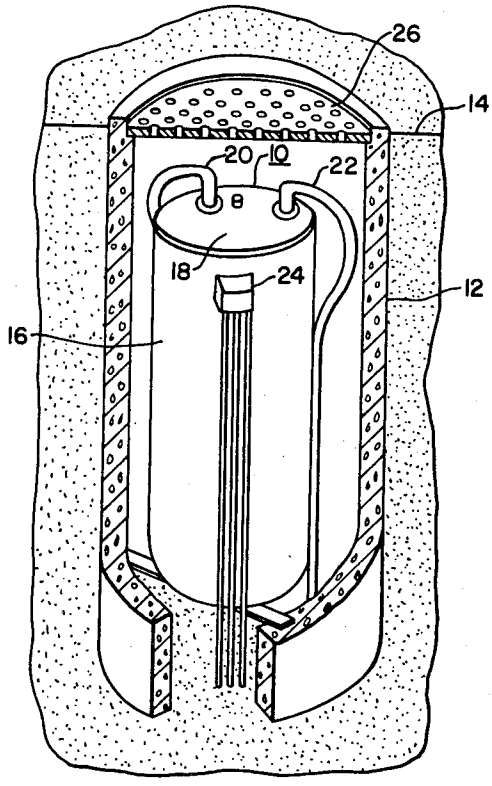


FIG. 3.

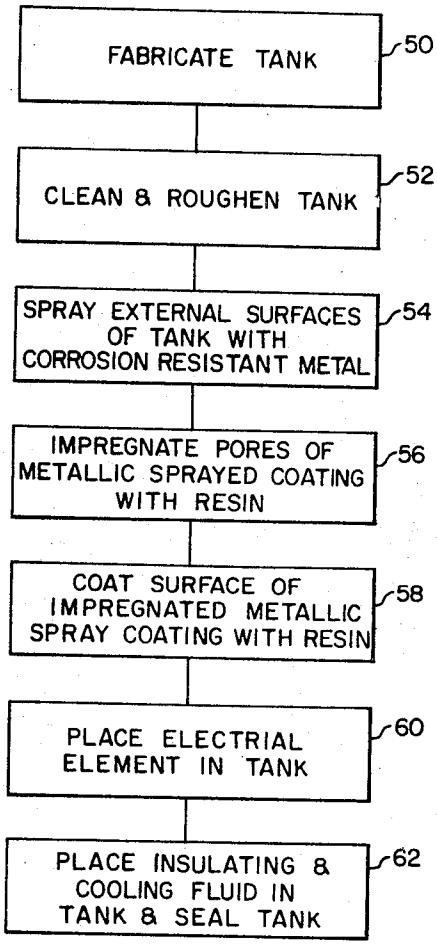


FIG. 1.

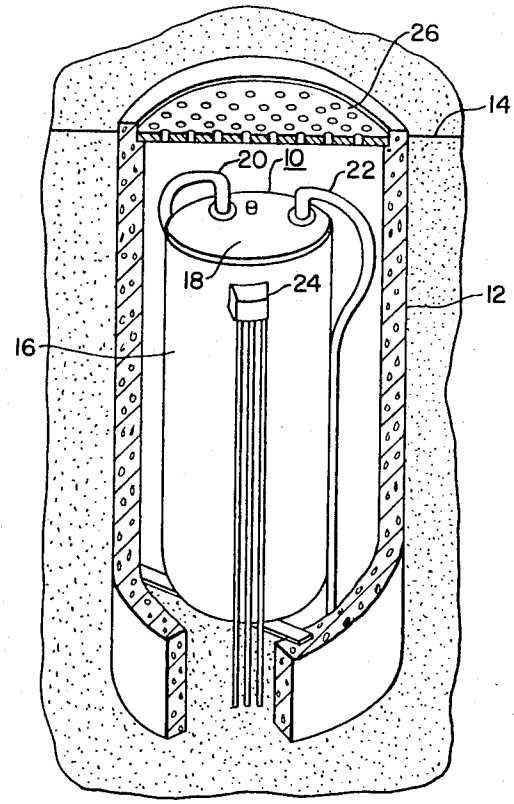
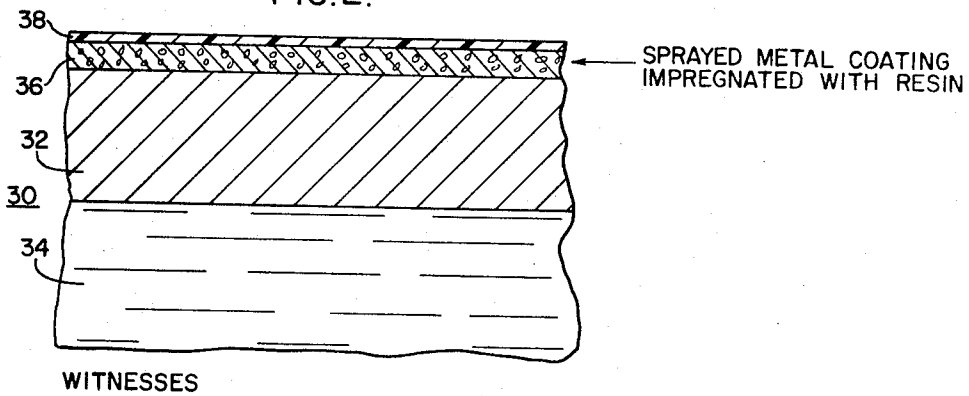


FIG. 2.



WITNESSES

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ENCASED FLUID FILLED TRANSFORMER

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates in general to fluid filled electrical inductive apparatus of the type which is disposed in highly corrosive environments, such as wholly or partially underground.

2. Description of the Prior Art

Electrical apparatus disposed wholly or partially underground, such as in specially designed vaults, or directly buried in the earth, are subject to damage due to the corrosion of their tanks or casings, which may seriously reduce the useful operating life of the apparatus. The corrosion mechanism of metals in water and soil has been studied for many years, and different methods and structures have been proposed for preventing or reducing the rate of corrosion. Electrical apparatus disposed below grade presents a much more difficult corrosion protection problem than nonelectrical structures, such as underground pipelines and buried tanks, because nonelectrical structures may be more easily protected from galvanic corrosion currents. Electrical components, on the other hand, are interconnected and grounded, tending to increase the magnitude of corrosion currents, and thus the rate of corrosion.

The severity of the environment surrounding electrical apparatus mounted wholly or partially below grade, from the standpoint of corrosion, depends upon a large plurality of factors, such as the type of soil, moisture, heat, polluted water, acids, alkalies, minerals, bacteria, and the like. Attempts to reduce corrosion in this environment have led to constructing tanks for electrical apparatus of stainless steel, plastic, or other noncorrosive materials, and to the development of organic protective coatings for tanks formed of mild steel.

Organic coatings over mild steel would be an economical answer to the corrosion problem, if it could be assumed that the protective coating would have no pin-holes and would not be scratched during handling, shipment and installation. Unfortunately, it cannot be assumed that there will be no flaws or scratches in the protective coating, and since mild steel disintegrates rapidly when subjected to a corrosive environment, this combination is not a satisfactory solution to the underground corrosion problem. In fact, the corrosive attack will usually be intensified at a flaw or scratch in the protective coating, which produces perforation of the tank faster than if the mild steel had no protective coating.

Stainless steels are generally excellent from the galvanic corrosion standpoint, but the stainless steels are not only costly, they increase fabrication costs, as they are more difficult to form, machine, and weld than mild steel. Further, while the stainless steels are not subject to a general galvanic corrosion attack, they are susceptible to severe localized attack under certain conditions, called pitting corrosion, which promotes stress-corrosion cracking.

Forming the casing of the apparatus from a material which includes mild steel clad with a stainless steel outer layer, such as may be formed by heating billets of mild steel and stainless steel to the welding temperature and rolling them together, reduces the cost of the tank material, compared to using all stainless steel. The stainless steel layer, however, is subject to severe localized attack, and the layer of stainless steel may cause fabrication problems when the material is formed into the casing or tank of the electrical apparatus.

Thus, it would be desirable to provide new and improved electrical apparatus, such as transformers, which have corrosion resistant tanks suitable for underground mounting, but which may be manufactured without undue economic penalty due to greatly increased material cost and/or fabrication cost.

SUMMARY OF THE INVENTION

Briefly, the present invention is new and improved electrical apparatus, such as a transformer, which has a casing or tank suitable for mounting the apparatus in a highly corrosive atmosphere, such as below grade in specially designed vaults, or directly buried in the earth. The electrical apparatus has a metallic casing, the external surfaces of which have a sprayed metal coating disposed thereon. The sprayed metal is a corrosion-resistant material, such as one of the stainless steels. A first organic protective coating is disposed over the sprayed metal coating, which impregnates and seals the pores of the sprayed metal coating, which is inherently porous by nature. A second, more viscous organic protective coating is applied over the first coating, to provide a tough, moisture and chemical-resistant outer surface on the casing. The porous corrosion-resistant material, impregnated with resin, provides a corrosion-resisting protective layer over the mild steel tank which is superior to a solid rolled cladding of the same material. The relatively porous structure of the sprayed metal, impregnated with an insulating resin, reduces galvanic corrosion currents, it eliminates intergranular corrosion, it inhibits the formation of local galvanic cells which cause rapid pitting corrosion of stainless steel, and stress corrosion cracking is also inhibited. Further, scratching of the outer protective layer does not promote severed localized attack at the exposed area, as the metallic protective layer is a sprayed metal coating impregnated with an organic material, which combination substantially reduces corrosive attack.

New and improved methods of constructing the electrical apparatus are also disclosed, which have the advantages of enabling the tank to be completely fabricated before the sprayed metal coating is applied, which methods also protect welded joints, and the like. Further, the sprayed metal coating, being inherently rough, promotes superior bonding of the organic protective coatings thereto, compared with organic coatings applied to rolled-type cladded materials.

BRIEF DESCRIPTION OF THE DRAWING

Further advantages and uses of the invention will become more apparent when considered in view of the following detailed description of exemplary embodiments thereof, taken in connection with the accompanying drawings, in which:

FIG. 1 is a perspective view, partially cut away, of an electrical transformer disposed in an underground vault, which may be constructed according to the teachings of the invention;

FIG. 2 is a fragmentary, cross-sectional view of a tank or casing for electrical apparatus, constructed according to the teachings of the invention; and

FIG. 3 is a block diagram which illustrates the steps of a method of constructing electrical apparatus according to the teachings of the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

The invention relates to new and improved fluid filled electrical apparatus of the type mounted in a highly corrosive environment, such as below grade level, and in general is applicable to any electrical apparatus of this type having an electrical element disposed in a tank or casing, with the electrical element being adapted for connection to an external electrical potential. Electrical transformers filled with mineral oil, askarel, SF6 or the like, may utilize the teachings of the invention, as well as protective apparatus, such as circuit breakers, which require a corrosion-resistant tank, and also capacitors which are intended for operation in a corrosive environment.

FIG. 1 is a perspective view of an electrical transformer **10** of the type which may be constructed according to the teachings of the invention. Transformer **10** is a distribution transformer of the type commonly used for underground residential distribution, and it may be disposed in a vault **12** below grade level **14**, as illustrated, it may be disposed in a vault which is partially below grade level, or it may be directly buried in the earth, as required by the electrical utility.

Transformer **10** includes a casing **16** having a cover **18** which encloses the core-winding assembly (not shown) of the transformer **10**. A suitable insulating and cooling fluid, such as mineral oil, is also disposed in casing **16**, to insulate and cool the electrical windings of the transformer. Transformer **10** is

hermetically sealed, with the electrical connectors to the encased high voltage winding being made through the sealed high voltage bushing-connector assemblies **20** and **22**, and through the sealed low voltage bushing assembly **24**. The vault **12** has a heavy access cover **26**, disposed thereon, which may be perforated to allow ventilation.

Transformer **10** is subjected to the highly corrosive atmosphere associated with below grade mounting, and must also withstand flooding of the vault for extended periods of time. Excellent organic protective coatings for underground transformers have been developed, but since coatings are not always pin-hole free, and since coatings may be scratched during the handling and installation of electrical apparatus, coatings alone do not provide the desired answer. Transformers and other fluid filled electrical apparatus only require one hole through the casing or tank to cause costly damage and even failure of the apparatus. The fact that most of the casing may be corrosion free is of no benefit if one small portion of the casing is severely attacked by corrosion. In fact, an excellent protective coating with one scratch may cause failure of the tank at the exposed area faster than if the tank had no protective coating.

Constructing the tanks of corrosion-resistant materials, such as stainless steel, is not desirable because of the economic penalty incurred in the initial cost of the material, and increased fabricating costs, and also because stainless steel, while not generally susceptible to corrosion, may in certain environments be subject to a localized pitting corrosion which is very rapid, perforating the casing at the point of attack while the majority of the surface is corrosion free. This localized attack may also promote stress-corrosion cracking of stainless steel, which may cause failure of the tank even before perforation due to pitting occurs.

The present invention discloses new and improved fluid filled electrical apparatus, and methods of constructing same, which has a tank structure highly resistant to corrosion, and it may be constructed without undue economic penalty. FIG. **2** is a fragmentary, cross-sectional view of electrical apparatus having a tank or casing **30** constructed according to the teachings of the invention. The wall of tank **30** is shown greatly magnified in order to more clearly illustrate the invention. Casing **30** may be the tank **16** or cover **18** of transformer **10** shown in FIG. **1**, or the casing of any fluid filled electrical apparatus having an electrically conductive member therein adapted for connection to an external source of electrical potential.

Casing **30** includes a main or structural metallic layer **32**, which forms the base material of the tank, and this layer is disposed adjacent the inside of the casing, such as adjacent the fluid **34**, a second, relatively thin metallic layer **36** of corrosion-resistant material disposed over the outer surfaces of the structural layer **32**, and a protective layer or coating **38** formed of an organic resin, disposed over the second metallic layer **36**. The protective layer **38**, although being shown as a single coating, is actually applied in two steps, as will be hereinafter explained.

The base or inner layer **32** provides the complete structural requirements of the casing **30**. Since the mild or carbon steel commonly used for tanks of electrical apparatus mounted above grade, such as S.A.E. 1010, is economically attractive, easy to fabricate, and possesses the requisite mechanical properties, layer **32** is preferably a mild or plain carbon steel.

The second layer **36** is formed of a corrosion-resistant material, such as one of the stainless steels, i.e., noncorroding alloys of iron and chromium, including at least 12 percent chromium in order to produce the required passivity. Layer **36** is preferably formed of a stainless steel from the 300 stainless series of the austenitic type, such as AISI types 304 and 316.

Metallic layer **36** is not the usual stainless steel cladding bonded to the base metal **32** before fabrication of the tank **30** by heating billets of the materials to be jointed to welding temperature, and then rolling them together to produce the laminate, but is a sprayed metallic coating of corrosion resistant material. Sprayed metal coatings are similar to the stronger types of sintered metals and, like sintered metals, are distinct metallurgical materials.

In metal spraying, a metal is heated to a molten or semimolten condition, and is deposited in a finely divided form on the surface to be coated. The molten particles flatten out upon striking the surface and they adhere tenaciously thereto, and to one another, producing a relatively porous structure formed of a largely plurality of castlike particles of the metal.

Because of the higher cost of the corrosion-resistant material compared with mild steel, the thickness of layer **36** should only be that required to perform its intended function. A layer thickness of about 0.010 to 0.015 inch is suitable.

Since the stainless steels are electropositive toward a base metal or inner layer formed of a carbon steel, the pores in the stainless steel would promote sacrificial dissolving of the base metal, which would thus defeat the purpose of the protective coating. The inherent porosity of the sprayed metal coating **36**, however, is used to advantage by impregnating the pores of layer **36** with a resin having a viscosity selected to assure complete sealing of layer **36**. Resin systems such as wash primers or other coatings formulated for adhesion to stainless steel are suitable for this purpose.

The resin impregnated layer **36** of corrosion-resistant material has a protective layer **38** applied to its external surfaces, which layer is formed of a more viscous organic resin system than that used to impregnate and seal the sprayed metal coating. Coating **38**, while being illustrated as a single layer, may actually include a portion of the first resin used to impregnate layer **36**. The impregnant used should be selected to be a primer for coating **38**, which promotes adhesion between the sprayed metal layer **36** and the final protective coating **38**. Adhesion between coating **38** and sprayed metal coating **36** is promoted due to the relatively rough surface of the sprayed metal coating, providing a much more tenacious coating than would be obtained by applying a coating to a rolled metal finish. Excellent materials for the final outer coating **38** are the epoxies, vinyls, polyurethanes, acrylics, and the like.

The disclosed construction of tank **30** has many advantages over prior art arrangements for preventing or reducing the rate of corrosion. The outermost protective layer **38** adheres tenaciously to sprayed metal layer **36** because of the relatively rough surface of the sprayed metal coating. Scratching or imperfections in coating **38**, do not reveal the base metal **32**, but expose a layer **36** of corrosion-resistant material, such as stainless steel. The sprayed metal layer **36** is applied as a large plurality of minute metal particles, with each having the metallurgical characteristics of cast material, not the granular-type structure which results from rolling. Thus, there is no possibility of intergranular corrosion which may occur in rolled metals due to improper heat treatment. Any pores in sprayed metal layer **36** are impregnated with a sealing resin system, which seals layer **36** and prevents anodic attack of the base metal **32**. The structure of layer **36**, having a large plurality of small metal particles inhibits galvanic corrosion currents in the sprayed layer, with the insulating material in the pores aiding in breaking up current paths. This structure reduces the incidence of localized attack of layer **36**, called pitting corrosion, at any exposed areas of layer **36**. Since layer **36** is not granular, but comprises a large plurality of interlocked metal particles, stress-corrosion cracking is also inhibited.

Tank **30** may be fabricated by new and improved methods which also possess advantages over methods of the prior art. When tanks are fabricated wholly of corrosion-resistant materials, such as stainless steel, the cost of the apparatus is not only penalized by the higher cost of the material, compared with the conventional mild steel, but the fabricating costs are also increased due to the fact that most corrosion-resistant materials are more difficult to form and weld. If conventional cladding of mild steel with stainless steel is used, the initial cost of the material is reduced, compared with using all stainless steel, but the cladding is present during the fabrica-

tion of the tank, and care must be taken to prevent delamination of the laminated materials. Further, the cladding not only complicates the welding of the material, but special welding procedures and materials may be necessary in order to prevent the weld joints from being preferentially attacked by galvanic corrosion.

The disclosed construction of the tank or casing **30** enables the tank to be completely fabricated of mild steel, using techniques used for apparatus which is to be mounted above grade, then, after the casing or tank is completely fabricated, the sprayed metal coating may be applied to all of the exposed surfaces, including the weld joints, which provides complete protection for the base metal.

FIG. **3** is a block diagram which illustrates the steps of a new and improved method of forming corrosion-resistant electrical apparatus suitable for below grade mounting. The first steps of the method, illustrated by block **50**, comprises the steps of completely fabricating the tank for the electrical apparatus, such as tank **16** and cover **18** of transformer **10** shown in FIG. **1**, including the welding of any brackets, and the like, thereto. The next steps, illustrated by block **52**, comprises the steps of cleaning and roughening the tank surface. Both of these steps may be performed by grit blasting the external surfaces, removing enough metal to assure that oil and other contaminants are removed from the tank surface, and at the same time roughening the surface of the tank to provide a receptive base for the sprayed metal coating. The cleaning step may also be performed individually, by using suitable solvents prior to the roughening step. The roughening step may still include the grit blasting, to obtain the desired surface finish.

The next step of the method, illustrated by block **54**, is to spray the external surfaces of the tank with corrosion-resistant material, such as one of the stainless steels. The spraying step may be accomplished with a wire gun or a powder gun. With a wire gun, the wire is melted by a flame, and is atomized by a gas which carries the metallic particles against the surface being coated. If the fuel for the flame is oxygen and acetylene, and the gas used to carry the atomized particles to the surface being coated is compressed air, extreme care must be taken to reduce the amount of oxides produced on each of the metallic particles. Stainless steel is more electronegative than its oxide, and each of the oxide coated particles may, under certain conditions, act as a plurality of galvanic cells, which contributes to corrosion. Therefore, it is preferable to spray the metal in a neutral atmosphere, such as nitrogen, or at least an atmosphere which is free from oxygen.

When using a powder gun, less carrier air is required to spray the metallic powder, than when spraying with a wire gun. Certain types of powder guns do not require compressed air, which may make it easier to develop coatings which are oxide free. Plasma spraying, in which a stream of ionized gas is produced by passing a gas through an electric arc, may also be used. While plasma spraying is more costly, it has the advantage that oxygen and combustion gases, as well as their by-products are not present in the gas stream, producing oxide free sprayed metal coatings.

The next step of the method, illustrated by block **56** in FIG. **3**, is to apply a first protective coating to the tank **30**, over the sprayed metal coating **36**, which coating has a viscosity selected to impregnate any pores in the sprayed metal coating. The first coating of resinous insulating material should also be selected to prime layer **36** and promote adhesion for the final or outer layer of protective material.

The next step, illustrated by block **58** is to coat the sprayed metal coating with a good tough moisture and chemical-resistant material, such as the vinyls or polyurethanes with the outer protective coating **38** being applied without the necessity of roughening the surface of sprayed metal coating **36**, as a sprayed metal coating is inherently rough, producing a surface which will tenaciously bond to the insulating outer coating **38**.

The next step, illustrated by block **60**, is to place the electrical element in the tank **30**, such as the core-winding assembly of an electrical transformer, as well as any other auxiliary elements which are required to complete the function of the apparatus, and then, as illustrated in block **62**, the insulating and cooling fluid is disposed in the tank to a predetermined level, with the insulating fluid being a mineral oil, a synthetic liquid, or an insulating gas. The tank **30** may then be hermetically sealed to prevent the entrance of moisture into the tank.

In summary, there has been disclosed new and improved electrical apparatus suitable for operation in the corrosive environments associated with below grade mounting, which provides an effective corrosion protective system without adding significantly to the manufacturing cost of the apparatus. The tank of the apparatus may be completely fabricated using the materials and manufacturing steps used for electrical apparatus manufactured for above grade use. The corrosion protective layer is not applied to the tank until the tank has been completely fabricated.

The corrosion protective metallic coating, being a sprayed metal coating, possesses unique metallurgical characteristics which, when impregnated with an insulating resin, aids in inhibiting localized attack or pitting corrosion, as well as stress-corrosion cracking. Intergranular corrosion is eliminated since the sprayed structure does not have grains. The outer surface of the sprayed metal coating is coated with a tough, moisture and chemical-resistant coating which adheres unusually well to layer **38**, because of its inherently rough surface. Thus, coating **38** has better than average ability in resisting scratches and damage due to abrasion. Scratches in coating **38** only reveal the corrosion resisting layer **36**, which is sealed by the impregnating resin to prevent anodic attack of the base metal **32**. The sprayed metal layer **36** exhibits superior corrosion resistance, compared with a rolled layer of the same material, due to the unique structure of a sprayed metallic coating.

We claim as our invention:

1. Electrical apparatus comprising:
a metallic casing,
an electrically conductive element disposed in said casing, said electrically conductive element being adapted for connection to an electrical potential,
and fluid means disposed in said casing,
the external surfaces of said metallic casing having a sprayed metal coating disposed thereon, with the metal being selected for its ability to resist corrosion,
and a protective coating disposed on said sprayed metal coating which impregnates the pores of the sprayed metal coating and provides a protective outer coating on said casing.

2. The electrical apparatus of claim **1** wherein the sprayed metal coating is a steel alloy containing at least 12 percent chromium.

3. The electrical apparatus of claim **1** wherein the metallic casing is formed of carbon steel and the sprayed metal coating is formed of stainless steel.

4. The electrical apparatus of claim **1** wherein the protective coating includes first and second coats, with the first coat providing the function of sealing the pores of the sprayed metal coating and promoting adhesion of the second coat, said second coat including an organic resin.

5. The electrical apparatus of claim **1** wherein the metallic casing is formed of carbon steel, the sprayed metal coating is formed of stainless steel, and the protective coating includes an organic resin.

6. The electrical apparatus of claim **1** wherein the sprayed metal coating is about 0.010 to 0.015 inch thick.

7. The electrical apparatus of claim **1** wherein the electrically conductive element includes electrical transformer windings.

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