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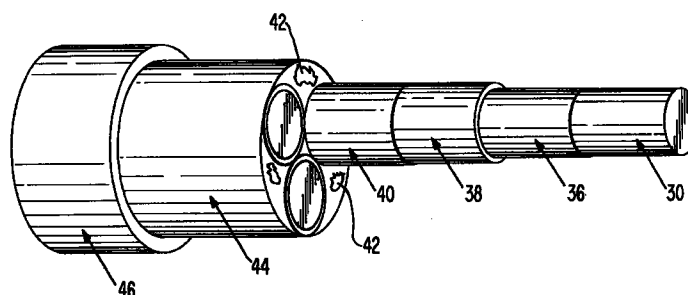
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(54) Improved primary resistance welding cable and assembly

(57) An improved primary resistance welding cable and assembly is provided which may include a non-replaceable, bonded and configurable polymeric strain

relief. The improved resistance welding cable provides a long operational life in a high-flex environment.

FIG. 4



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Description**FIELD OF THE INVENTION**

5 The present invention relates to an improved primary resistance welding cable assembly for robotic resistance welding and assembly equipment, or other suitable mechanically automated manufacturing equipment.

BACKGROUND OF THE INVENTION

10 In primary resistance welding operations, electrical current (e.g. 480 volts (V) and 110 amps (A)) is passed through a flexible electrical cable to a transformer, where the power is transformed into lower voltage and higher amperage (e.g. 20 volts and 10,000 amps). This current then passes through welding tips, and through resistive heat and pressure at the faying surface between two pieces of metal, a weld joint is formed. The high amperage current causes fusion of parts to be welded at the joint. To accomplish the resistance welding operation, a flexible primary electrical cable formed
 15 of two or more stranded conductors is typically connected between a power source and a transformer/welding gun. The welding gun includes welding tips which may be closed on opposite sides of the joint to be welded.

In many resistance welding operations, such as robotic resistance welding operations which support the automobile industry for example, the operation of the welding gun results in a continuous movement and flexing of the primary welding cable. Over time, this flexing causes the copper conductors within the cable to work harden which results in the
 20 breakage of the fine strands of the conductors. This results in the copper conductors within the primary welding cable to gradually increase in resistance over a period of time. As the resistance increases, the amount of heat generated in the cable increases, and the amount of current available for the welding tips of the welding gun reduces significantly. A drop in current eventually will produce an inferior weld. Also, increased heat generated at the conductors accelerates work hardening of the copper which leads to embrittlement and premature breakage.

25 Typically, manufacturers replace welding cables at predetermined time intervals.

In order to determine when a cable has reached the point of replacement, the general practice is to shut down the welding line, disconnect the cable, and test the resistance of the cable. If the cable is satisfactory based on the resistivity limits defined by the manufacturer, the cable is reconnected and used until the next test period. If the resistance of the cable is found to be more than the predetermined percentage higher than the original cable resistance measured, the
 30 cable is replaced. The increase in cable resistance is dependent upon a number of factors, including temperature, the amount of flexing the cable has encountered, and the amount of use placed on the cable in the welding operation. Because of this, it is not possible to predict exactly when a cable is due for replacement. Although self-diagnostic equipment is available to test the cable during use, without having to disconnect the cable from the welding system, conventional welding cables wear quickly, and must be replaced often. In such industries as the automobile industry, shutting
 35 down an assembly line to replace a worn or failed welding cable is extremely costly due to the lost manufacturing time associated with the cable replacement. It is not uncommon for a welding cable in a robotic automobile assembly line to need replacement after only four to six weeks of use.

Conventional resistance welding cables include a termination which incorporates a stainless steel "Cord Grip" which is used to limit the twist or bend angle at the connector termination. However, conventional resistance welding
 40 cables suffer from shortcomings which detract from their usefulness. For example, the "Cord Grip" type strain relief and termination does not effectively reduce torsional strain, or fully protect the cable termination from failure due to the abrasion of the metal grip on the cable insulation which is inherent in the design.

The foregoing illustrates limitations known to exist in present welding cables. Thus, it is apparent that it would be advantageous to provide an improved welding cable directed to overcoming one or more of the limitations set forth
 45 above. Accordingly, a suitable alternative is provided including features more fully disclosed hereinafter.

SUMMARY OF THE INVENTION

The present invention advances the art of resistance welding cables beyond which is known to date. In one aspect
 50 of the present invention a resistance welding cable is provided which comprises a plurality of electrical conductors, an insulation material which is disposed about each electrical conductor, and a jacket material which is disposed about the insulated conductors. The jacket material defines a predetermined diameter for the resistance welding cable. At least one connector or termination interface may be electrically terminated to at least a first end of the resistance welding cable. At least one strain relief may be made integral with the jacket material and the connector or termination interface.
 55 The at least one strain relief has at least a first frusto-conically shaped first portion defined by opposed first and second ends. The first end is defined by a diameter which is substantially equal to the diameter of the cable jacket. The second end is defined by a diameter which is greater than the diameter of the first end. The at least one strain relief provides a smooth continuous transition from the second end of the strain relief to the cable jacket. A wrapping of porous polytetrafluoroethylene may be disposed about each electrical conductor, wherein the insulation material is disposed about

said wrapping of each electrical conductor. A wrapping of porous polytetrafluoroethylene may be disposed about the insulation material of each electrical conductor. A wrapping of porous polytetrafluoroethylene may be disposed about the plurality of electrical conductors to form a bundle of electrical conductors, wherein the jacket material is formed about said wrapping. The durometer hardness of the strain relief may be substantially equal to the durometer hardness of the cable jacket. The strain relief may additionally include a second portion which is molded with the first portion to form a unitary strain relief; the second portion encapsulating a predetermined portion of the at least one connector. The strain relief may be comprised of a two-part, castable polyurethane which chemically bonds to the cable jacket.

It is a purpose of the present invention to provide an improved primary resistance welding cable having a long operational life in a high flex environment.

It is another purpose of the present invention to provide an improved primary resistance welding cable having a non-replaceable, bonded and configurable polymeric strain relief which does not abrade a cable jacket, which effectively reduces torsional strain on a connector of the cable and the conductors within, and which provides non-abrasive bending limitations at a connector joint.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing summary, as well as the following detailed description of a preferred embodiment of the invention, will be better understood when read in conjunction with the appended drawings. For purposes of illustrating the invention, there is shown in the drawings an embodiment which is presently preferred. It should be understood, however, that the invention is not limited to the precise arrangement and instrumentality shown. In the drawings:

Figure 1 is a partial perspective view of an embodiment of the improved resistance welding cable of the present invention;

Figure 2 is an end elevational view of a first end of the resistance welding cable of Figure 1;

Figure 3 is an end elevational view of a second end of the resistance welding cable of Figure 1;

Figure 4 is a partial, cut-away view of the resistance welding cable of Figure 1 which illustrates an internal construction thereof;

Figure 5 is an environmental view showing the resistance welding cable of the present invention employed with an automated resistance welding apparatus;

Figure 6 is a diagram illustrating normal stress in strain relief; and

Figure 7 is a view of a prior art resistance welding cable.

DETAILED DESCRIPTION OF THE INVENTION

Referring to the drawings, a resistance welding apparatus is illustrated generally at 10 in Figure 5. The resistance welding apparatus comprises a robotic assembly 12, a trans-gun unit 14, a junction box 16, an improved resistance welding cable 18, made in accordance with the teachings of the present invention, and a power source (not shown).

The trans-gun unit 14 includes a pair of welding tips 20 which may be closed on opposite sides of a joint to be welded (not shown).

As should be understood, the trans-gun unit 14 is a combination of a transformer and a resistance weld gun. The resistance weld gun uses high current and pressure to produce a weld. Heat for the weld is generated by the resistance of the two pieces of metal being welded. Electrical power is provided to the trans-gun unit 14 through the resistance welding cable 18, which is electrically connected with the junction box 16, which may be located on an arm or hip of the robot. The transformer of the trans-gun unit 14 takes primary power at high voltage and transforms it into secondary power at high current. Typically, primary voltage may come in at 480 volts, which is transformed into secondary current, which may be as high as 13,000 to 15,000 amps, depending on the size of the trans-gun unit. The gun of the trans-gun unit 14, may typically have a kilo volt-amps (KVA) rating of between 45-150 KVA. The power rating of the gun is best understood by the following expression:

$$P_{x\text{-gun}} = VI$$

where:

$P_{x\text{-gun}}$ = KVA rating of trans gun;

I = current from power source; and

V = voltage of power source.

As should be understood, the primary resistance welding cable 18 of the present invention is not limited to the use illustrated herein. Instead, the primary resistance welding cable 18 may be used in any resistance welding operation,

including but not limited to other robotic resistance welding operations or manual mechanical primary resistance welding operations.

As best illustrated by reference to Figure 7, a conventional resistance welding cable is illustrated generally at 22. The conventional resistance welding cable includes a cable 25, a connector 24 and a strain relief 26. The strain relief 26 is typically referred to in the art as a "Cord Grip" type strain relief which comprises a stiff steel braid. The strain relief 26 does not adhere to a jacket of the cable 25 which causes significant abrasion of the cable 25 which results in an early failure of the cable. Also, the strain relief 26 does not effectively reduce torsional strain upon the cable 22, which also may cause premature failure of the cable. Additionally, the conventional resistance welding cable 22 does not provide a smooth transition from the strain relief 26 to the cable 25 which creates a pinch point on the cable jacket. Further, the stiffness of the steel braid of the "Cord Grip" type strain relief does not allow bending flex near the connector. In minor bending, the cable 25 only flexes at the end of the braid.

The resistance welding cable 18 of the present invention is best understood by reference to Figures 1-4. The resistance welding cable 18 includes a plurality of electrical conductors 30, at least one strain relief 32, and may include at least one electrical connector or anchoring device 34. The anchoring device may include, but is not limited to, threaded type inserts, or other suitable mechanical termination members.

In a presently preferred embodiment, the plurality of electrical conductors 30 may be defined by 2/0 to 10 AWG (American Wire Gauge) bare copper. A tape 36 of porous polytetrafluoroethylene may be helically wrapped around each electrical conductor 30. The tape 36 may have a total wrap thickness of about 0.0045 thickness inches. Applied over each electrical conductor 30, or over the tape 36 if it is provided, is a primary insulation 38, which may comprise polyurethane. The primary insulation may be applied in any suitable fashion, such as but not limited to extruding the material or polyurethane over each wrapped electrical conductor 30. An overall voltage rating of from about 300V to 2000V, and an overall temperature rating of from about 90°C to 105°C can be obtained by varying the wall thickness and formulations of insulation materials of the primary insulation. In this regard, the primary insulation may have a thickness ranging from, but not limited to 0.030 to 0.110 inches. A tape 40 of porous polytetrafluoroethylene may be helically wrapped around each insulated electrical conductor 30. The tape 40 may have a total wrap thickness of about 0.0045 inches. After the electrical conductors 30 have been prepared in the above described fashion, the electrical conductors are cabled, at which time a filler material 42 such as but not limited to, nylon, cotton, polyester rope or strands, or a wrapped, extruded polyurethane or other suitable cylindrical material, may be arranged in an intermingled fashion with the prepared electrical conductors 30. About the cabled electrical conductors and filler material may be helically wrapped a binder tape 44 of porous polytetrafluoroethylene. The tape 44 may have a total wrap thickness of about 0.0045 inches. Applied over the binder tape 44 is an overall cable jacket 46, which may comprise polyurethane of the same type used for the primary insulation 38. The cable jacket 46 may be applied in any suitable fashion, such as but not limited to extruding the polyurethane over the binder tape 44. The total wrap thickness of the cable jacket 46 may range from about 0.0045 inches to about 0.120 inches.

As the term is used herein, porous polytetrafluoroethylene (PTFE) shall mean a membrane which may be prepared by any number of known processes, for example, by stretching or drawing processes, by papermaking processes, by processes in which filler materials are incorporated with the PTFE resin and which are subsequently removed to leave a porous structure, or by powder sintering processes. Preferably, the porous polytetrafluoroethylene film is porous expanded polytetrafluoroethylene film having a microstructure of interconnected nodes and fibrils, as described in U.S. Patent Nos. 3,953,566 and 4,187,390, which are incorporated herein by reference, and which fully describe the preferred material and processes for making them. The porous polytetrafluoroethylene membrane may have a pore volume in a range from about 20 to about 98 percent.

The above described design of the resistance welding cable 18 provides electrical conductors 30 that are isolated from the primary insulation 38. Also, the primary insulation 38 is isolated from the overall cable jacket 46. Such a design provides a construction in which the insulated electrical conductors 30 are constrained within a cable jacket 46, yet are moveable independent of each other and the cable jacket 46 when the cable experiences a bending flex. Accordingly, by reducing friction at the interfaces of the cable jacket 46 and the primary insulation 38, and the interfaces of the primary insulations 38 and the electrical conductors 30, stresses on the electrical conductors 30, can be reduced which causes flex life of the cable 18 to be increased.

As best seen by reference to Figure 6, when the resistance welding cable 18 undergoes bending flex, a bending moment is created in the cable about its neutral axis. This bending moment increases linearly with distance from the point of bending to a fixed boundary, which in the case of the resistance welding cable illustrated in Figures 1-5 is a connector or anchoring device 34. This bending moment creates normal compression and tension stresses in the cable. These stresses are equal to zero at the neutral axis and increase with distance from the neutral axis. Thus, maximum normal stress (both compression and tension) occur at the farthest point from the neutral axis, which in the resistance welding cable 18 is the cable jacket 46. The maximum normal stress is directly proportional to the bending moment mentioned above. Therefore, the maximum normal stresses increase as the bending moment increases. The maximum normal stresses, however, are inversely proportional to the moment of inertia.

These relationships are best illustrated by reference to the following equations wherein:

σ_{\max} =	maximum normal stress
M =	bending moment
χ =	distance along frustum
d =	diameter of cross section
5 S =	section moduli
I =	moment of inertia
γ =	distance from neutral axis
σ_{χ} =	normal stresses at χ and γ distance from neutral axis
p =	load
10 c =	maximum distance from neutral axis

$$15 \quad \sigma_{\max} = \frac{M}{S} = \frac{P\chi}{S} = \frac{32 P\chi}{\pi \cdot d^3 \chi (1 + \chi/L)^3};$$

where

$$20 \quad S = \frac{I}{c}; \text{ and } c = \frac{d}{2} \therefore S = \frac{\pi d^3}{32}; \text{ and}$$

$$25 \quad \sigma_{\chi} = \frac{M\gamma}{I}; \text{ and } M = P\chi \text{ and } I = \frac{\pi d^4}{64}$$

and $d = d_a(1 + \chi/L)$ for a frustum.

The strain relief 32 incorporates a two part polyurethane cast mold that is mechanically and chemically bonded to the cable jacket 46. The strain relief 32 is a frusto-conically shaped part that is molded directly to the cable assembly. 30 As the term is used herein, "frusto-conically" means a part of a solid cone between two parallel planes cutting the solid cone, especially the section between the base and a plane parallel to the base of the cone.

The shape of the strain relief 32 is important in that as the cross section of the strain relief increases, the moment of inertia increases. Since the maximum normal stresses are inversely proportional to the moment of inertia, the maximum normal stresses decrease as the moment of inertia increases. Therefore, as the bending moment increases 35 along the cable 18 to the connector 34, the diameter of the strain relief increases along the cable to the connector 34, increasing the moment of inertia, resulting in the decreasing of the maximum normal stresses in the cable 18 and connector 34.

The strain relief 32 may be molded or formed by any suitable material which may be made integral with, or may be affixed to, the cable jacket 46. In a preferred embodiment, the strain relief is molded from a two-part castable polyurethane to form a strain relief which bonds to the cable jacket 46. Because the strain relief 32 is made integral with the cable jacket 46, abrasion of the cable 18 is eliminated. Also, the strain relief 32 provides a smooth continuous transition 40 from the strain relief to the cable 18, which eliminates pinch points. More particularly, and as best seen by reference to Figure 1, the strain relief is defined by a first portion 50 having a first end 52 and a second end 54. The first end 52 is defined by a diameter which is substantially equal to the diameter of the cable jacket 46. The second end 54 is defined 45 by a diameter which is greater than the diameter of the first end 52. The first portion 50 of the strain relief 32 provides a smooth, continuous transition from the strain relief 32 to the cable 18, at the first end 52. The strain relief 32 also includes a second portion 56 which is molded with the first portion 50 to form the unitary strain relief 32. The second portion 56 of the strain relief 32 encapsulates a portion of the connector or anchoring device 34 thereby providing strain relief at the interface of the connector 34 and the cable 18. Additionally, and in a preferred embodiment, the durometer 50 hardness of the strain relief 32 is substantially equal to the durometer hardness of the cable jacket 46 to permit bending flex near the connector 34.

The strain relief 32 may be made in accordance with the teachings of U.S. Patent 4,814,412 which is incorporated herein by reference. In a preferred embodiment of the present invention, the strain relief 32 is formed in accordance with the following example, which is provided for purposes of illustration only, and is in no way intended to limit the teachings 55 of the present invention.

Example

Component I consists of 100 parts of a mixture of aromatic polyisocyanates derived from methylene diphenyl diiso-

cyanate having an isocyanate functionality of 2.2 and a free isocyanate content of 27.3%. Component P was prepared by mixing 88.3 parts of an ethylene oxide capped trio with a molecular weight of 4,500; 6.1 parts of 1,4 butanediol; 4.7 parts of an inorganic desiccant; 0.9 parts of carbon black powder; and 0.00005 parts of an organic tin catalyst, and then degassing the mixture under ambient conditions at 31.6 in. water for 1 hour.

Components I and P were mixed at a 0.306:1 weight ratio for about two minutes in a desiccator. The mixture was de-gassed under vacuum for about 4-5 minutes, while the mixture was agitated. The mixture was removed from vacuum and gently shaken to remove any excess air bubbles. Thereafter, the mixture was poured into a mold.

The mold was pretreated by coating the mold with a dry film mold release spray. Necessary inserts were added to the mold. The mold was heated to about 80°C. The interconnected cable 18, with connector 32, was then positioned within the mold.

The mixture was allowed to cure in the heated mold at 80°C, for about 40 minutes. The gel time of the mixture was about 20 minutes. The reaction mixture had a ratio of molar equivalents of isocyanate to hydroxyl of 1.2. When cured, the polyurethane was an opaque black solid with a Shore A hardness of 60.

Although a few exemplary embodiments of the present invention have been described in detail above, those skilled in the art readily appreciate that many modifications are possible without materially departing from the novel teachings and advantages which are described herein. Accordingly, all such modifications are intended to be included within the scope of the present invention, as defined by the following claims.

Claims

1. An improved primary resistance welding cable comprising:

a plurality of electrical conductors;
an insulation material which is disposed about each electrical conductor;
a jacket material which is disposed about the insulated conductors, the jacket material defining a predetermined diameter for the resistance welding cable; and
at least one strain relief which is affixed to the jacket material, the at least one strain relief having at least a first frusto-conically shaped first portion defined by opposed first and second ends, the first end being defined by a diameter which is substantially equal to the diameter of the cable jacket, and the second end being defined by a diameter which is greater than the diameter of the first end, the at least one strain relief providing a smooth continuous transition from the second end of the at least one strain relief to the cable jacket.

2. The invention of claim 1 further including a wrapping of porous polytetrafluoroethylene which is disposed about each electrical conductor, wherein the insulation material is disposed about said wrapping of each electrical conductor.

3. The invention of claim 2 further including a wrapping of porous polytetrafluoroethylene which is disposed about the insulation material of each electrical conductor.

4. The invention of claim 3 further including a wrapping of porous polytetrafluoroethylene which is disposed about the plurality of electrical conductors to form a bundle, wherein the jacket material is formed about said wrapping.

5. The invention of claim 1, wherein the durometer hardness of the strain relief is substantially equal to the durometer hardness of the cable jacket.

6. The invention of claim 1, wherein the strain relief additionally includes a second portion which is molded with the first portion to form a unitary strain relief, the second portion encapsulating a predetermined portion of the at least one connector.

7. The invention of claim 1, wherein the strain relief is comprised of a two-part, castable polyurethane which bonds to the cable jacket.

8. An improved primary resistance welding cable comprising:

a plurality of electrical conductors;
a wrapping of porous polytetrafluoroethylene which is disposed about each electrical conductor;
an insulation material which is disposed about the porous polytetrafluoroethylene wrapping of each electrical conductor;
a wrapping of porous polytetrafluoroethylene which is disposed about the insulation material of each electrical

conductor;

a wrapping of porous polytetrafluoroethylene which is disposed about the plurality of electrical conductors to form a bundle;

a jacket material which is disposed about said bundle, the jacket material defining a predetermined diameter for the resistance welding cable;

at least one connector electrically terminated to at least a first end of the resistance welding cable; and

at least one strain relief which is made integral with the jacket material, the at least one strain relief having at least a first frusto-conically shaped first portion defined by opposed first and second ends, the first end being defined by a diameter which is substantially equal to the diameter of the cable jacket, and the second end being defined by a diameter which is greater than the diameter of the first end, the at least one strain relief providing a smooth continuous transition from the second end of the strain relief to the cable jacket.

9. The invention of claim 8, wherein the durometer hardness of the strain relief is substantially equal to the durometer hardness of the cable jacket.

10. The invention of claim 8, wherein the strain relief additionally includes a second portion which is molded with the first portion to form a unitary strain relief, the second portion encapsulating a predetermined portion of the at least one connector.

11. The invention of claim 8, wherein the strain relief is comprised of a two-part, castable polyurethane which bonds to the cable jacket.

12. An improved primary resistance welding cable comprising:

a plurality of electrical conductors;

a wrapping of porous polytetrafluoroethylene which is disposed about each electrical conductor;

an insulation material which is disposed about the porous polytetrafluoroethylene wrapping of each electrical conductor;

a wrapping of porous polytetrafluoroethylene which is disposed about the insulation material of each electrical conductor;

a wrapping of porous polytetrafluoroethylene which is disposed about the plurality of electrical conductors to form a bundle;

a jacket material which is disposed about said bundle, the jacket material defining a predetermined diameter for the resistance welding cable; and

at least one connector electrically terminated to at least a first end of the resistance welding cable.

13. An improved primary resistance welding cable comprising:

a plurality of electrical conductors;

an insulation material which is disposed about each electrical conductor;

a jacket material which is disposed about the insulated conductors, the jacket material defining a predetermined diameter for the resistance welding cable; and

at least one strain relief having at least a first frusto-conically shaped first portion defined by opposed first and second ends, the first end being defined by a diameter which is substantially equal to the diameter of the cable jacket, and the second end being defined by a diameter which is greater than the diameter of the first end, the at least one strain relief providing a smooth continuous transition from the second end of the at least one strain relief to the cable jacket.

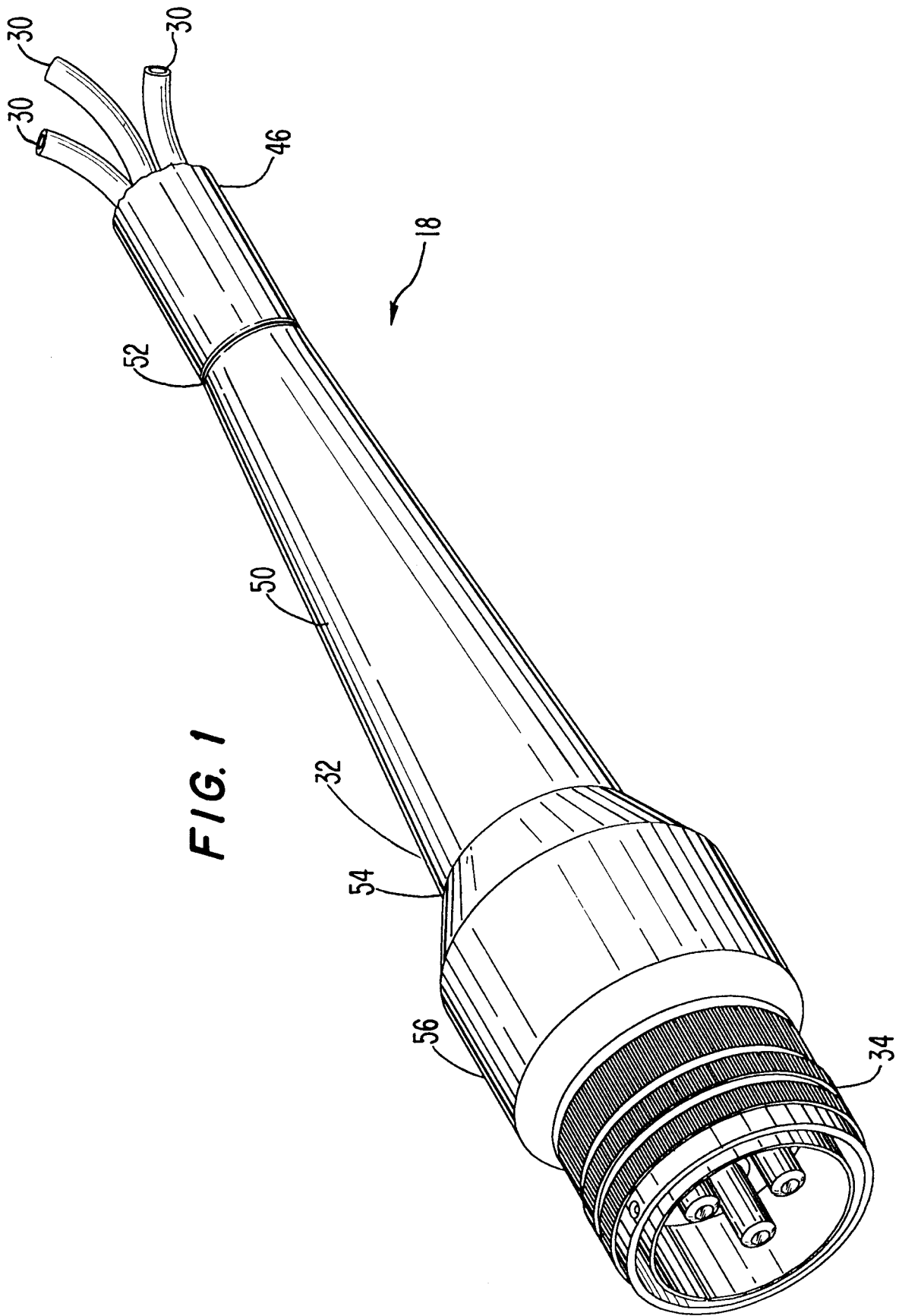


FIG. 2

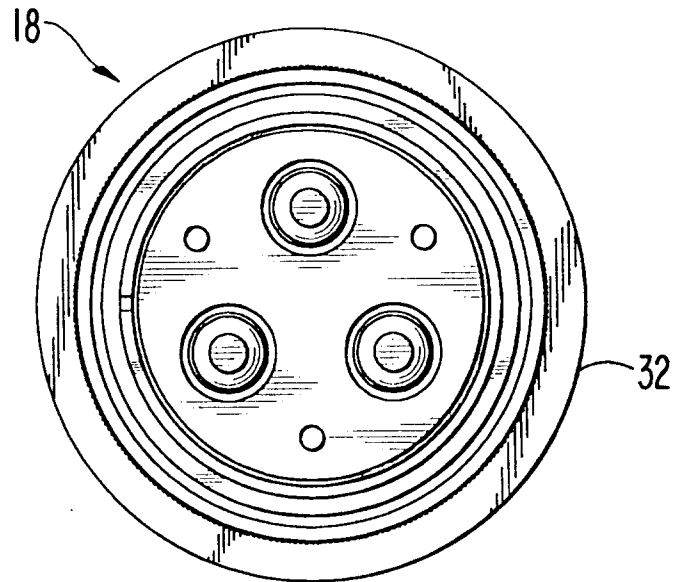


FIG. 3

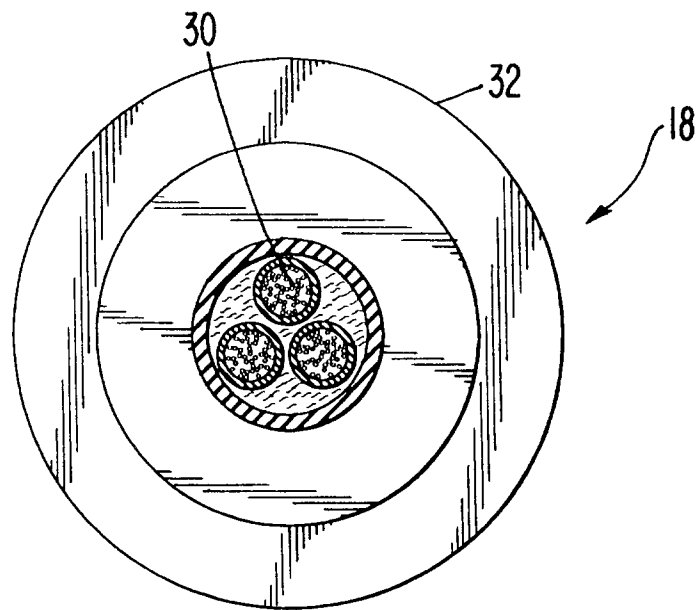
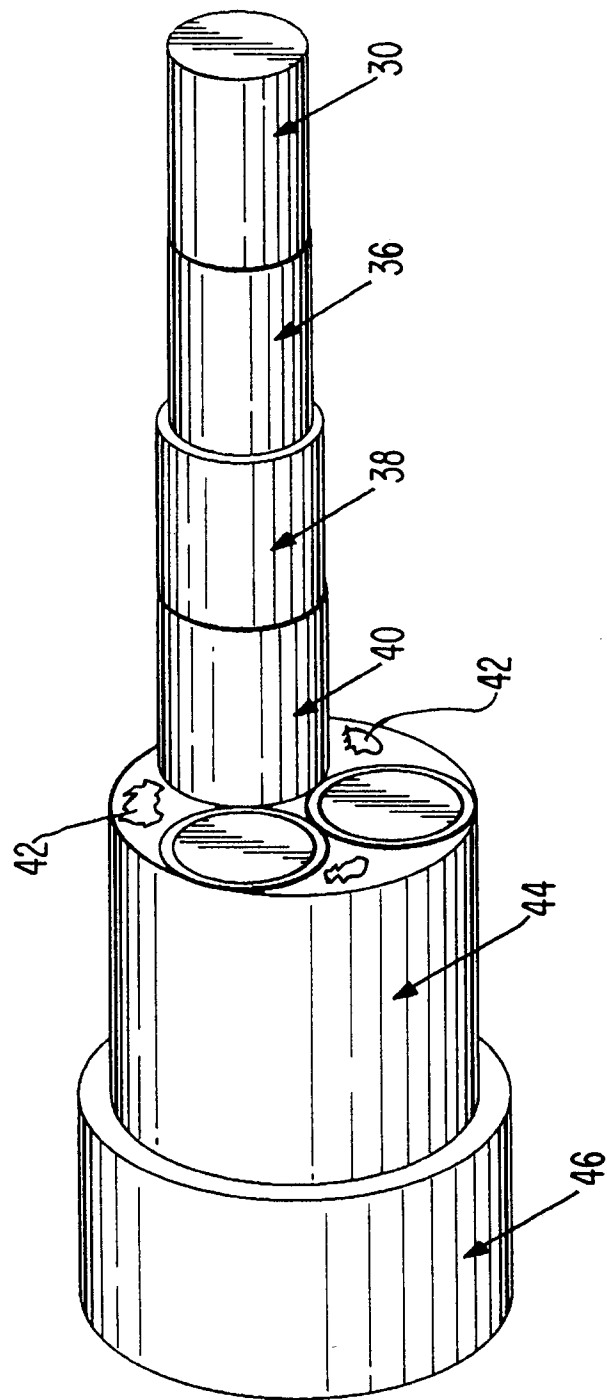


FIG. 4



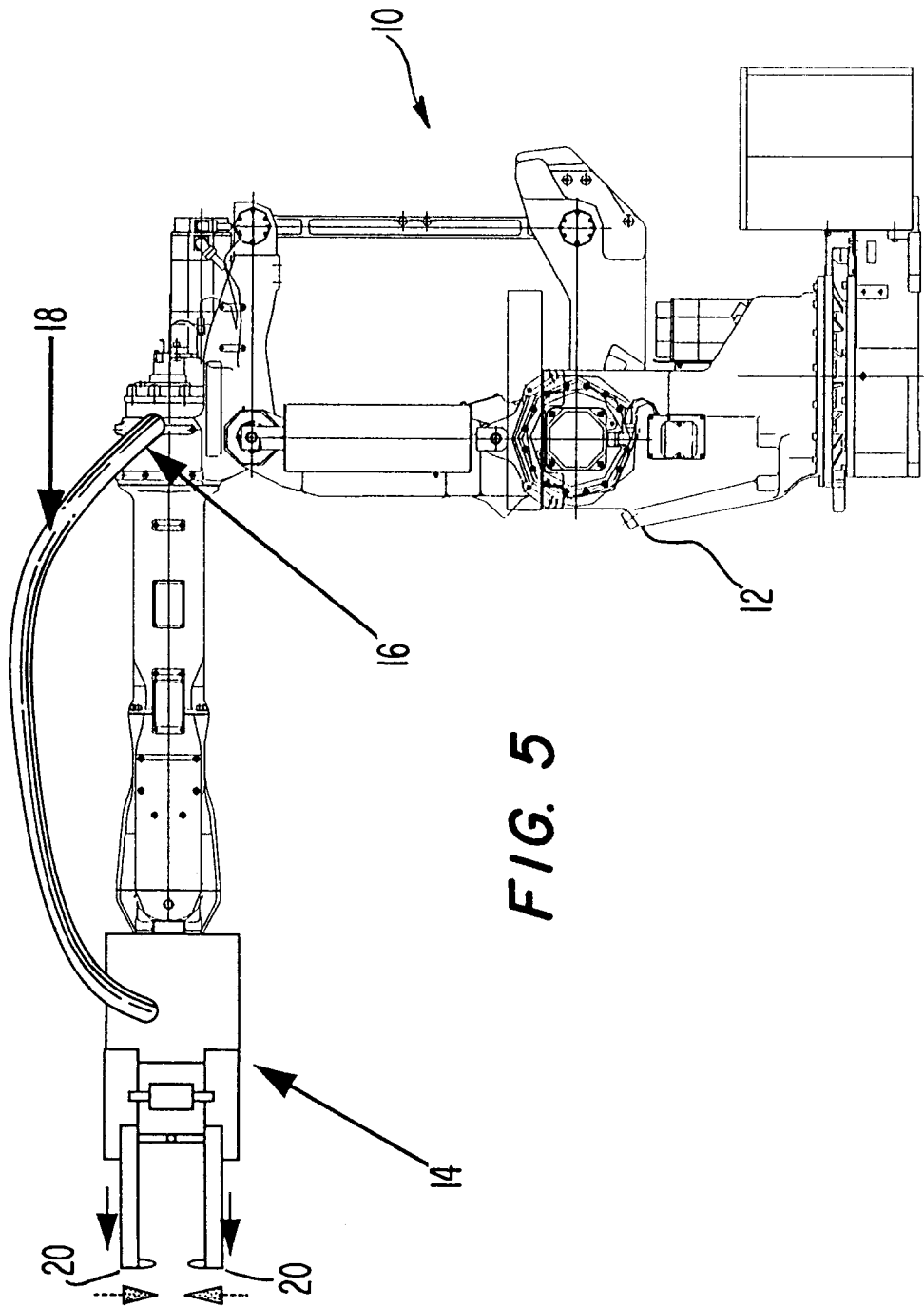


FIG. 6

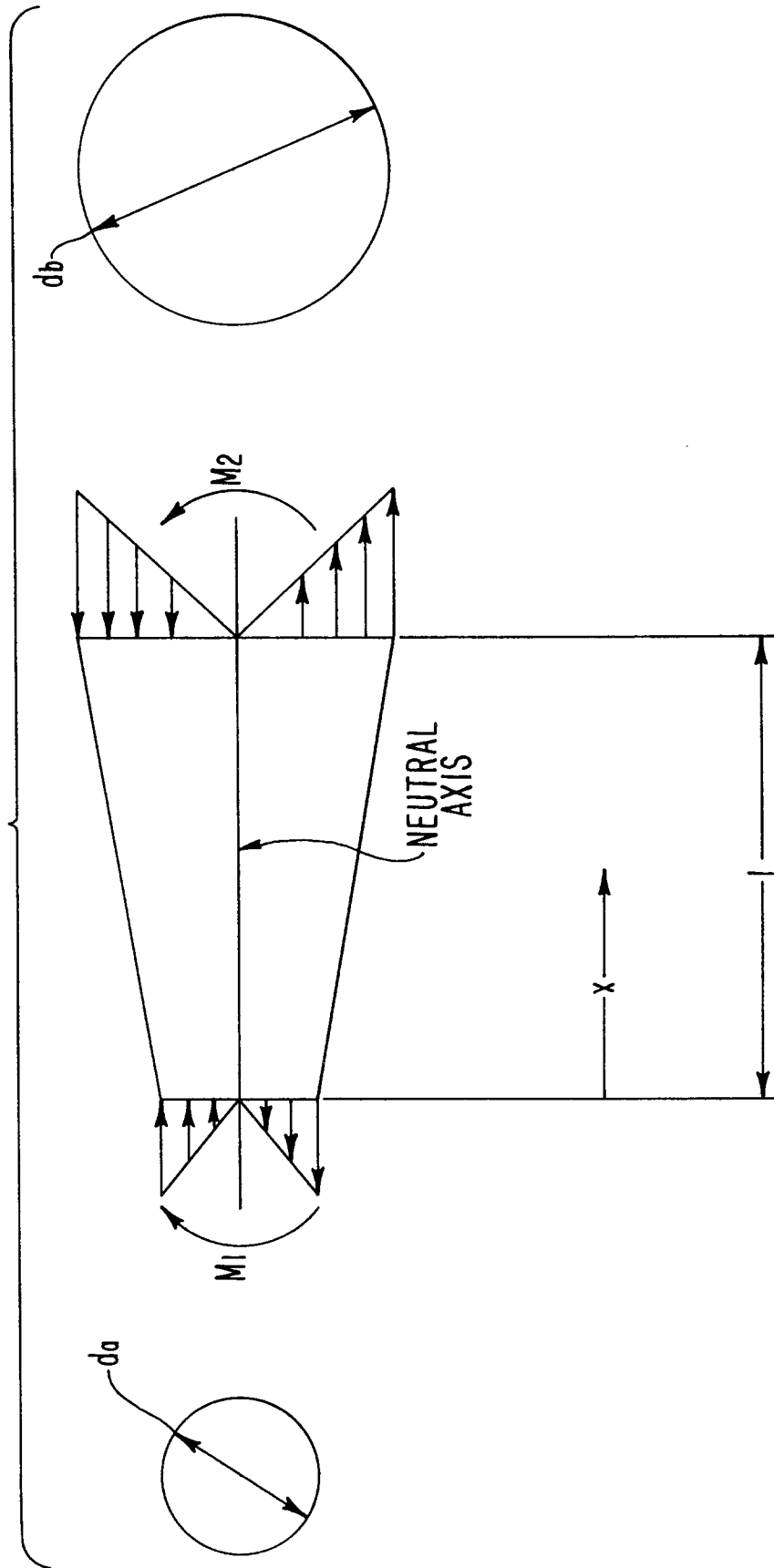


FIG. 7
(PRIOR ART)

