(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 075 471 A1**

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: **82304933.3**

(22) Date of filing: **20.09.82**

(51) Int. Cl.³: **H 01 B 17/28**

(30) Priority: **21.09.81 US 304233**

(43) Date of publication of application: **30.03.83 Bulletin 83/13**

(84) Designated Contracting States: **AT BE CH DE FR IT LI NL SE**

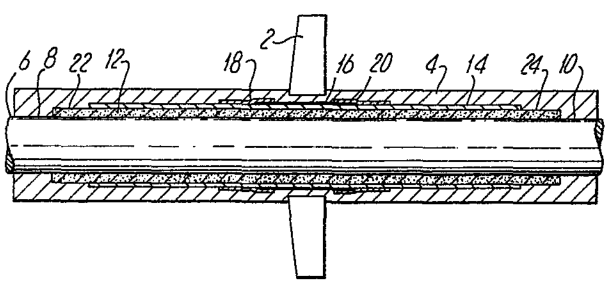
(71) Applicant: **RAYCHEM CORPORATION, 300 Constitution Drive, Menlo Park California 94025 (US)**

(72) Inventor: **Fritsche, Joel Leigh, 249 Upland Road, Redwood City California 94062 (US)**
Inventor: **Link, William Trevor, 130 The Uplands, Berkeley California 94705 (US)**

(74) Representative: **Jones, David Colin et al, RAYCHEM LIMITED Morley House 26 Holborn Viaduct, London E.C.1. (GB)**

(54) **Electrical bushing and method of manufacture thereof.**

(57) An electric bushing comprises an electrical conductor (6), a first insulating layer (12) on the conductor, a stress grading layer (14) over the insulating layer, and an outer insulating layer (4) mechanically connected to a flange (2) which is electrically connected to the stress grading layer in such a manner that minimal, if any, mechanical stress is transmitted from the flange (2) to the stress-grading layer (14). The flange (2) serves to mount the bushing on to the metal housing of an electrical apparatus, such as switchgear or transformers. The flange (2) is of metal or contains a metal element and is electrically connected to the housing, when installed, making an electrical connection between the housing and the stress grading layer (14). The outer insulating layer (4) is sealed to the end regions (8, 10) of the electrical conductor (6) providing mechanical attachment between the conductor (6) and the flange (2) which secures the bushing to the electrical apparatus.



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DESCRIPTION

ELECTRICAL BUSHING AND METHOD OF MANUFACTURE THEREOF

This invention relates to an electrical bushing and to a method of manufacturing such electrical bushing.

Electrical bushings are used to conduct high voltage electrical power safely from a power line into an electrical apparatus such as switchgear or transformers. The metal housing of such electrical equipment is an electrical ground and must be insulated from the high voltage power being conducted into the electrical equipment, generally through an opening in the housing. Electrical bushings provide, as minimum features, a conductor for high voltage power, insulation means and means for mounting the bushing in electrical equipment.

Electrical bushings frequently comprise an electrical conductor surrounded by metal cylinders of decreasing length at predetermined spacings from the conductor. The spacings between the conductor and the innermost cylinder and between each cylinder are filled with insulation material. Such insulation material can be of phenolic impregnated paper, cast epoxy or polyester or resin. Such bushings are difficult to manufacture as the insulation must be void-free. This is difficult to achieve and can involve casting of the insulation material under vacuum conditions.

Other electrical bushings comprise an electrical conductor, a first layer of insulation surrounding the conductor, a ground plane and a stress-grading material surrounding the insulation, a flange for mounting the bushing to the electrical equipment or apparatus with which it is to be used and an outer insulating layer. The stress-grading material can extend a predetermined distance from the ground plane. The insulation of the first layer can be, for example, a cured epoxy resin, or the like. A typical bushing of this type is disclosed in U.S. Patent No. 3,646,251 to Freidrich. It is important that the insulation layer, the interface between the insulation and stress grading material, and the interface between the insulation and the conductor be void-free. When an epoxy resin system is used, this generally requires that the epoxy resin be degassed then cast in a vacuum and cured under pressure to prevent void formation. This process is difficult to perform in large scale manufacture resulting in unacceptable numbers of unusable or defective bushings being produced.

In accordance with one aspect of the present invention, there is provided an electrical bushing comprising:

(a) an electrical conductor;

(b) a first insulation layer comprising a void-free electrical insulation material superimposed over an intermediate length of the conductor with the end regions of the conductor extending beyond said layer;

(c) a layer of stress-grading material superimposed over at least an intermediate length of said first insulating layer;

(d) a flange electrically connected to said stress-grading layer; and

(e) an outer rigid insulation layer bonded to the flange and to the extending end regions of the conductor, thereby providing rigid mechanical connection between the flange and the conductor.

In accordance with another aspect of the invention, there is provided a method of manufacturing an electrical bushing comprising the steps of:

(a) applying a first insulation layer comprising a void-free electrical insulation material over an intermediate level of an electrical conductor leaving the end regions of the conductor extending beyond said layer;

(b) applying a layer of stress-grading material over at least an intermediate length of the first insulation layer;

(c) electrically connecting a flange to said stress-grading layer; and

(d) bonding an outer rigid insulation layer to the flange and to the extending end regions of the conductor thereby providing rigid mechanical connection between the flange and the conductor.

This invention thus provides an electrical bushing and a method of manufacture thereof utilising void-free insulation without the need for casting a void-free layer of epoxy, or similar resin on an electrical conductor. Furthermore, the electrical connection and the mechanical connection of the bushing to the electrical apparatus are separated.

The electrical bushing of this invention can be used in high voltage applications of up to about 69 kilovolts, typically of 15, 35 or 69 kilovolts. The electrical conductor of the bushing can be a metal cylinder, either solid or hollow, capable of carrying electric current. The conductor is preferably of copper or other highly conductive metal such as aluminium, silver plated copper and the like.

The electric conductor is adapted for use with switchgear, transformers and the like. Use of the bushing permits high voltage electric power to be conducted through the grounded metal casing of such electrical apparatus. The electric conductor of the bushing is provided with suitable termination means to permit it to be connected to the incoming power line and to the electric circuit of the electrical apparatus with which it is used. For example, the conductor can be provided at one end with a flattened terminal plate to which the power line can be bolted. The other end of the conductor can be in the shape of a plug to be inserted into a mating socket in the electrical apparatus. The means used for connecting the conductor to the power supply and to the electrical circuit of the equipment is not critical and any convenient means can be used.

The first insulation layer is positioned over an intermediate length, for example a central region, of the electrical conductor so as to leave the end regions uninsulated, i.e. not covered by the first layer of insulation.

The first layer of insulation can be resilient or non-resilient, and may comprise a layer of void-free thermoplastic, preferably polymeric, material. By "void-free" is meant material that is relatively free of voids and contains essentially no voids greater than about 0.007 inch (0.018 cms), preferably none greater than about 0.005 inch (0.013 cms). The material of the first layer should have a dielectric strength of at least 200 Volts/mil (78 kilovolts/cm) and preferably at least 300 volts/mil (118 kilovolts/cm). When the material is polymeric, it can be, for example, polyethylene, ethylene-propylene copolymer or ethylene or propylene-diene terpolymers, polyacrylates, silicone polymers and epoxy resins. The polymer can contain the usual additives, such as stabilisers, antioxidants, anti-tracking agents and the like.

Typical compositions for use as high voltage insulating material are described in U.S. Patents Nos. 4,001,128 to Penneck, 4,100,089 to Cammack, 4,189,392 to Penneck and 4,219,607 to Cammack et al, and U.K. Patents Nos. 1,337,951 and 1,337,952 of Penneck.

The thickness of the first insulation layer depends on the voltage to be applied to the bushing and the dielectric properties of the particular material, e.g.polymer composition used. The thickness is generally in the range of about 0.1 cm to about 5.0 cm, preferably in the range of about 0.5 cm to about 2.0 cm.

The first layer of insulation can be applied by any conventional technique. One method of applying the insulation layer is to place a dimensionally-recoverable, in particular a heat-shrinkable, tubular article of polymeric material over the conductor and then heating to cause the tube to shrink into intimate contact with the conductor. Heat-shrinkable polymeric tubular articles and methods for their manufacture are known, see for example, U.S. Patent No. 3,086,242 to Cook. Dimensionally-recoverable articles which recover without application of heat are also known, for example, see U.S. Patent No. 4,135,553 to Evans et al.

The interface between the insulation layer and the conductor should be void-free, as voids at the interface result in localized electric fields between the conductor and the insulation which cause electrical discharge and ultimately failure of the bushing. Because of imperfections in the surfaces of the metal conductor and the insulation layer, it is difficult to provide a void-free interface between the conductor and the first insulation layer. To obviate this problem, an intermediate conductive layer adhering to the surface of the insulation layer can be used. This conductive layer renders the surface of the insulation layer conductive and any voids between this conductive layer and the conductor will not, in accordance with Faraday's Law, result in destructive electric fields. The conductive layer is suitably a layer of metal, carbon black, graphite, or other conductive material coated on the inside of the insulation layer. The conductive layer can be applied by vacuum deposition of a metal or coating with a conductive paint, for example, by spraying the paint onto the inner surface of the insulation. Alternatively, a layer of metal, eg. aluminum foil can be applied over the conductor before the insulation layer is applied. The foil is bonded to the insulation layer in a void-free interface.

The stress-grading layer is applied over the first insulation layer. The stress-grading layer can be coextensive with, i.e. can extend the full length of, the insulation layer but is generally shorter so as to extend over an intermediate length, for example a central region, of the first insulating layer, such that the end regions of the first insulation layer extend beyond the stress-grading layer. The stress-grading layer grades the potential between the electrical conductor and ground thereby reducing the resulting electric fields. Ground in this case is the point where the metal housing of the electric apparatus is electrically connected to the bushing. As discussed in more detail below, using the bushing of this invention the apparatus is electrically connected through the flange to the stress control layer of the bushing. The stress-grading layer should extend from the point at which it is connected to ground for a distance sufficient to produce a minimum electric field at each end of the stress-grading layer.

Stress-grading materials which can be used are well known. Such materials typically comprise a polymeric, preferably thermoplastic, material having conductive particles dispersed therein. The conductive particles can be, for example, carbon black, particulate graphite, silicon carbide particles and the like. Such materials can be in the form of a paint or solid polymeric materials capable of being formed into shaped articles. An example of a stress-grading material can be found in U.S. Patent No. 3,950,604 to Penneck.

The stress-grading material can be applied to the first insulation layer by any convenient technique. If the stress-grading material is in the form of a paint, eg. a mixture of silicon carbide particles in a liquid curable resin system such as an epoxy resin, the material can be coated on to the surface of the first insulation layer by spraying, brushing or the like.

The stress-grading material can be in the form of a dimensionally-recoverable, for example a heat-shrinkable, tubular article, for example, as described in above-mentioned U.S. Patent No. 3,950,604. The stress-grading layer can then be applied, for example, by positioning a heat-shrinkable tubular article over the first insulation layer and heating to cause the tubular article to shrink into intimate contact with the first insulation layer.

Another method of applying the stress-grading layer to the first insulation layer is to coextrude the insulation material and the stress-grading material to form a laminate of the two materials. A coextruded tube of these materials can be rendered dimensionally-recoverable, for example heat-shrinkable, using well known methods, such as that described in the above-mentioned U.S. Patent Nos. 3,086,242, and 4,135,553. Coextrusion of the materials produces a void-free interface between them. Elimination of voids is important as it prevents localized electrical discharge which can untimately lead to failure of the bushing.

The flange is electrically grounded and is electrically connected to the stress-grading layer of the bushing to prevent discharge between the metal housing of the apparatus and the electrical conductor. The connection is generally made at about the mid-point of the bushing. Prior methods of connecting a metal flange of a bushing to the insulation layer surrounding an electrical conductor have generally produced a direct mechanical and electrical connection between the centre of the bushing and the flange. This places mechanical stress on the bushing at the same place as the maximum electrical stress which has been found to be disadvantageous. With the present bushing the electrical and mechanical connections of the bushing to the apparatus are separated. The flange is preferably of metal but need not be entirely of metal, for example, it can be primarily of plastic containing a metal element. Such a metal element can be embedded in the plastic or can be a metal bolt inserted through the plastic flange to fasten it to the wall of the electrical apparatus. Reference to a metal flange herein is to be understood to refer to an all metal flange or a non-metal flange having a metal element therein or passing therethrough.

The electrical connection is made between the stress-grading layer and the metal flange by placing an electrical conductor between them in such a manner to exert little force on the stress-grading material to insure minimal mechanical stress on the stress-grading layer and the underlying first insulation layer. For example, as described in more detail hereinafter, the stress-grading layer can be provided with a conductive surface layer with a wire or metal braid being connected between this layer and the metal flange or metal element of a non-metal flange.

The mechanical connection between the flange and the conductor comprises an outer rigid insulating layer connecting the flange to the ends of the conductor extending beyond the first insulating layer. This insulation is of a material capable of withstanding forces to which the bushing may be subjected during installation or use. Such forces can be in the range of, for example, a compression force in the axial direction between the conductor and the flange in the order of 4,000 pounds (18,000 Newtons). Materials that can be used in the outer insulating layer include, for example, curable epoxy resins, polyester resins, fiber-reinforced epoxy resins and polyesters, especially glass-fibre reinforced epoxy resins and polyesters, and the like. The cured epoxy resin may be a cycloaliphatic epoxy resin. The material used should be substantially non-tracking and known antitracking additives such as alumina trihydrate can be added to the resin. In the event that a tracking material is used a non-tracking layer can be coated on to the material.

In some embodiments, the outer insulation can be separated from the surface of the stress-grading layer by a small gap. The gap, if present, is preferably an air gap, but can be filled with a flexible material such as a silicone resin or gas such as sulfur hexafluoride, if desired. The outer insulation is preferably sealed to the end regions of the first insulation layer to prevent electrical discharge in the gap. The outer insulation is sealed to the conductor to prevent ingress of moisture into the bushing and to provide mechanical connection between the outer insulation layer and the conductor.

In some embodiments the stress grading layer may have an additional insulating layer placed on the top of it but not touching the outer insulation, thus providing improved electrical performance.

The outer insulation layer can be cast in place over the inner components of the bushing. In this case, it is important that the cast material, e.g. resin wet the conductor and the outer ends of the first insulating layer in order to effect a seal. In this case, if an air gap is to be provided between the stress-grading layer and the outer insulation, it can be created by use of a mould release agent applied over the stress-grading material.

The outer insulating layer can be preformed in one piece or in segments by casting the material in an appropriate mould or moulds. The insulating layer is then assembled over the inner components of the bushing. The outer insulating layer is sealed to the flange and to the conductor and the first insulation layer by appropriate means, for example, by the in-place casting of a plug of the same type of material as the outer insulating layer. If the outer insulating layer is preformed in segments, the segments are positioned over the bushing components and sealed to each other to form a unitary insulating layer. In one embodiment, the insulation layer is a tube of fibre-reinforced plastic with each end secured to the conductor using metal end caps at each end of the insulating tube. The metal end caps are machined to fit tightly between the conductor and insulating tube.

An electrical bushing, and its method of manufacture, in accordance with the present invention, will now be described, by way of example, with reference to the accompanying drawing, in which:

Fig.1 is a side elevation of the bushing; and

Fig.2 is an enlarged side elevation of part of the bushing of Fig.1 showing the electrical connection between the flange and the stress-grading layer and the mechanical attachment between the flange and the electrical conductor.

Referring to Figure 1, a metal flange 2 is embedded in an outer insulation layer 4. The insulation layer is sealed to an electrical conductor 6 at end regions 8 and 10 thereof. A first insulation layer 12 covers the length of conductor 6 between the ends 8 and 10. The first insulation layer 12 is a void-free layer of polymeric material having a dielectric strength of about 300 Volts/mil (118 kilovolts/cm). The inner surface of insulation layer 12 has a deposited conductive layer, eg. of aluminium, silver or graphite (not shown). A layer of stress-grading material 14 is over the first insulation layer 12. The flange 2 is of metal and is electrically connected to the stress-grading material (as shown in more detail in Figure 2) through a conductive layer 16, which passes under two sleeves of stress-grading material 18 and 20.

The bushing shown in Figure 1, can be manufactured by positioning polymeric insulating material 12 in the form of a tube or sleeve of heat-shrinkable over the electrical conductor 6 leaving end regions 8 and 10 of the conductor extending beyond the tube 12. The inner surface of the sleeve is coated with an adherent conductive layer of deposited aluminium, silver or graphite. The sleeve of heat-shrinkable material is then heated causing the sleeve to shrink into contact with the electrical conductor. Stress-grading material 14 in the form of a heat-shrinkable tube or sleeve is then positioned over the heat-recovered insulation layer 12 and heated so that it shrinks into contact with the insulation layer. The tube of stress-grading material should be somewhat shorter than the insulation layer as shown in Figure 1, so that end regions 22 and 24 of the insulation layer, 12, extend beyond the stress-grading material.

The interface between the insulation layer 12 and the stress-grading layer 14 should be void-free. The insulation layer 12 and stress-grading layer 14 can be coextruded in which case a void-free interface is produced. In this embodiment, they are applied as separate heat-shrinkable tubes or sleeves. To provide a void-free interface between the heat-recovered tubes it is desirable to apply a layer of grease, for example, a silicone grease, to the heat-recovered insulation layer 12 before the stress-grading layer 14 is applied.

The metal flange 2 is electrically connected to the stress-grading layer 14 as shown in detail in

Figure 2. The stress-grading layer and the connection to the metal flange is coated with a mould release agent. The outer insulating layer 4, comprising a non-tracking epoxy resin, is moulded into position. The layer 4 need not be void-free. The epoxy resin wets the metal flange 2, the end regions 8 and 10 of the conductor, and the end regions of the first insulating layer 12 at 22 and 24. On curing, the resin solidifies, sealing to the conductor at 8 and 10 to prevent ingress of moisture, embedding the flange 2 to provide an inflexible mechanical connection between the flange and the conductor, and sealing to the first insulation layer at 22 and 24. As mentioned above, the outer insulating layer 4 can be formed by casting in place over the other components of the bushing or can be preformed by casting in separate moulds and then assembled over the bushing components and sealed together and to the flange and conductor.

To facilitate the electrical connection between the flange 2 and stress-grading layer 14, a hole 5 is drilled through the flange 2 and insulating layer 4. (For purposes of illustration, only one hole is shown, additional holes through the flange, or other configurations, may be provided, if desired). The conductive layer 16, which covers a portion of the surface of the stress-grading layer 14, is a layer of carbon black-containing conductive paint. The use of other conductive layers, for example, a metal plate in the order of 10 mils (0.025 cm) thick is also contemplated. The conductive layer passes under the two shorter sleeves 18 and 20 of stress-grading material and is connected to the stress-grading layer 14. A metal wire 9 is wound around the conductive layer 16 and inserted through the hole 5 in insulating layer 4 and metal flange 2. The wire is connected to the metal flange 2 by a plug 11. As can be seen in Figure 2, an air gap 13 exists between stress-grading layer 14 and insulating layer 4. Thus, it can be seen that at the central region of the bushing, the metal flange is electrically connected to the rest of the bushing but is not mechanically connected thereto. This minimizes mechanical stress between the flange and the stress-grading layer, in particular at the region of highest electrical stress.

The mechanical connection of the flange to one end of the conductor of the bushing is also shown in Figure 2. Metal flange, 2, is bolted to the electrical apparatus with which it is used (not shown). Metal flange 2 is embedded in outer insulating layer 4. The outer insulating layer is separated from the stress-grading layer 14 of the bushing by air gap 13. The outer insulating layer 4 is sealed to conductor end region 8. The mechanical attachment of the flange to the conductor must be able to withstand an axial load of about 4,000 pounds (18,000 Newtons) and a bending moment of about 3,000 inch-pounds (49,000 Nm) with a deflection of less than about 1°.

CLAIMS

1. An electrical bushing comprising:

(a) an electrical conductor;

(b) a first insulation layer comprising a void-free electrical insulation material superimposed over an intermediate length of the conductor with the end regions of the conductor extending beyond said layer;

(c) a layer of stress-grading material superimposed over at least an intermediate length of said first insulating layer;

(d) a flange electrically connected to said stress-grading layer; and

(e) an outer rigid insulation layer bonded to the flange and to the extending end regions of the conductor, thereby providing rigid mechanical connection between the flange and the conductor.

2. A bushing in accordance with Claim 1, wherein the stress-grading layer is coextensive with said first insulation layer.

3. A bushing in accordance with Claim 1, wherein the stress-grading layer extends over the central region of said first insulation layer leaving end regions of the insulation layer extending beyond the stress-grading layer.

4. A bushing in accordance with any preceding Claim, wherein said first insulation layer is a layer of resilient material.

5. A bushing in accordance with any preceding Claim, wherein said first insulation layer is a layer of thermoplastic material.

6. A bushing in accordance with any preceding Claim, wherein said stress grading layer comprises a thermoplastic polymer having conductive particles dispersed therein.

7. A bushing in accordance with any preceding Claim, wherein said outer rigid insulation layer comprises a cured epoxy resin, preferably a cycloaliphatic epoxy resin.

8. A bushing in accordance with any preceding Claim, wherein said outer rigid insulation layer is substantially non-tracking.

9. A bushing in accordance with any preceding Claim, wherein said first insulation layer and/or said stress-grading layer comprises a dimensionally-recoverable, preferably heat-shrinkable, tubular article of polymeric material.

10. A method of manufacturing an electrical bushing comprising the steps of:

(a) applying a first insulation layer comprising a void-free electrical insulation material over an intermediate length of an electrical conductor leaving the end regions of the conductor extending beyond said layer;

(b) applying a layer of stress-grading material over at least an intermediate length of the first insulation layer;

(c) electrically connecting a flange to said stress-grading layer; and

(d) bonding an outer rigid insulation layer to the flange and to the extending end regions of the conductor thereby providing rigid mechanical connection between the flange and the conductor.

11. A method in accordance with Claim 10, wherein said first insulation layer is applied by positioning a dimensionally-recoverable, preferably heat-shrinkable, tubular article of polymeric insulating material over the conductor and then causing the article to recover into intimate contact with the conductor.

12. A method in accordance with Claim 10 or 11, wherein said stress-grading layer is applied by positioning a dimensionally-recoverable, preferably heat-shrinkable, tubular article of polymeric stress-grading material over the first insulation layer and then causing the article to recover into intimate contact with the first insulation layer.

13. A method in accordance with Claim 10, wherein said first insulation layer and said stress-grading layer are applied by positioning a dimensionally-recoverable, preferably heat-shrinkable, coextruded tubular article over said conductor and then causing the article to recover into intimate contact with the conductor.

14. A method in accordance with any of Claims 10 to 13, wherein said outer rigid insulation layer is bonded to the flange and the extending ends of the conductor by casting a curable resin over the inner components of the bushing and curing the resin.

15. A method in accordance with any of Claims 10 to 13, wherein said outer rigid insulation layer is preformed, then assembled over the inner components of the bushing and sealed to the flange and to the extending end regions of the conductor.

Fig.1.

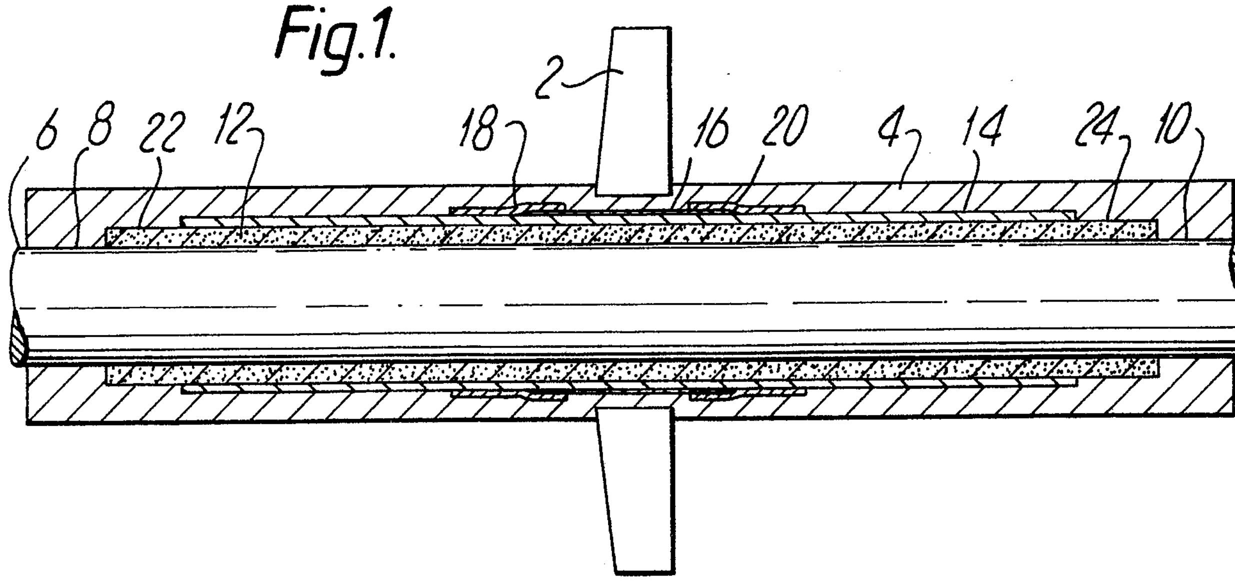
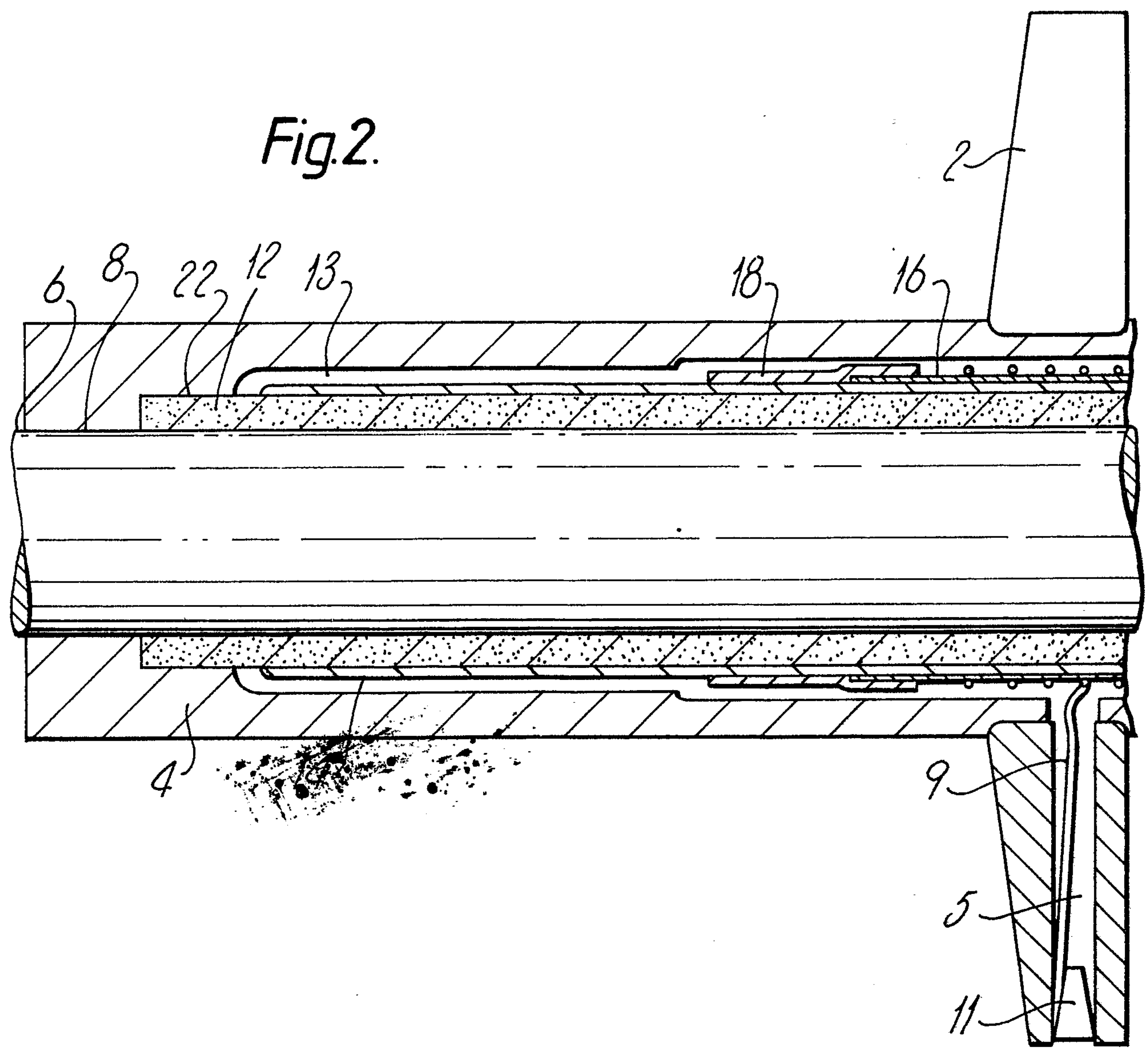


Fig.2.



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European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 82 30 4933

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)
Y	US-A-3 312 776 (DECK) *Column 1, lines 31-43; column 3, lines 11-17,52-55; column 4, lines 14-32; figures 3-6*	1,3,7,8,10,14	H 01 B 17/28
Y	CH-A- 354 132 (WESTINGHOUSE) *Page 8, lines 53-57,74-77,88-90; figure 4*	1,3-5,7,8,10,14	
A	GB-A- 793 974 (THOMSON-HOUSTON) *Page 2, lines 78-104; figures*	1,2,4,7,8,10,14	
			TECHNICAL FIELDS SEARCHED (Int. Cl. 3)
A,D	US-A-3 646 251 (FRIEDRICH) *Column 2, lines 22-54; column 3, lines 1-16; column 4, lines 30-45; column 5, lines 1-11*	1,2,6-8,10	H 01 B 17/00
A	US-A-1 503 073 (STEINBERGER) *Page 1, lines 42-71,101-110; figure 1*	1,3,10	
A,D	US-A-3 950 604 (PENNECK) *Column 12, lines 23-31; figure 2*	9,11-13	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	22-12-1982	TIELEMANS H.L.A.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
O : non-written disclosure
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T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
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