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(54) **Anode ribbon system for cathodic protection of steelreinforced concrete.**

(57) A cathodic protection system for steel reinforced concrete and having ease of installation has now been developed. The system relies on metal anode ribbon elements, with current distributor members for such elements that are typically of the same or similar metal. The ribbon elements can be long, thin strips, e.g., they may be conveniently brought to the work site in coiled form, and deployed on the concrete surface or in slots in continuous manner. The system provides for economy of installation even under inclement weather conditions. Anode ribbon elements and current feeders may be readily connected in the field during installation, as by spot welding.

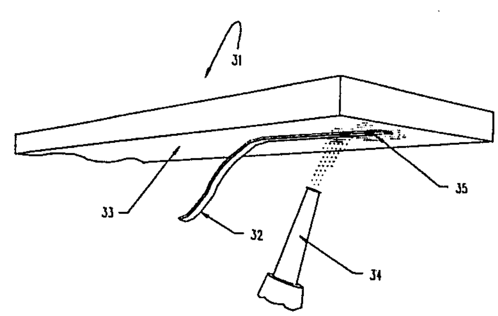

FIG. 1

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Description

ANODE RIBBON SYSTEM FOR CATHODIC PROTECTION OF STEEL-REINFORCED CONCRETE

BACKGROUND OF THE INVENTION

Steel reinforced concrete structures such as bridge decks and parking garages have generally performed well. But a dramatic increase in the use of road salt, combined with an increase in coastal construction, has resulted in a wide spread deterioration problem.

One type of approach for providing cathodic protection of steel in concrete has been the slotted non-overlay. Slotted non-overlay anodes were developed to provide an approach that would not increase the dead load and height of the concrete structure. The slots can be filled with a "conductive grout" mixture of carbon and organic resin which serves as the anode surface. Because the conductive grout has a limited conductivity, current is distributed to the anode by a system of platinized metal wire and carbon strand conductors.

Initial slotted non-overlay systems used platinized wire embedded in portland cement mortar with a cap of polymer modified mortar. The backfill failed because of attack by the gases and acid which are produced at the wire surface by the anodic reactions.

As discussed in U.S. Patent No. 4,255,241 there is shown a system where slots are cut into a concrete surface, the slots being cut with caution so as to avoid exposing any of the steel reinforcing bars. The bottom of the slot can be covered by a plastic tape. Then a wire anode, e.g., platinized niobium, is placed in the slot, with the wire being surrounded by a carbonaceous conductive backfill. Useful materials for the backfill can contain graphite. In actual practice, this system has proven to be labor intensive and furthermore installations have shown early failure, as exhibited by concrete surface cracking or other surface discontinuity.

Vale metal electrodes as typified by expanded titanium mesh have recently gained wide acceptance for application over a broad expanse of steel-reinforced concrete. Such electrodes, as detailed in PCT Published Application No. 86/06759 can readily cover broad surfaces. They are most advantageous when rolled out on such a broad surface as a flat bridge deck. Such broad coverage has lead to the acceptance of this type of cathodic protection system. When installed, the system is provided with an entire cover overlay. Such system thus not only requires a broad cover overlay but may also require some adjusting to work around obstructions.

Slotted non-overlay systems therefore have not met with the widespread commercial acceptance and have fallen short of expectations as a solution for providing cathodic protection to steel-reinforced concrete structures. Expanded mesh systems can at least be supplemented by compatible electrodes that are easily engineered around irregular surfaces. There nevertheless exists a continuing need to provide a suitable system where a non-overlay is desired or necessary, or where such may be useful in the protection of an existing concrete structure.

SUMMARY OF THE INVENTION

There has now been devised an anodic system for the cathodic protection of concrete, and especially useful as a slotted or non-slotted system, which system offers enhanced current distribution to reinforcing steel. The system is thus versatile, is simplistic in not requiring special labor intensive operation and is economical in not requiring the formulation on-site, or the need to have at hand at the work site, of special unusual materials. The system readily lends itself to working on a variety of surfaces, e.g., an overhead surface, and around numerous obstructions on such surfaces, as well as requiring only a bead of overlay, where desired. The system may be prepared in part off-site, but is also useful when mounted on-site such as directly on a concrete surface.

In a broad consideration, the invention is directed to a cathodic protection system for steel reinforced concrete, which system comprises a thin and elongate, corrosion resistant valve metal ribbon anode having ribbon width greater than its thickness, and ribbon length greater than its width, while having an electrochemically active surface coating, said ribbon anode being installed on or within a concrete surface but spaced apart from steel reinforcing members in said concrete, a bead of ionically conductive cementitious material in an amount sufficient to embed said ribbon anode within said cementitious material at the concrete surface, said cementitious material having a volumetric resistivity of less than 50,000 ohms-cm., and a corrosion resistant valve metal current distributor member electrically connected to said ribbon anode and being of greater mass per unit length than said ribbon anode.

In another aspect the invention is directed to the method of cathodically protecting a pre-existing metal reinforced concrete structure. In other aspects the invention is directed to a composite structure of steel reinforced concrete cathodically protected with the system as hereinbefore described, as well as to surfaces of such concrete having surface applied, slotted or non-slotted systems.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective view of a portion of a concrete structure underside receiving cathodic protection employing ribbon anode.

Fig. 2 is a perspective view of a portion of a concrete structure receiving cathodic protection around an obstruction.

Fig. 3 is a perspective view of a reinforced concrete bridge support structure having ribbon anodes in place.

Fig. 4 is a perspective view of a portion of a ribbon anode assembly on edge for installation in a slotted reinforced concrete structure.

Fig. 5 is an overhead view of a slotted reinforced concrete structure of a bridge deck or the like being prepared for the assembly of Fig. 4.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In general, this invention will find utility in any application where a reinforced concrete structure is in need of cathodic protection and presents a surface, horizontal, vertical, inclined or overhead, for system application. The invention will find utility for application directly on a surface or where slots can be cut into the surface of the structure. The invention will find particular utility on vertical or overhead surfaces where complete coverage of an existing structure with a cementitious overlay is undesired or will be impractical. Thus it is contemplated that the protection system of the present invention will find use in steel reinforced concrete structures such as bridge decks, parking garage decks, bridge substructures and building structural members.

Referring to Fig. 1, there is shown, in part, a reinforced concrete structure, shown generally at 31, receiving cathodic protection on the underside. For the protection an imperforate anode ribbon 32 feeding from a source such as a coil of ribbon, not shown, is applied to the underside 33 of the concrete structure 31 such that one face of the anode ribbon 32 is applied to the surface of the concrete structure 31. During application of the anode ribbon 32 to the underside 33, the ribbon 32 may be initially fastened into the steel reinforced concrete structure 31 such as plastic or other non-conductive fasteners which may be inserted into drilled holes or glued to the structure surface. Following application of the ribbon 32 to the underside 33 of the structure 31, there is applied, by means of a sprayer 34, a bead 35 of ionically conductive cementitious material. This bead 35 covers the face of the anode ribbon 32 that is left exposed at the underside 33. By this application of cementitious material, the sprayer 34 can deliver a sufficient bead 35 to embed the anode ribbon 32, but need not cover the entire surface of the underside 33. After several anode ribbons 32 have been applied and thus embedded, and being usually spaced apart parallel to one another as more particularly described further hereinbelow, such anode ribbons 32 can then be connected to a current feeder, not shown, which is then connected to a source of impressed current.

Referring then to Fig. 2, a portion of a concrete structure such as the edge of a parking garage deck is shown generally at 41. This structure 41 has a floor 42 and a side wall 43. The edge between the floor 42 and side wall 43 is interrupted by an obstruction, as shown in the drawing in this case a standpipe 44, which runs along the side wall 43 and protrudes through an aperture in the floor 42. For receiving cathodic protection for the floor 42, there is initially applied, such as from a coil, not shown, and anode ribbon 45. The anode ribbon 45 readily lends itself to application on the floor 42 around the standpipe 44 by being at first readily bendable back on itself by 180°. Then, in the plane of its application, i.e., at the surface of the floor 42, the ribbon 45 that is bent back can be twisted perpendicular to its longitudinal axis at 90° angles to form ribbon anode corners 46. Following this application of the anode ribbon 45, such can then be embedded in an ionically conductive cementitious material, not shown, as in the manner shown in Fig. 1.

Referring then to Fig. 3, there is depicted a reinforced concrete support structure, viewed from underneath, shown generally at 51. This structure 51 has a vertical surface 52, rounded at the end, as well as an underneath flat underside surface 53. Anode ribbon 54 is applied by wrapping around the vertical surface 52 and can be initially during application fastened to the underlying vertical concrete surface 52, such as by plastic fasteners. On the underside reinforced concrete surface 53, the ribbon is initially applied on the underside surface 53 as a flat section 55. When the rounded end of the concrete structure 51 is reached, the proceeding flat section 55 of the ribbon is twisted on its longitudinal axis at approximately a 90° angle whereby the corner end of the anode ribbon 55 is an edge section 56. Thus the anode ribbon 55 is initially in face contact with the concrete structure 53, but in twisting 90° of the ribbon 55 along the longitudinal axis for the corner, proceeds to edge contact with the concrete structure. As the path of the ribbon 55 extends on around the corner, the ribbon 55 twists back 90° along its longitudinal axis to again face contact for the anode ribbon 55 with the concrete structure 53. It is to be understood however that the anode ribbon could be tailored to the corner by many flat folds, rather than twisted on edge. All of the applied anode ribbons 54 can then be embedded in an ionically conductive cementitious material, not shown, such as in the manner taught in Fig. 1.

Referring then to Fig. 4, there is shown, in part, an anode ribbon system of the present invention shown generally at 10. This anode ribbon system 10 has individual anode strips or ribbons 2 which are to be set in slots in concrete (not shown). These anode ribbons 2 are spaced apart one from the other at least in substantially parallel configuration. The anode ribbons 2 have ribbon end sections 3. As shown in the Figure, these ribbon end sections 3 can be readily formed as the ribbon configuration provides for ease of bending the ribbons back on themselves at a 90° angle so that the end sections 3 can be a continuation of the anode ribbons 2. The overall effect is a continuous strip anode with the anode ribbons 2 continuing into ribbon end sections 3 and so on. The ribbon end sections 3 are adjoined to a current feeder 4. For good electrical contact between the ribbon end sections 3 and current feeder 4 such can be joined by spot welds 5. The current feeder 4 can then be connected, by means not shown, to a source of impressed current.

Referring then to Fig. 5, an overview of a slotted, steel reinforced concrete structure is shown generally at 20. On the surface 12 of this concrete structure 20, are slots 11 cut into the surface 12. In addition to the anode ribbon slots 11 the concrete surface 12 has current feeder slots 13 cut therein. This surface 12 as thus prepared is then ready for insertion of anode ribbons and current feeders.

For the installation, upon selection of a concrete surface 12,42 of a parking garage deck or the like, the selection of a direct application (non-slotted) or slotted system can then be made. If a slotted system is chosen, anode ribbon slots 11 can be cut, e.g., by saw, into the surface 12. It is a particular advantage of the system of the invention that owing to the narrow ribbon structure, a saw cut of a single blade width, or possibly two blades ganged together, need be made, rather than a multi-cut larger groove or trench to provide an adequate aperture. Usually these saw cuts will be in parallel lines as shown in Fig. 2, although such need not be the case. Other configurations such as zig zag or arcuate, e.g., so as to avoid obstructions such as columns or the like, are contemplated. For best protection, the cuts will be placed so as to provide an at least somewhat equidistant spacing between cuts thereby providing evenness to the current discharge over the total protected surface. In spacing considerations, the distance between applied ribbon anodes 54, or between slots 11, will be at least about 15 centimeter (cm.) for economy while such spacing will usually not exceed above about 60 cm. to insure an even current distribution to the reinforcing steel. Most typically the spacing between adjacent ribbons, in surface applications as in cuts, will be within the range from about 25 to about 40 cm.

Taking into consideration these spacings, it will usually be sufficient for desirable current discharge to the surrounding concrete that anode ribbons 2 have a width of about 2.5 cm. or less. Although, for convenience, usually only the anode ribbons 2 will be referred to hereinafter for convenience, it is to be understood that such references are meant to include any and all of the anode ribbons 2, 32, 45 and 54. An anode ribbon 2 of greater than about 2.5 cm. width can be uneconomical. On the other hand, an anode ribbon 2 having a width of less than about 0.25 cm. will require an uneconomical number of closely spaced ribbons or slots 11. Furthermore, such anode ribbon 2 will usually have a thickness of about 0.15 cm. or less to provide most efficient current flow at low resistance, and more typically will have a thickness of less than about 0.1 cm. On the other hand, the anode ribbon 2 for adequate distribution of current along the anode ribbon 2, will have a thickness of at least about 0.02 cm. To provide an advantageously efficient configuration for achieving high surface anode ribbon area, coupled with uniform current distribution to the surrounding concrete, the anode ribbon 2 will most always have a width of on the order of from about 0.5 to 0.8 cm. and a thickness of from about 0.05 to about 0.08 cm.

Thus the ribbon anode is at least substantially ribbon dimension. That is, the ribbon anode has a ribbon width at least substantially greater than its thickness. Furthermore, it will have a ribbon length at least substantially greater than its width, e.g., as shown in the figures. As supplied in the field for installation, the anode ribbon will frequently be in coil form, for efficiency of storage and handling. Typically such coils will contain a length of from 100 meters to 200 meters of anode ribbon, or more, although shorter length coils, e.g., of 10 to 50 meters of anode ribbon, may be serviceable. With regard to thickness and width, the ribbon anode can be expected to have a width to thickness ratio within the range from about 20:1 to about 5:1. Moreover it will have at least substantially rectangular cross-section, i.e., it will generally be rectangular in cross-section, but it is to be understood that cross-sectional variations are contemplated, e.g., tapered edges wherein the anode will have greater thickness in cross-section at the middle of the anode. The ribbon configuration provides an advantageous aspect ratio, i.e., a high ratio of anode surface area to anode length.

The dimensions for the ribbon anode as above discussed provide for an anode which can be readily bent back on itself, e.g., initially at a 90° angle as depicted in Fig. 4 or at a 180°, angle and rotated in its plane of application as depicted by the corners 46 in Fig. 2. This provides for desirable ease of application of the anode during installation, e.g., in rectangular patterns as depicted in Figs. 4 and 5 or around corners or obstructions which can often occur on a concrete surface as depicted in Fig. 2. Moreover, the ribbon anode will have desirable ease of twisting along its longitudinal axis, such as to the extent as depicted in the underside surface 53 in Fig. 3 where the anode may be twisted around corners to a 90° angle and thereby interface on its edge to the underlying concrete surface. When the corner or obstruction has been traversed, the ribbon anode can again resume a more usual flat surface contact with the concrete surface. It is however to be understood that especially when the ribbon anode has an active coating on both flat faces, that the entire installation can contain the ribbon anode mounted on its edge on the concrete surface. If applied on edge or at an angle, the resulting height of an anode of maximum width will be at most about 2.5 cm., which can readily be covered by cementitious material. Typically a layer of such material of from about 3 to about 5 cm. in thickness is applied over installed ribbon anode where the surface is to be utilized as a wear layer, e.g., as a traffic bearing layer. However, so long as no ribbon anodes on edge need to be embedded, a layer of cementitious material of at least about 1.2 cm., up to about 3 cm. thickness, will usually be applied, e.g., where the ribbon anode is utilized on an overhead or vertical surface.

Such anode ribbons 2 corresponding to these dimensions will readily handle operative current densities of 200 milliamps per square meter (mA/m^2) of anode area without damage to surrounding concrete. It is contemplated that the current densities in operation may be on the order of at least about 50 mA/m^2 and such anodes 2 as described herein will efficiently carry such loads while maintaining current distribution uniformity. It is however to be understood that current densities on the order of about 400 to 600 mA/m^2 or more are contemplated, although densities on the order of 100-300 mA/m^2 will be most advantageous for best steel reinforcement corrosion protection.

Taking into consideration the foregoing with respect to anode ribbon 2 dimensions for slotted systems, the anode ribbon slots 11 are thus cut of sufficient width and depth to provide for ease of installation of the ribbon 2. For this, a slot depth of on the order of about 1.25 to about 2.5 cm. will be typical. More usually, such a slot 11 will be cut to a depth of on the order of 1 cm. or less, e.g., 0.6-0.8 cm. It will be desirable to have the ribbon inserted into the slot to a depth to place it below the surface of the concrete, and more particularly to a depth of at least about 0.1 cm. below the concrete surface. To ensure complete embedment of the anode ribbon 2 in backfill and thus retard against surface exposure of the anode ribbon 2, the anode slot 11 will typically be cut to a depth exceeding the anode ribbon width by about 0.5 to 1.0 cm., e.g., to a depth not exceeding about 2.5 to 4 cm. By a single saw blade cut a slot of about 0.3 cm. width will be prepared. This can be serviceable for anode ribbon 2 insertion, but for best ease of backfilling, such as with pumpable grout, two blades are most always ganged together so that a slot of about 0.6 cm. will be cut, although ganging up to provide slot widths of about 1.25 cm. may be utilized.

As shown in Fig. 5, for the slotted systems the current feeders 4 can also be inserted into slots 13. These slots can likewise be saw cut into the concrete surface. For slotted or unslotted systems, such feeders 4 may generally be essentially equally spaced from one another, although it is not as necessary that the current feeders 4 be equidistant from one another, as it is for the anode ribbons 2. Also, whether the anode ribbons 2 are applied on the concrete surface or in slots, adjacent ribbons will usually run parallel to each other, although other configurations are contemplated. For the lower current densities, the distance between current feeders 4 may be as great as about 100 meters, while for more elevated current densities such distance should be reduced to on the order of 25 to 30 meters. Usually, current feeders will be spaced apart on the order of from about 50 to about 80 meters.

For the current feeders, these are also advantageously in elongated form of at least substantially ribbon dimension, as such has been discussed hereinbefore. Such provide ease of attachment of the anode ribbons to the current feeder either in edge or vertical position, as shown in Fig. 5, or when both are horizontal or flat on a concrete surface. However, other configurations for the current feeders 11 are contemplated including rods. The current feeders as elongated strips will be thicker, or wider, or thicker and wider than anode ribbons, e.g., as thick as about 0.3 cm. and up to about 5 cm. wide, in order to distribute current evenly to such ribbons 2 with minimal IR voltage loss. It will not be unusual for the current feeders to be twice the width or twice the thickness, or both, of the individual anode ribbons although width or thickness relationships of feeder to anode may generally range from on the order of 1.1:1 to 3:1. It will thus be appreciated that the slots 13 for the current feeders can have similar width as for the anode ribbons, and may even have similar depth, but may be more, e.g., 5 cm. deep.

When the concrete surface is ready to receive the anode ribbon cathodic protection system, e.g., has been slotted to receive anode ribbons in slots, the installation can be initiated in one method by laying out anode ribbon on the concrete, such as typically by unrolling a continuous strip of ribbon from an anode ribbon coil. In the uncoiling, the anode ribbon can be laid along the concrete surface as depicted in Fig. 1 or laid into cut slots 11, as shown in Figs. 4 and 5, all in continuous manner. Current feeders 4 may also be laid out at the surface of the concrete. As the anode ribbon 2 is bent to go between individual ribbon slots 11 and through the current feeder slot 13, the ribbon end section 3 can be fastened to the current feeder 4. The same system may be used for flat, or horizontal, application at the concrete surface. Any means suitable for providing an adherent, electrically conductive connection between the anode ribbon and current feeder may be used, e.g., crimping. In the field during installation, welding is most advantageous for efficiency and economy, e.g., roller welding and spot welding, and spot welding is preferred for best efficiency. After the anode ribbon has been distributed such as by uncoiling and fastening to the current feeders, the system can be covered or may be first installed by simply slipping the anode ribbons 2 and current feeders 4 into the cut slots 11. Other, alternative methods may be employed, e.g., cutting anode ribbons into essentially predetermined length, but with end tabs and then fastening the tabs to current feeders.

Upon insertion of the anode ribbons 2 and current feeders 4, the slots 11 and 13 can then be backfilled. So long as the slots 11 and 13 have not been cut to a depth so as to jeopardize contact between the anode ribbons 2 or current feeders 4 and the steel reinforcing elements of the concrete structure, no preparation of the slots 11 and 13 before installation of the anode ribbons 2 and current feeders 4 is necessary. For surface application, as shown in Fig. 1, the anode ribbons 32 need only be laid on the surface and usually fastened thereto. For backfilling, or for embedding surface applied anode ribbons, any ionically conductive cementitious material with a volumetric resistivity of less than about 50,000 ohm-cm. will be suitable. Thus no special on-site formulating and blending of unusual backfill or surface coatings is necessary. It is further necessary that the backfill not be a conductive carbonaceous backfill or other such conductive backfill since this will result in the carbonaceous material becoming anodically active which may result in damage to the surrounding concrete. Representative cementitious backfills or surface coatings that can be used include non-shrink, self-leveling and pumpable grouts, Portland cement, and other cements and will most typically have a volumetric resistivity of less than about 20,000 ohm-cm.

The backfill will most always be applied to the anode-containing slots 11 and the current feeder-containing slots 13 in sufficient amount to fill the slots 11 and 13 at least flush with the reinforced concrete surface. In surface application, the applied material will be sufficient to completely embed the anodes 32. By such application, complete coverage of the anode ribbons and current feeder will ensue. If portions of the current feeders extend beyond the surface, e.g., down below a bridge deck, such portions of the current feeders need not be so embedded in backfill. It is also contemplated, particularly for wear surfaces, that the anode ribbon system can be serviceable where an overlay will be included in he finishing operation. Such overlay may be any of those which are useful in the operation of providing an overlay to a reinforced concrete structure.

As mentioned hereinbefore, the anode ribbons may be placed, as in flat surface mounting, in non-slotted application to a reinforced concrete structure, e.g., a bridge or building support column. Such application may be especially serviceable for application in a vertical plane. The anode ribbons in such surface mounting can be as parallel strips, or spiraled around a column, or in arcuate or zig zag or other shapes. Aspects of dimensions and spacings for both anode ribbons and current feeders are as have been discussed hereinbefore. The anode ribbons can be uncoiled onto the concrete surface, fastened by any means suitable for fastening metal anodes to concrete, and then overlaid, all as has been discussed hereinabove.

Following the installation of the anode ribbon system, the current feeders are electrically connected to the positive pole of a suitable power supply, and the reinforcing steel of the concrete structure is connected to the negative pole of the power supply. A direct current suitable for the cathodic protection of the reinforcing steel is then applied. It is contemplated that any power source suitable for use with the cathodic protection of assemblies for use in protecting concrete such as in bridge decks and parking garages and the like, will be useful in the present invention.

The ribbons for both the anode ribbons and the current feeders will be metal ribbons. Advantageously for good conductivity and durability such metals of the ribbons and current feeders will be titanium, tantalum zirconium or niobium. As well as the elemental metals themselves, the suitable metals of the ribbons and feeders can include alloys of these metals with themselves and other metals as well as their intermetallic mixtures. Of particular interest for its ruggedness, corrosion resistance, e.g., resistance to corrosion in a chloride contaminated concrete environment, and also for its availability is titanium. As representative of such serviceable metals is Grade 1 titanium, an annealed titanium of low embrittlement. Such feature is advantageous for providing for ribbon installation without deleterious ribbon breakage. Moreover, alloying may add to the embrittlement of an elemental metal and thus suitable alloys may have to be carefully selected.

The metal ribbons can be prepared directly from the selected metal such as by slitting a sheet or coil of valve metal into desired widths of ribbon, with the sheet or coil itself providing the desirable ribbon thickness. Slitters can be useful in preparing the metal ribbons. After slitting, the resulting ribbon can be readily rolled into coiled configuration, such as for storage or transport for further operation.

The anode ribbons can be coated as a final step in their preparation. This coating may be applied to both flat faces of the ribbon anode, as well as the anode edges, e.g., by initial immersion of the ribbon anode into coating composition. Such can be particularly serviceable when the anode will be used on edge, either in slots or at the concrete surface. Where the ribbon anode will be mounted on the surface but installed flat to the surface, it is contemplated that for some installations only the flat face of the ribbon anode facing the concrete surface needs to have the active coating. It is to be understood that the ribbons may also be coated before they are in ribbon form whereby on forming, e.g., cutting, the ribbon widths will bear coating but the ribbon thicknesses will not. Whether coated before or after being in ribbon form, the substrate can be particularly useful for bearing a catalytic active material, thereby forming a catalytic structure. As an aspect of this use, the ribbon substrate can have a catalyst coating, resulting in an anode structure. Usually before any of this, the valve metal ribbon will be subjected to a cleaning operation, e.g., a degreasing operation, which can include cleaning plus etching, as is well known in the art of preparing a valve metal to receive an electrochemically active coating. It is also well known that a valve metal, which may also be referred to herein as a "film-forming" metal, will not function as an anode without an electrochemically active coating which prevents passivation of the valve metal surface. This electrochemically active coating may be provided from platinum or other platinum group metal, or it may be any of a number of active oxide coatings such as the platinum group metal oxides, magnetite, ferrite, cobalt spinel, or mixed metal oxide coatings, which have been developed for use as anode coatings in the industrial electrochemical industry. It is particularly preferred for extended life protection of concrete structures that the anode coating be a mixed metal oxide, which can be a solid solution of a film-forming metal oxide and a platinum group metal oxide.

For this extended protection application, the coating should be present in an amount of from about 0.025 to about 0.5 gram of active coating per square meter of valve metal ribbon. Less than about 0.025 gram of active coating, e.g., of platinum group metal will provide insufficient electrochemically active coating to serve for preventing passivation of the valve metal substrate over extended time, or to economically function at a sufficiently low single electrode potential to promote selectivity of the anodic reaction. On the other hand, the presence of greater than about 0.5 gram of active coating, or more often of greater than about 0.25 gram of platinum group metal, per square meter of the valve metal ribbon can contribute an expense without commensurate improvement in anode lifetime. In this particular embodiment of the invention, the mixed metal oxide coating is highly catalytic for the oxygen evolution reaction, and at low current densities in a chloride contaminated concrete environment, will evolve no chlorine or hypochlorite. The platinum group metal or mixed metal oxides for the coating are such as have generally been described in one or more of U.S. Patent Nos. 3,265,526, 3,632,498, 3,711,385 and 4,528,084. More particularly, such platinum group metals include platinum, palladium, rhodium, iridium and ruthenium or alloys of themselves and with other metals. Mixed metal oxides include at least one of the oxides of these platinum group metals in combination with at least one oxide of a valve metal or another non-precious metal. It is preferred for economy that the coatings be such as have been disclosed in the U.S. Patent No. 4,528,084.

In the installed anode ribbon system, the anode ribbon 2 will be connected to a current feeder 4, e.g., the metal strip current feeder 4 of Fig. 4. Such feeder 4 will most always be a valve metal and preferably is the same metal including alloy or intermetallic mixture, as the metal most predominantly found in the valve metal anode ribbon 2. This current feeder 4 must be firmly affixed to the metal anode ribbon 2. Such a manner of firmly fixing the feeder 4 to the ribbon 2 can be by welding, as has been discussed hereinabove. Moreover, the welding can proceed through the coating. Thus, a coated ribbon current feeder 4 can be pressed against a coated anode ribbon 2 with coated faces of each in contact, and yet the welding can readily proceed. The ribbon current feeder 4 can be sufficiently welded to the anode ribbon 2 to provide uniform distribution of current thereto.

In the installed anode ribbon system, the embedded portion of current feeders 4 may also be coated, such as with the same electrochemically active coating of the anode ribbon 2, but most always the current feeders 4 will be left uncoated. If coated, like considerations for the coating weight, such as for the anode ribbon 2, are also important for the current feeders 4. These feeders 4 may be attached to the anode ribbon 2 before or after coating. Such current feeders 4 can then connect outside of the concrete environment to a current conductor, which current conductor being external to the concrete need not be so coated. For example in the case of a concrete bridge deck, the current feeder may include a bar extending through a hole to the underside of the deck surface and extending upwardly to where a strip current feeder 4 is located. In this way, mechanical current connections can be made external to the finished concrete structure, and are thereby readily available for access and service if necessary. Connections to a current distribution bar external to the concrete may be of conventional mechanical means such as a bolted spade-lug connector.

Claims

1. A cathodic protection system for steel reinforced concrete, which system comprises:

a thin and elongate, corrosion resistant valve metal ribbon anode having ribbon width greater than its thickness, and ribbon length greater than its width, while having an electrochemically active surface coating, said ribbon anode being installed on or within a concrete surface but spaced apart from steel reinforcing members in said concrete;

a bead of ionically conductive cementitious material in an amount sufficient to embed said ribbon anode within said cementitious material at the concrete surface, said cementitious material having a volumetric resistivity of less than 50,000 ohms-cm., and

a corrosion resistant valve metal current distributor member electrically connected to said ribbon anode and being of greater mass per unit length than said ribbon anode.

2. The cathodic protection system of claim 1, wherein said ribbon anode is installed onto a horizontal, inclined, vertical or overhead concrete surface.

3. The cathodic protection system of claim 2, wherein installed ribbon anodes have a face of the ribbon applied on said concrete surface, with said anodes being sufficiently spaced apart such that said applied bead of cementitious material is sufficient to embed said ribbon anodes but insufficient to cover all of said concrete surface.

4. The cathodic protection system of claim 1, wherein said ribbon anode has an at least substantially rectangular cross-section, a width within the range from about 0.25 to about 2.5 cm., a thickness within the range from about 0.02 to about 0.15 cm. and a width to thickness ratio within the range from about 20:1 to about 5:1, thereby having a ribbon width substantially greater than its thickness while also having a ribbon length substantially greater than its width.

5. The cathodic protection system of claim 2, wherein installed ribbon anode has a face of the ribbon applied on said concrete surface and said applied bead of cementitious material is in an amount sufficient to embed said ribbon anode as well as sufficient to cover all of said concrete surface.

6. The cathodic protection system of claim 1, wherein said ribbon anode is installed in a slot cut in the surface of said concrete and said slot is not greater than about 4 cm. in depth and 1.25 cm. in width.

7. The cathodic protection system of claim 6, wherein said system comprises a great multitude of adjacent slots containing said valve metal ribbons, said adjacent slots being spaced apart one from the other at a distance within the range from about 15 to about 60 cm.

8. The cathodic protection system of claim 6, wherein said slot is backfilled with said ionically conductive cementitious material.

9. The cathodic protection system of claim 6, wherein said backfilled slot containing said ribbon anode is covered with a concrete overlay.

10. The cathodic protection system of claim 1, wherein said cementitious material has a volume resistivity of less than about 20,000 ohm-cm. and is a non-shrink, self-leveling pumpable grout.

11. The cathodic protection system of claim 1, wherein said valve metal ribbon anode and said valve metal current distributor member each comprise metal selected from the group consisting of titanium, tantalum, zirconium, niobium, their alloys and intermetallic mixtures.

12. The cathodic protection system of claim 1, wherein said ribbon anode is electrically resistance welded to said current distributor member and said anode and member are in face-to-face contact.

13. The cathodic protection system of claim 12, wherein said current distributor member electrically connected to said ribbon anode is free from electrochemically active surface coating.

14. The cathodic protection system of claim 1, wherein said current distributor member is an elongate current distributor member and has an at least substantially rectangular cross-section with a width of not greater than about 5 cm., a thickness of not greater than about 0.3 cm. and a width in relation to the width of said ribbon anode within the range of from about 3:1 to about 1.1:1.

15. The cathodic protection system of claim 1, wherein said current distributor member is at least in part inserted into a slot cut in the surface of said concrete and adjacent slots are spaced apart one from the other at a distance within the range from about 25 to about 100 meters.

16. The cathodic protection system of claim 1, wherein said current distributor member is connected to a power source impressing an operative current on said ribbon anode of from about 50 to about 600 mA/m^2.

17. In a cathodic protection system for steel reinforced concrete, wherein said system comprises a series of thin and elongate, corrosion resistant valve metal ribbon anodes having electrochemically active surface coating, said active anodes being applied on a surface of said concrete spaced apart from steel reinforcing members in said concrete, which anodes are electrically connected to a current distributor member while being embedded in an ionically conductive cementitious material applied to said anodes, the improvement comprising:

thin and elongate, corrosion resistant valve metal current distributor members having greater mass per unit length than said ribbon anodes, with said current distributor members being free from said active surface coating, even on portions of said members electrically connected to said ribbon anodes and which portions can thereby be embedded in said cementitious materials.

18. A method of retarding corrosion in a steel reinforced concrete structure, which method comprises:

applying to a surface of said concrete a thin and elongate, corrosion resistant valve metal ribbon anode having ribbon width greater than its thickness, and ribbon length greater than its width, while having an electrochemically active surface coating, said ribbon anode being installed on or within a concrete surface but spaced apart from steel reinforcing members in said concrete;

applying a bead of conductive cementitious material in an amount sufficient to embed said ribbon anode within said cementitious material on the concrete surface, said cementitious material having a volumetric resistivity of less than 50,000 ohms-cm., and

electrically connecting said anode to a corrosion resistant valve metal current distributor member being of greater mass per unit length than said ribbon anode.

19. The method of claim 18, wherein said ribbon anode is applied to a horizontal, inclined, vertical or overhead concrete surface.

20. The method of claim 18, wherein said ribbon anode is applied flat on said concrete surface and is sufficiently spaced apart whereby said applied bead of cementitious material is sufficient to embed said ribbon anode but insufficient to cover all of said concrete surface.

21. The method of claim 18, wherein said ribbon anode is applied to a slot cut in the surfaces of said concrete.

22. The method of claim 21, wherein said ribbon anode is initially deployed in a slot, said current distributor member is deployed, the portion of said ribbon anode adjacent said current distributor member is removed from said slot and electrically connected to said current distributor member, and the resulting connected ribbon anode is returned to said slot.

23. The method of claim 18, wherein applied ribbon anode is electrically resistant welded to said current distributor member.

24. The method of claim 18, wherein said cementitious material applied to said ribbon anode is a pumpable grout having a volumetric resistivity of less than about 20,000 ohm-cm.

25. The method of claim 18, wherein said current distributor member is connected to a power source impressing an operative current on said ribbon anode of from about 50 to about 600 mA/m^2.

26. A cathodic protection system for steel reinforced concrete, wherein a metal anode is installed on a concrete surface while being spaced apart from steel reinforcing members for said concrete, said system being especially adapted for application to overhead and vertical surfaces, which system comprises a thin and elongate corrosion resistant valve metal ribbon anode having a ribbon width greater than its thickness and having ribbon length greater than its width, while being sufficiently thin so as to be

readily bent back upon itself by at least substantially 180° and then twisted at the bend in a direction perpendicular to the longitudinal axis of the ribbon for providing abrupt anode corners in its plane of installation on said concrete, said anode ribbon being also easily twistable along its longitudinal axis to a 90° angle during application to said concrete, whereby said anode when installed can proceed along its longitudinal axis from initially flat anode surface contact with said concrete, then twist 90° to anode edge contact with said concrete, and then twist back 90° to flat anode surface contact, said ribbon anode having an electrochemically active surface coating and being electrically connected to an elongate corrosion resistant valve metal current distributor member which is of greater mass per unit length than said ribbon anode.

27. The cathodic protection system of claim 26, wherein said ribbon anode has an at least substantially rectangular cross-section, a width within the range from about 0.25 to about 2.5 cm., a thickness within the range from about 0.02 to about 0.15 cm. and a width to thickness ratio within the range from about 20:1 to about 5:1, thereby having a ribbon width substantially greater than its thickness while also having a ribbon length substantially greater than its width.

28. The cathodic protection system of claim 26, wherein said valve metal ribbon anode and said valve metal current distributor member each comprise metal selected from the group consisting of titanium, tantalum, zirconium, niobium, their alloys and intermetallic mixtures.

29. The cathodic protection system of claim 26, wherein said valve metal anode has an electrochemically active surface coating containing a platinum group metal or metal oxide and said coating contains from about 0.025 to about 0.5 gram of catalytic metal per square meter of said ribbon anode.

30. The cathodic protection system of claim 26, wherein said electrochemically active surface coating contains at least one oxide selected from the group consisting of platinum group metal oxides, magnetite, ferrite and cobalt oxide spinel.

31. The cathodic protection system of claim 26, wherein said electrochemically active surface coating contains a mixed crystal material of at least one oxide of a valve metal and at least one oxide of a platinum group metal.

32. The cathodic protection system of claim 26, wherein said ribbon anode is electrically resistance welded to said elongate current distributor member and said anode and member are in face-to-face contact.

33. The cathodic protection system of claim 26, wherein said elongate current distributor member has an at least substantially rectangular cross-section with a width of not greater than about 5 cm., a thickness of not greater than about 0.3 cm., and a width in relation to the width of said ribbon anode within the range of from about 3:1 to about 1.1:1.

34. The cathodic protection system of claim 26, wherein said current distributor member is connected to a power source impressing an operative current on said ribbon anode of from about 50 to about 600 mA/m^2.

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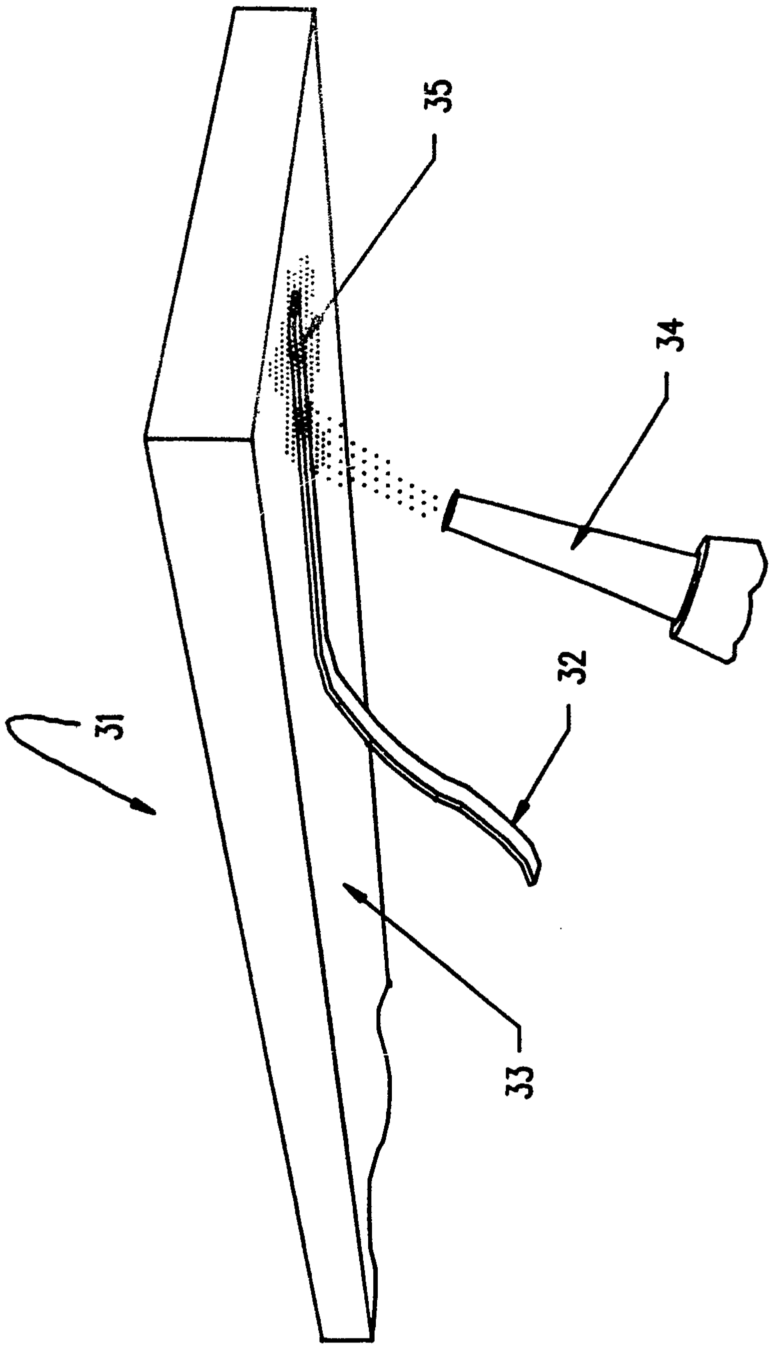

FIG. 1

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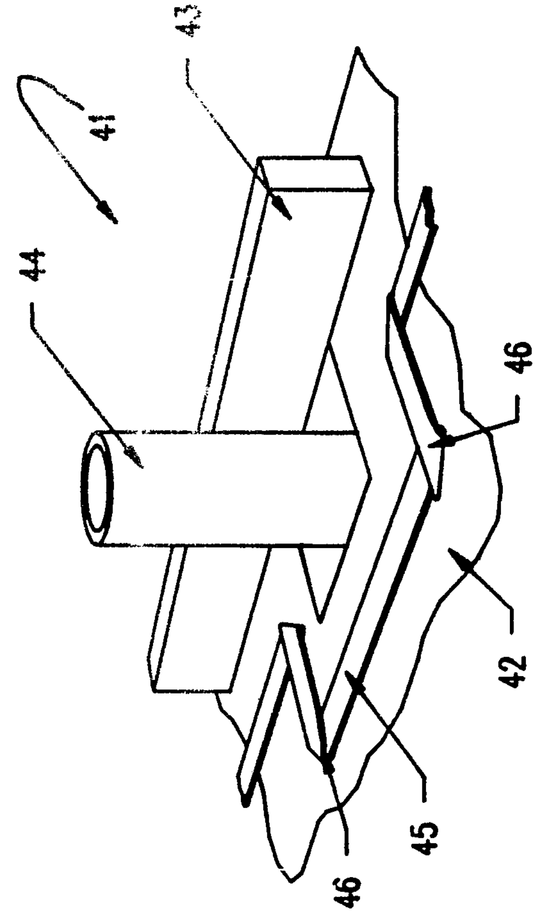

FIG. 2

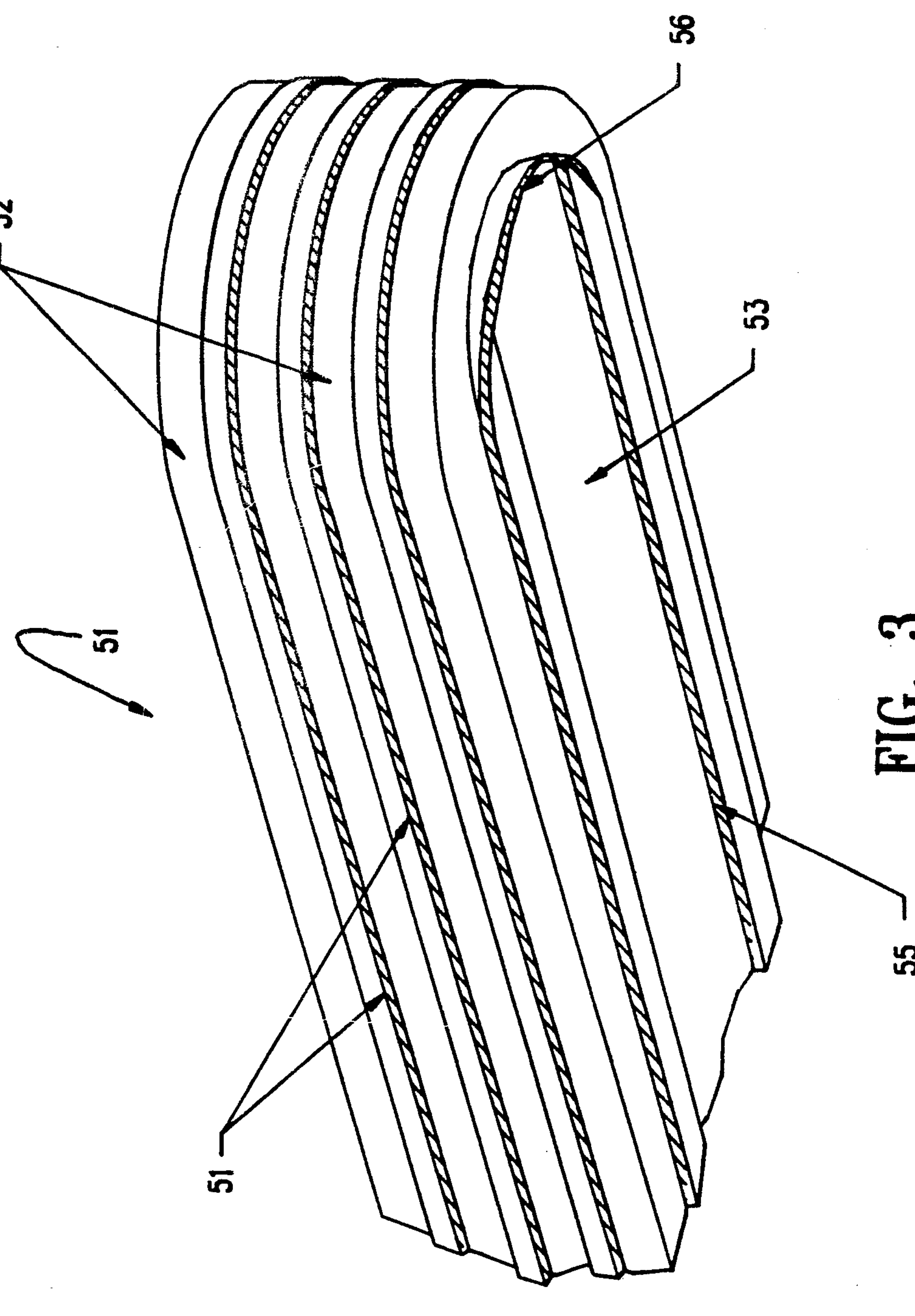

FIG. 3

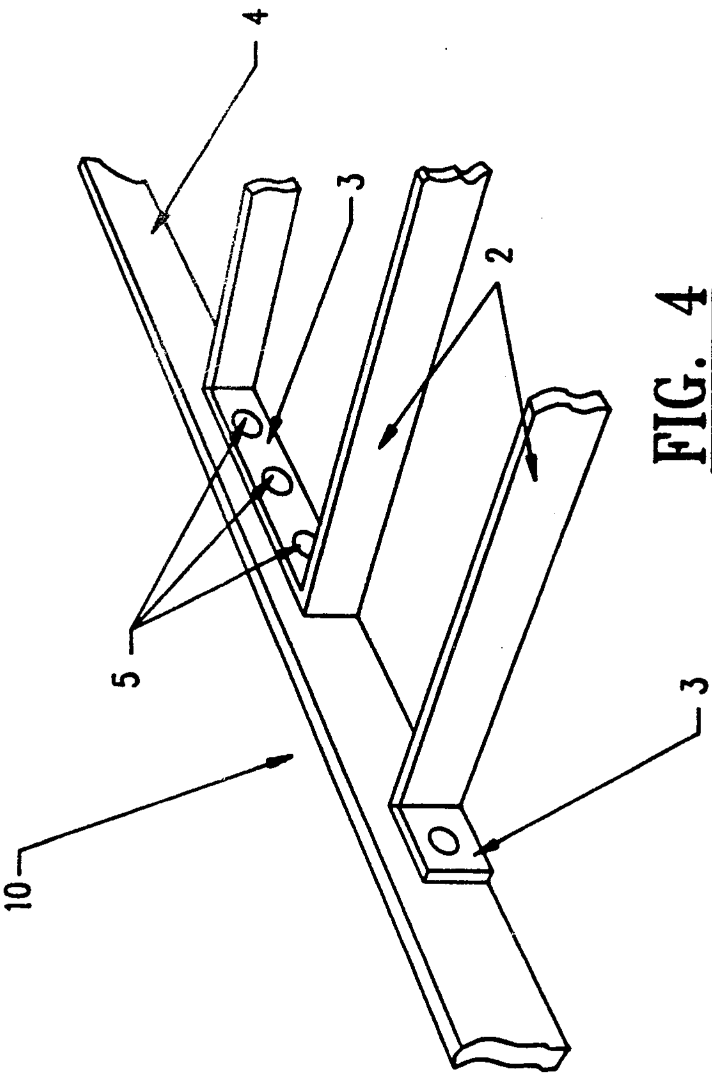

FIG. 4

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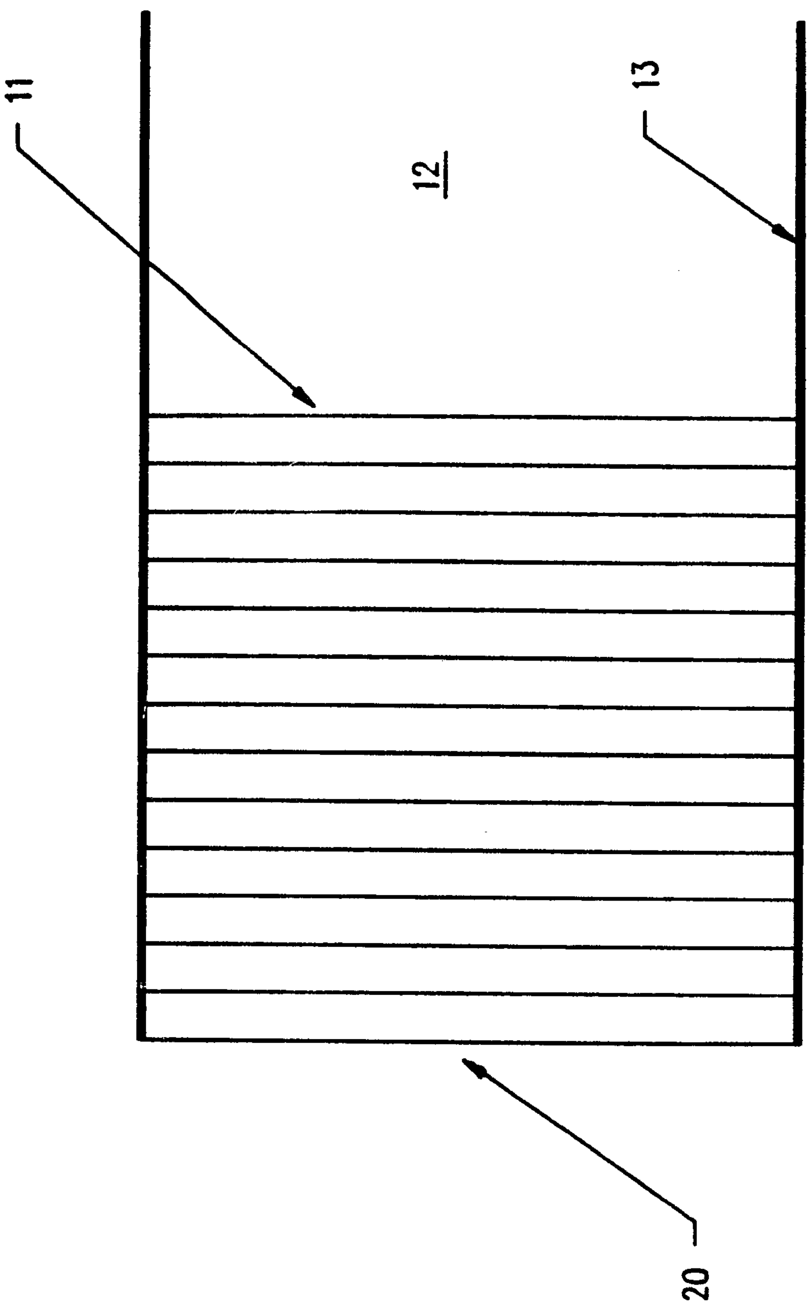

FIG. 5