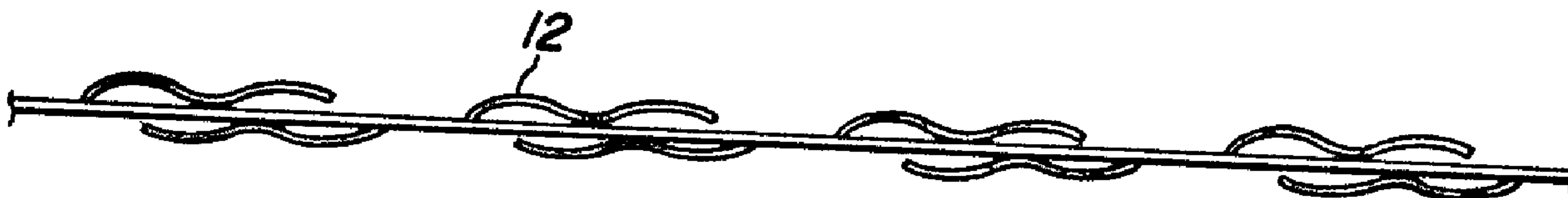




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 (54) Title: FLOW THROUGH ANODE FOR CATHODIC PROTECTION SYSTEMS



(57) **Abrégé/Abstract:**

An anode for use is a cathodic protection system for steel reinforced concrete structures comprising a unitary, multi-plane, porous, metal anode having a plurality of trough and crest nodes defining upper and lower planes at the extremities of said nodes. The anode is useful at an anode current density of up to about 20 milliamps per square foot when said anode consists of a valve metal or alloy thereof. Composite anodes having an electrocatalytically active coating on a valve metal substrate are useful at a higher anode current density as are valve metal anodes which have been activated by heat treatment prior to use.

FLOW THROUGH ANODE FOR CATHODIC PROTECTION SYSTEMS**ABSTRACT OF THE INVENTION**

5 An anode for use is a cathodic protection system for steel reinforced concrete structures comprising a unitary, multi-plane, porous, metal anode having a plurality of trough and crest nodes defining upper and lower planes at the extremities of said nodes. The anode is useful at an anode current density of up to about 20 milliamps per square foot when said anode consists of a valve metal or alloy thereof. Composite anodes having an electrocatalytically active coating on a valve metal substrate are useful at a
10 higher anode current density as are valve metal anodes which have been activated by heat treatment prior to use.

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FLOW THROUGH ANODE FOR CATHODIC PROTECTION SYSTEMS**BACKGROUND OF THE INVENTION**1. **Field of the Invention**

5 This invention is directed to anodes for use in cathodic protection systems.

2. **Description of Related Prior Art**

10 Cathodic protection of metal structures, or of metal containing structures, in order to inhibit or prevent corrosion of the metal in the structure is well known by use of impressed current cathodic protection systems. In such systems, counter electrodes and the metal of the structure are connected to a source of direct current. In operation the metal of the structure, such as a steel reinforcement for a concrete structure, is cathodically polarized. The steel reinforcement becomes cathodically polarized being spaced from the anodically polarized electrode and is inhibited against corrosion. While cathodic protection is well known for metal or metal containing structures such

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as in the protection of offshore steel drilling platforms, oil wells, fuel pipes submerged beneath the sea, and in the protection of the hulls of ships, a particularly difficult problem is presented by the corrosion of steel reinforcement bars in steel-reinforced concrete structures. Most Portland cement concrete is porous and allows the passage of oxygen and aqueous electrolytes. Salt solutions which remain in the concrete as a consequence of the use of calcium chloride to lower the freezing point of wet concrete or snow or ice melting salt solutions which penetrate the concrete structure from the environment can cause more rapid corrosion of steel reinforcing elements in the concrete. For example, concrete structures which are exposed to the ocean and concrete structures in bridges, parking garages, and roadways which are exposed to water containing salt used for deicing purposes are weakened rapidly as the steel reinforcing elements corrode. This is because such elements when corroded create local pressure on the surrounding concrete structure which brings about cracking and eventual spalling of the concrete.

Known methods of introducing an anode into existing concrete structures may involve insertion of an anode into a slot cut into the concrete. After application of the anode a cap of grout is applied to backfill the slot. Representative anodes for cathodic protection of steel reinforced concrete structures are disclosed in U.S. 5,062,934 to Mussinellil in which a grid electrode comprised of a plurality of valve metal strips having voids are disclosed. Another type of anode strip for cathodic protection of steel reinforced concrete structures is disclosed in Canadian 2,078,616 to Bushman

in which mesh anodes are disclosed consisting of an electrocatalytically coated valve metal which is embedded in a reinforced concrete structure so as to function as the anode in a cathodic protection system. In U.S. 5,031,290 a process is disclosed for the production of an open metal mesh having a coating of an electrocatalytically active material formed by fitting a sheet and stretching the coated sheet to expand the sheet and form an open mesh. In U.S. 4,401,530 to Clere, a three dimensional electrode having substantially coplanar, substantially flat portions, and ribbon-like curved portions is disclosed for use as a dimensionally stable anode in the production of chlorine and caustic soda. The ribbon-like portions of the anode are symmetrical and alternate in rows above and below the flat portions of the anode.

In U.S. 3,929,607 to Krause, an anode assembly for an electrolytic cell is disclosed comprising a film-forming metal foraminate structure comprising a plurality of longitudinal members spaced with their longitudinal axis parallel to one another and carrying on at least part of their surface an electrocatalytically active coating. Each longitudinal member comprises a channel blade member constituted by a pair of parallel blades having one or more bridge portions connected to the current lead-in means.

In Canadian 1,325,789 to Martin et al., a cathodic protection system for steel reinforced concrete is disclosed in which a valve metal anode is used having an electrochemically active surface coating which can be an oxide selected from the group consisting of platinum group metal oxides, magnetite,

ferrite, and cobalt oxide spinel.

5 A permeable sheet metal useful for acoustical and other special purposes is disclosed in U.S. 3,279,043 which is prepared by perforating a metal sheet and bending portions of the metal in a plurality of locations so as to produce what can be characterized as a double corrugated sheet metal. Similarly, in U.S. 3,376,684 a double corrugated sheet is produced from flat metal sheet stock by slitting a metal sheet and bending portions of the sheet so as to provide curved portions above and below the plane of the flat sheet metal stock.

10 The novel anodes of the invention in comparison with prior art anodes for cathodic protection of steel reinforced concrete provide less resistance to flow of concrete grout and improved current flow characteristics.

SUMMARY OF THE INVENTION

15 Unitary, multi-plane, porous, metal anodes are disclosed which are useful in a cathodic protection system for steel reinforced concrete structures. The anodes of the invention are characterized by nodes protruding both above and beneath an intermediate plane of the metal sheets from which the anodes are formed. The nodes of the anode are spaced longitudinally to allow an intermediate plane to separate the upper and lower nodes. The lower, trough, and upper, crest, nodes in a preferred embodiment alternate both laterally and
20 longitudinally. The anode is, generally, formed on an uncoated or

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electrocatalytically active coated valve metal or the anodes can be electrocatalytically coated after formation. Where the valve metal is coated with an electrocatalytically active layer, it is preferred that the coating comprise a platinum group metal oxide. Where the valve metal anode is uncoated, the usefulness of the anode is limited to cathodic protection systems operating at low current densities unless the valve metal is activated by heating at an elevated temperature.

10 In accordance with an aspect of the present invention, there is provided in a cathodic protection system for a steel reinforced concrete structure comprising a plurality of porous anodes, the improvement wherein each of said anodes comprises: A) a unitary, multi-plane, porous, metal strip (1) consisting of a plurality of trough and crest nodes defining upper and lower planes at the extremities of said nodes, or (2) consisting of a plurality of trough or crest nodes defining either an upper or a lower plane at the extremities of said nodes, B) said nodes spaced longitudinally to provide an intermediate plane separating said nodes, and C) said trough and crest nodes alternating laterally.

25 In accordance with another aspect of the present invention, there is provided a reinforced concrete article having a valve metal anode having an electrocatalytically active surface coating, said anode deposited on a surface of said concrete article or installed in a slot cut in a surface of said concrete article and utilizing a cathodic protection system comprising a plurality of porous anodes wherein each anode comprises A) a unitary, multi-plane, porous, metal strip anode (1) comprising a plurality of trough and crest nodes defining upper and lower planes at

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the extremities of said nodes, or (2) comprising a plurality of trough or crest nodes defining either an upper or a lower plane at the extremities of said nodes, B) said nodes spaced longitudinally to provide an intermediate plane separating said nodes, and C) said trough and crest nodes alternating laterally.

In accordance with yet another aspect of the present invention, there is provided a method of producing a porous valve metal anode having a plurality of trough or crest nodes or trough and crest nodes, defining upper and lower planes or upper or lower planes at the extremities of said nodes, and spaced longitudinally to provide an intermediate plane between said upper and lower planes, said method comprising: A) perforating said metal strip by shearing preselected portions thereof in uniform and closely spaced relation of one to another thereby forming exposed edges and portions of said strip having a greater longitudinal dimension than a lateral dimension, and B) deforming said portions of said perforated strip to produce either raised or lowered portions or both raised and lowered portions extending in a direction normal to the plane of said sheet.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a plan view of one embodiment of a portion of a unitary, multi-plane, porous, metal anode of the invention showing perforation of a metal sheet with openings of predetermined size, shape and arrangement and bending of nodes to form trough and crest nodes.

Figure 2 is a cross sectional view of the perforated sheet shown in Figure 1 showing the appearance on bending the perforated sheet so as to raise upper, crest and

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lower, trough nodes in a direction normal to the plane of the perforated sheet.

Figure 3 is a plan view of a second embodiment of a portion of a unitary, multi-plane, porous, metal anode of the invention showing a perforated sheet prior to bending the rows between perforated sections so as to form an anode having a plurality of trough and crest nodes.

Figure 4 is a cross sectional view of a portion of the metal anode

subsequent to bending the rows between perforated sections of the sheet shown in Figure 3.

Figure 5 is an isometric view of a portion of the porous, metal anode shown in cross section in Figure 4.

5 Figure 6 is an isometric view of a portion of the metal anode shown in cross section in Figure 2.

DETAILED DESCRIPTION OF THE INVENTION

10 The present invention is a novel, unitary, multi-plane, porous, metal anode consisting of a plurality of trough and crest nodes or protrusions defining upper and lower planes at the extremities of said nodes. The nodes are spaced longitudinally to provide an intermediate plane separating the upper and lower nodes. The trough and crest nodes, in a preferred embodiment, alternate both laterally and longitudinally. The metal anodes of
15 the invention, generally, can be of an uncoated valve metal or a valve metal coated with an electrocatalytically active coating. Where the anode of the invention is an uncoated valve metal, the use of the anode in a cathodic protection system for reinforced steel elements in concrete is limited to those applications where the anode current density is controlled at up to about 20
20 milliamps per square foot unless the valve metal is activated by heating at an elevated temperature. The metal anodes of the invention can be used for the cathodic protection of steel reinforcing elements in concrete and for the

cathodic protection of steel pipelines placed in sea water, saline muds, or in the ground. Generally, the anodes of the invention can be prepared from a valve metal such as grade I titanium which normally has an oxide film on the surface thereof. Preferably, a valve metal such as titanium is activated prior to use as an anode so as to extend the lifetime of the anode and allow use of the anode at higher anode current densities. Activation can be accomplished by heating the valve metal anodes at elevated temperature. Preferably, activation is accomplished by exposure of the valve metal to a temperature of about 250°C to about 750°C, preferably, for a period of about 3 minutes to about 5 hours. Upon activation a substantial improvement in anode lifetime occurs, as indicated by the time for passivation of the anode to occur at a given anode current density. Useful valve metals are selected from the group consisting of titanium, tantalum, zirconium, niobium, and alloys and mixtures thereof.

While anode current densities of up to 20 milliamps per square foot can be used with the valve metal anode of the invention not coated with an electrocatalytically active coating, preferably, cathodic protection systems in which steel reinforcing elements are embedded in concrete are operated at an anode current density of about 2 to about 10 milliamps per square foot, most preferably, a current density of about 2 to about 5 milliamps per square foot. As indicated above, the extension of the lifetime of the valve metal anodes can be obtained by heating the anode. Upon heat activation of the valve metal

anode, anode current densities of up to about 50 milliamps per square foot can be used, preferably, about 20 to about 40 milliamps per square foot.

Where the novel anode of the invention is utilized with a valve metal base and an electrocatalytically active coating thereon, cathodic protection systems can be operated at substantially higher current densities such as up to about 80 to about 120 amperes per square foot. The application of an electrocatalytically active coating on the surface of a valve metal substrate can involve painting or spraying an aqueous or organic solvent solution of a soluble precursor compound on the surface of the valve metal. Application of the precursor catalyst compound can also be made by electrolytic and electroless plating and by thermal spraying. Thermal spraying is defined to include arc-spraying as well as plasma and flame spraying. Subsequent to application of a precursor compound, the coating is heated to convert the precursor compound to the electrocatalytically active material such as the oxide. Thermally sprayed coatings may not require heating to convert the coating to the catalytically active form.

Typical catalyst precursor compounds consist of platinum group metal compounds selected from the group consisting of metal compounds of platinum, palladium, ruthenium, rhodium, osmium, iridium, or mixtures or alloys thereof. Cobalt, nickel, and tin compounds can also be utilized as electrocatalytic precursor compounds which when heated to convert to their oxides are effective electrocatalytically active catalyst coatings.

The anodes are produced by first perforating a metal strip by shearing preselected portions thereof in uniform and closely spaced relation of one to another so as to form exposed edges and portions of strips having a greater longitudinal dimension than a lateral dimension. Subsequently, the metal rows between perforations are deformed by bending portions of the perforated strip so as to raise or lower adjacent portions in a direction normal to the plane of the perforated sheet. The anode of the invention is formed using conventional metal working equipment such as a piercing die to perforate the metal strip in preselected portions and a die mechanism which is employed to impart the final shape to the nodes, which can project above or both above and below the surface of the metal sheet.

Referring now to the drawings, Figure 1 shows one embodiment of the anode of the invention in which flat sheet stock valve metal material 10 is slit so as to define nodes 12 which are raised or lowered in a direction normal to the plane of the flat sheet stock. The plane of the flat sheet stock is also defined as an intermediate plane in describing the geometry of the fabrication of the anode of the invention. Perforated portions or slots shown as 12 are produced by shearing preselected portions of flat sheet stock material 10 in closely spaced relation of one to another thereby forming exposed edges on each side. Slots 12 are pierced in sheet 10 by means of a piercing die (not shown) or by other known means and expanded to produce the finished configuration of the inventive structure. Slots 12 are symmetrically offset as

laterally displaced rows which project slightly into longitudinally adjacent rows so as to provide a release area 14 as sections between slotted areas which are alternately raised and depressed to form the anode having trough and crest nodes defining upper and lower planes at the extremities of said nodes. The release areas 14 define an intermediate plane between crest and trough nodes. The nodes are formed from slotted areas by forcing these areas in a direction normal to the flat sheet stock intermediate plane while contracting or foreshortening the material longitudinally. The lateral dimensions of sheet stock material 10 remain unchanged during formation of the anode.

In Figure 2 there is shown more clearly in a cross-sectional view the expanded nodes which are termed crests, upper nodes, and troughs, lower nodes. The expanded slots 12 are symmetrically staggered or offset and laterally displaced row on row and column on column with one slot end attached to sheet stock material 10.

As shown in a second embodiment of the anode of the invention in Figure 3, the anode of the invention is formed by first perforating valve metal sheet stock 10 to provide a plurality of longitudinally aligned slots 12 longitudinally separated by release areas 14.

In Figure 4 which is a cross-sectional view of the anode shown in Figure 3, upper nodes 16 and lower nodes 18 are formed by alternately raising or lowering the flat sheet stock material 10 so as to provide upper and lower nodes which alternate both longitudinally and laterally and are separated by

release areas 14.

Figure 5 is an isometric view of one embodiment of the anode of the invention showing the plurality of alternating trough nodes 18 and crest nodes 16 separated by release areas 14.

5 Figure 6 is an isometric view of the embodiment of the invention shown in Figure 2. The anode shown in Figures 1 and 2 which is formed from metal sheet stock 10 exhibits an intermediate plane 10 between upper nodes 16 and lower nodes 18. Release areas 14 separate the successive crest and trough nodes 16 and 18.

10 The following Examples illustrate the present invention but should not be construed, by implication or otherwise, as limiting the scope of the appended claims.

EXAMPLE 1:

15 An anode of the invention as shown in Figures 3 - 5, is prepared by slitting a grade I titanium tape having a thickness of 0.020 inches and a width of 0.75 inches. The longitudinal slits in the titanium tape are approximately equally distant in the lateral dimensions so as to provide a total of eight nodes upon deformation of the rows between the slitted areas of the tape. Four
20 nodes are deformed upward, in a direction normal to the plane of the titanium anode, and four nodes are deformed downward, in a direction normal to the plane of the titanium anode. The width of each node of the tape is about

0.0938 inches, the unit length of each node is 3.75 inches and the uncut area separating the nodes measures 0.75 inches in the lateral direction and 1.375 inches in the longitudinal direction. The height of the deformed tape, measuring from the maximum extension of the upper node to the maximum extension of the lower node is 0.125 inches.

EXAMPLE 2 (Control, forming no part of this invention):

Using a grade I titanium ribbon measuring 0.75 inches by 0.020 inches, a series of slots are made in the longitudinal direction having a unit length of 3.75 inches. The width between slotted portions of the titanium ribbon is about 0.0938 inches. A total of seven slots are made in the longitudinal direction being exactly equal to the number of slots, and the dimensions provided in Example 1 for the titanium ribbon described in Example 1.

EXAMPLE 3 (Control, forming no part of this invention):

A grade I titanium ribbon having a width of 0.75 inches and a thickness of 0.020 inches.

EXAMPLE 4 (Control, forming no part of this invention):

A grade I titanium strip having a width of 0.75 inches and a thickness of 0.020 inches is expanded to form a diamond shaped mesh in accordance with the teachings of the prior art. The expanded mesh has a width of 2-1/2

inches, a mesh thickness of 1/8 inch, a mesh strand width of 3/32 inch, a diamond long way dimension of 2-1/2 inches, and a diamond short way dimension of 5/8 inch.

5 EXAMPLE 5:

The anodes prepared in Examples 1 - 4 are evaluated for voltage drop (IR drop) over a 48 inch length of each of the anodes described in Examples 1 - 4. The voltage drop is measured both at a current of 1 ampere and at a current of 2 amperes. The results are shown in Table I below:

10

TABLE I

<u>Current</u> (amperes)	<u>Voltage (IR) drop</u> (millivolts)			
	EXAMPL E 1	EXAMPL E 2	EXAMPL E 3	EXAMPL E 4
1	61	61	58	65
2	122	123	115	129

15

20 EXAMPLE 6:

In order to evaluate the anodes described and shown in Figures 4 and 5 as to the ease with which a concrete grout flows around and below the nodes of the anode, a series of anodes are embedded in a concrete grout. The anodes and grout are placed on a 1/4 inch thick plate of glass so that the effect

of any blockage of the flow of grout can be made visible from below. To simulate the application of the anode into 1 inch slots cut into an existing concrete surface in which such anodes are placed in order to provide cathodic protection for steel reinforcing rods in such a structure, suitable long rectangular polyvinyl chloride bars are placed on the plate of glass spaced 1 inch from each other. Thereafter, three anodes are placed on the glass at the bottom of the slots formed by the rectangular bars previously described. The anodes utilized are those prepared in Examples 1 - 3.

Thereafter, a concrete grout is prepared by thoroughly mixing 1 kilogram of Portland cement, type I with 0.4 kilograms of water and 2.0 kilograms of sand. The concrete is poured into the slots containing the samples and packed and troweled with a spoon. The final top surface is smoothed with a flat spatula. After the concrete has hardened, the apparatus is turned over and the areas underneath the samples are inspected through the plate of glass. The results are as follows:

The tape prepared in Example 1 when tested as described above shows that the area between the glass plate and the anode was filled approximately 99 percent with concrete. The concrete looks uniformly packed and the nodes of the anode are well encased in the concrete. A single area without concrete is a bubble measuring about 1/8 inch in diameter.

The anode prepared in Example 2, when viewed through the plate glass, is about 80 percent encased in concrete. The 20 percent of the area of the

anode without concrete encasement is composed of oblong spaces, the largest being about 1/2 inch by 1/4 inch.

The anode prepared in Example 3 when viewed through the plate glass shows about 75 percent of the area of the anode encased with concrete. Most of the areas containing concrete contain only a thin, non-uniform layer. The 25 percent of the area without concrete is composed of large, oblong spaces, the largest being about 3/4 inch by 1/4 inch.

EXAMPLE 7:

A concrete slab is fabricated having dimensions of 14 inches by 7 inches by 2 inches. Sodium chloride is added to the wet concrete mix in order to simulate the conditions found in the preparation of typical reinforced concrete or structures exposed to salt containing environments as a result of the use of salt during winter months on roadways and bridges. A concentration of about 5 pounds of sodium chloride per cubic yard of concrete is used. Embedded in the concrete slab is a steel bar simulating reinforcing steel bar typical in many concrete bridge structures. The steel bar protrudes at one end of the concrete slab in order to allow connection to an electrical circuit.

The anode of Example 1 is placed in a slot cut in the surface of the concrete slab and thereafter back filled with concrete grout. The concrete block is placed in an atmosphere having a relative humidity of 90 - 100 percent and the titanium anode is connected to a positive post of a regulated power

supply. The reinforcing steel bar is connected to a negative post. The power supply for the circuit is adjusted to give a constant current of 1.16 milliamps which is calculated to be equivalent to a current density on the surface of the titanium anode of 2 milliamps per square foot. Comparison of the initial cell voltage which is measured between the titanium anode and the steel bar and the cell voltage after 31 days of operation indicates that no passivation of the titanium anode has occurred.

EXAMPLE 8:

Three titanium anode samples identical to Example 1 are prepared and placed in separate beakers, each containing a solution of sodium hydroxide, at 0.85 molar. The surface areas of the anodes are sized so that the anode current densities in an electrical circuit are 0.8, 2, and 5 amperes per square foot. These samples are placed in series in the electrical circuit, the titanium anode pieces being connected to the positive post of a regulated power supply. Four steel sheets are each immersed in said solutions in said separate beakers and connected to the negative post of the power supply. After energizing the electrical circuit, the initial voltages on start-up of the 3 cells so formed are recorded as well as the times for a cell voltage increase of 6 volts. It is believed that the time for the cells to show a voltage increase of 6 volts is directly proportional to the expected useful lifetime of a titanium anode (time to passivation) when connected to an electrical circuit in a cathodic protection

system.

EXAMPLE 9:

5 Three samples of the titanium anode of Example 1 previously heated to a temperature of 550°C are utilized in the test procedure of Example 8 such that a current density of 5 amps per square foot and 10 amps per square foot are placed upon these samples of titanium anodes in the electrolytic cell described in Example 8. Comparison of the time in seconds for a 6 volt cell voltage increase at each of these current densities indicates that the previously
10 heated anodes of Example 9 take a substantially longer time before passivation occurs, as indicated by a 6 volt cell voltage increase, than the anodes of Example 8.

EXAMPLE 10:

15 Three samples of the titanium anode of Example 1 previously heated to a temperature of 350°C for a period of thirty minutes are evaluated in accordance with the procedure described in Example 8 at system current densities of 2, 5, and 10 amps per square foot. Comparison of the anodes of Examples 8 and 9 with those of Example 10 indicates the anodes of Example
20 10 take a substantially longer time before passivation occurs, as indicated by a 6 volt cell voltage increase.

While this invention has been described with reference to certain specific embodiments, it will be recognized by those skilled in the art but many variations are possible without departing from the scope and spirit of the invention, and it will be understood that it is intended to cover all changes and
5 of the invention disclosed herein for the purposes of illustration which do not constitute departures from the spirit and scope of the invention.

I claim:

1. In a cathodic protection system for a steel reinforced concrete structure comprising a plurality of porous anodes, the improvement wherein each of said anodes comprises:

5 A) a unitary, multi-plane, porous, metal strip

(1) consisting of a plurality of trough and crest nodes defining upper and lower planes at the extremities of said nodes, or

(2) consisting of a plurality of trough or crest nodes defining either an upper or a lower plane at the extremities of said nodes,

10 B) said nodes spaced longitudinally to provide an intermediate plane separating said nodes, and

C) said trough and crest nodes alternating laterally.

2. The cathodic protection system of claim 1 wherein said trough and crest nodes alternate longitudinally and said porous anode comprises a valve metal anode having a length greater than a width and said width greater than a thickness, said anode being deposited within a concrete surface of a steel reinforced concrete structure but spaced apart from a steel reinforcing member in said concrete structure.

3. The cathodic protection system of claim 2 wherein said anode is deposited on a horizontal, inclined, vertical, or overhead surface of said steel reinforced concrete structure.

4. The cathodic protection system of claim 3 wherein said anode crest and trough nodes are each produced by deforming a longitudinal row between an elongated, substantially parallel slotted portion and an adjacent, elongated, substantially parallel slotted portion of said anode, each having a cut area which is staggered in relation to a laterally adjacent row of said parallel slotted portions.

5. The cathodic protection system of claim 3 wherein said anode is formed by deformation of successive, elongated, substantially parallel slotted portions cut in a valve metal sheet material to provide a plurality of longitudinally aligned and laterally extending rows wherein successive, longitudinally extending crest nodes alternate with longitudinally extending trough nodes.

6. The cathodic protection system of claim 3 wherein said anode is a valve metal selected from the group consisting of titanium, tantalum, zirconium, niobium, and alloys and mixtures thereof and said cathodic protection system is operated at an anode current density of up to about 20 milliamps per square foot.

7. The cathodic protection system of claim 6 wherein said valve metal is titanium and said anode current density is about 0.1 to about 15 milliamps per square foot.

8. A reinforced concrete article having a valve metal anode having an electrocatalytically active surface coating, said anode deposited on a surface of said concrete article or installed in a slot cut in a surface of said concrete article and utilizing a cathodic protection system comprising a plurality of porous anodes wherein each anode comprises

A) a unitary, multi-plane, porous, metal strip anode

(1) comprising a plurality of trough and crest nodes defining upper and lower planes at the extremities of said nodes, or

(2) comprising a plurality of trough or crest nodes defining either an upper or a lower plane at the extremities of said nodes,

B) said nodes spaced longitudinally to provide an intermediate plane separating said nodes, and

C) said trough and crest nodes alternating laterally.

9. The reinforced concrete article of claim 8 wherein said trough and crest nodes alternate longitudinally and said valve metal is selected from the group consisting of titanium, tantalum, zirconium, niobium, and mixtures and alloys thereof and said electrocatalytically active surface coating comprises an

oxide of a platinum group metal or an oxide of cobalt, tin, or nickel.

10. The reinforced concrete article of claim 9 wherein said valve metal is titanium.

11. A method of producing a porous valve metal anode having a plurality of trough or crest nodes or trough and crest nodes, defining upper and lower planes or upper or lower planes at the extremities of said nodes, and spaced longitudinally to provide an intermediate plane between said upper and lower planes, said method comprising:

A) perforating said metal strip by shearing preselected portions thereof in uniform and closely spaced relation of one to another thereby forming exposed edges and portions of said strip having a greater longitudinal dimension than a lateral dimension, and

B) deforming said portions of said perforated strip to produce either raised or lowered portions or both raised and lowered portions extending in a direction normal to the plane of said sheet.

12. The method of claim 11 wherein said valve metal anode crest and trough nodes are each produced by deforming a longitudinal row between an elongated, substantially parallel slotted portion and an adjacent, elongated, substantially parallel slotted portion of said anode, each having a cut area

which is staggered in relation to a laterally adjacent row of said parallel slotted portions.

13. The method of claim 12 wherein said anode is formed by deformation of successive, elongated, substantially parallel slotted portions cut in a valve metal sheet material to provide a plurality of longitudinally aligned and laterally extending rows wherein successive, longitudinally extending crest nodes alternate with longitudinally extending trough nodes.

14. The method of claim 13 wherein said valve metal is selected from the group consisting of titanium, tantalum, zirconium, niobium, and alloys and mixtures thereof and said cathodic protection system is operated at an anode current density of up to about 20 milliamps per square foot.

15. The method of claim 14 wherein said valve metal is titanium and said anode current density is about 0.1 to about 15 milliamps per square foot.

16. The method of claim 11 wherein said anode is formed by deformation of successive, elongated, substantially parallel slotted portions cut in a valve metal sheet material to provide a plurality of longitudinally aligned and laterally extending rows wherein successive, longitudinally extending crest nodes alternate with longitudinally extending trough nodes and said valve

metal is activated so as to extend the lifetime of the anode at a temperature of about 250°C to about 750°C.

17. The method of claim 16 wherein said valve metal is selected from the group consisting of titanium, tantalum, zirconium, niobium, and alloys and mixtures thereof and said cathodic protection system is operated at an anode current density of up to about 50 milliamps per square foot.

18. The method of claim 17 wherein said valve metal is titanium and said anode current density is about 0.1 about 20 milliamps per square foot.

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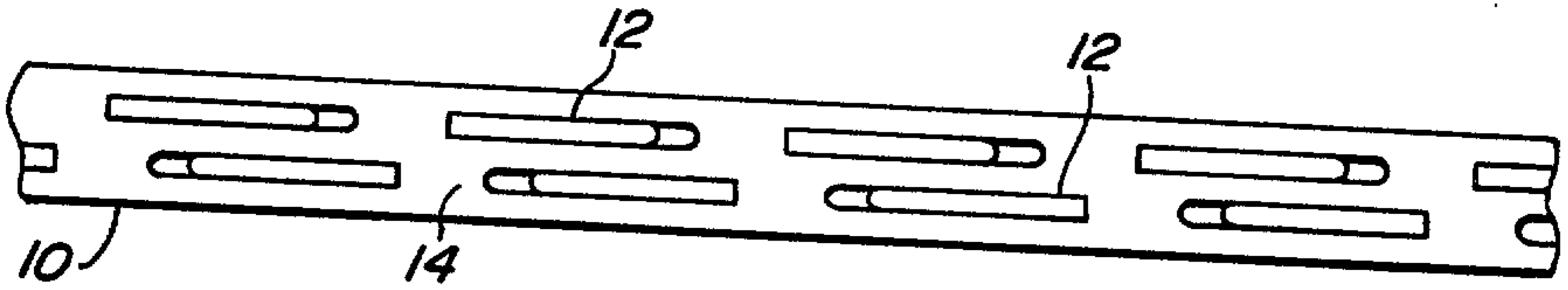


Fig-1



Fig-2

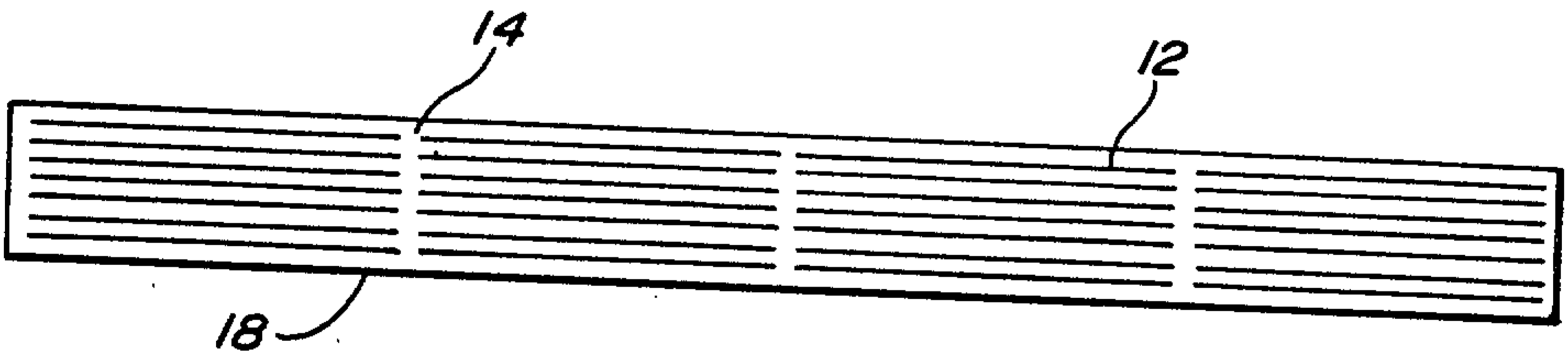


Fig-3

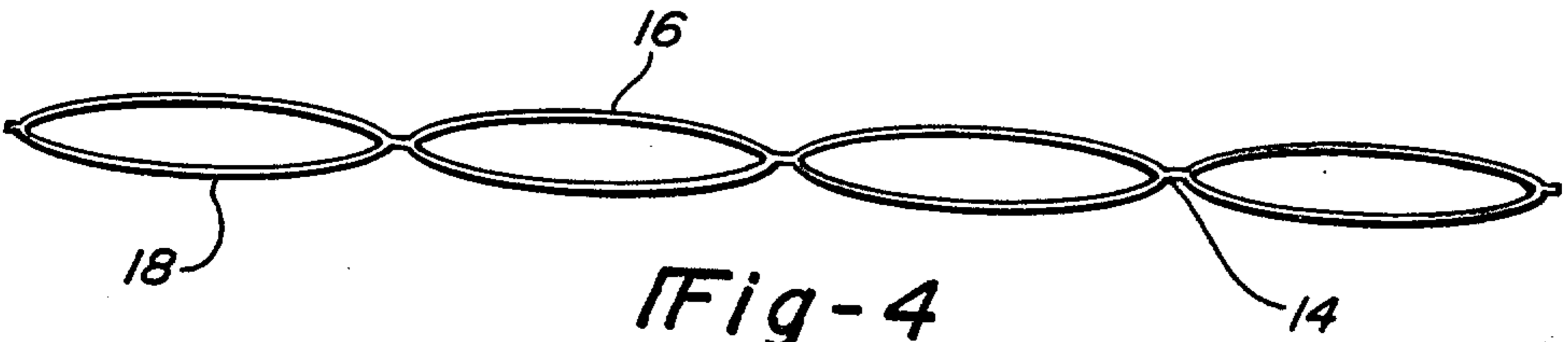


Fig-4

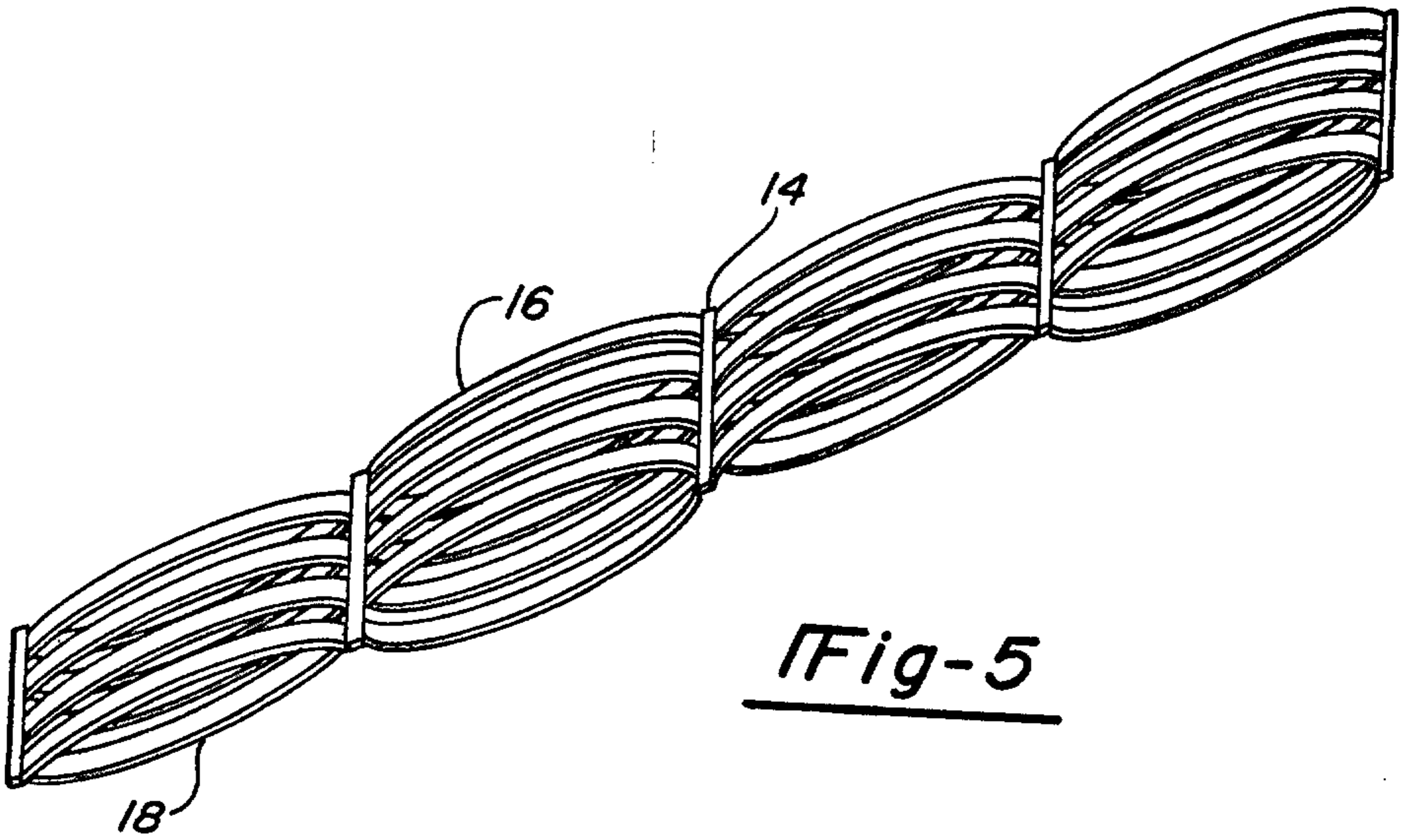


Fig-5

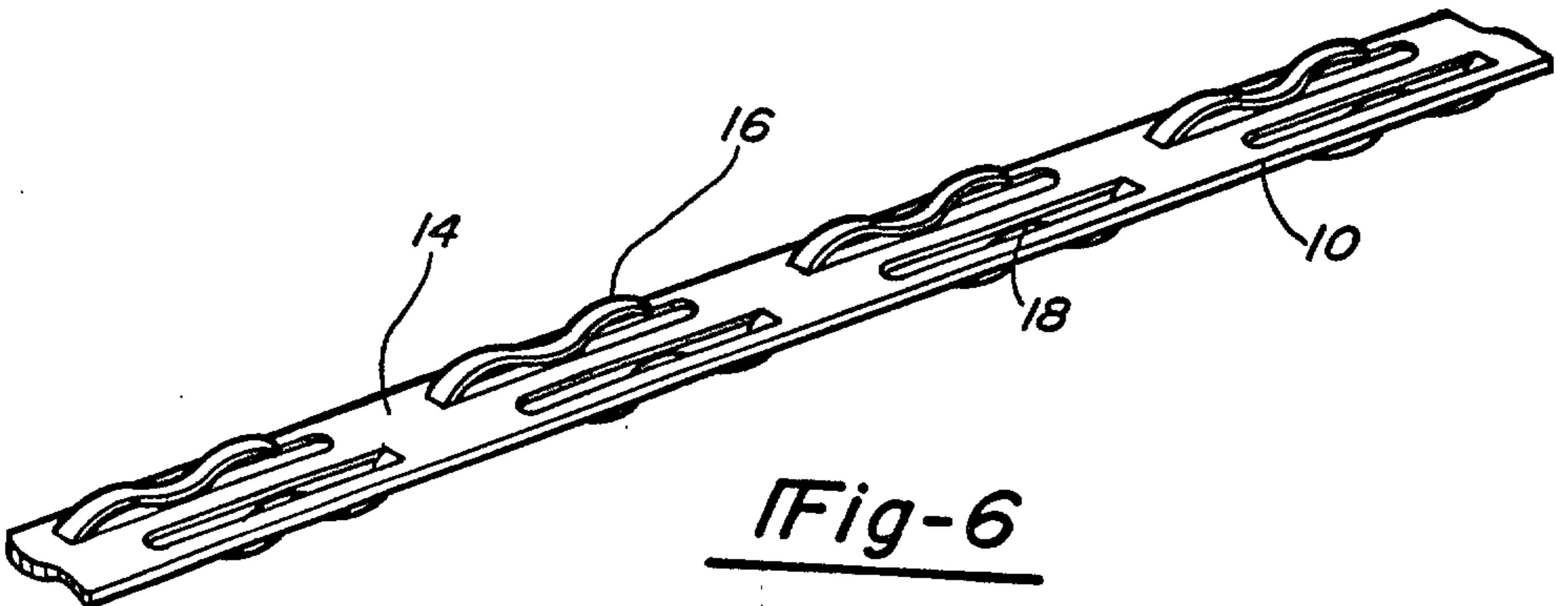


Fig-6

