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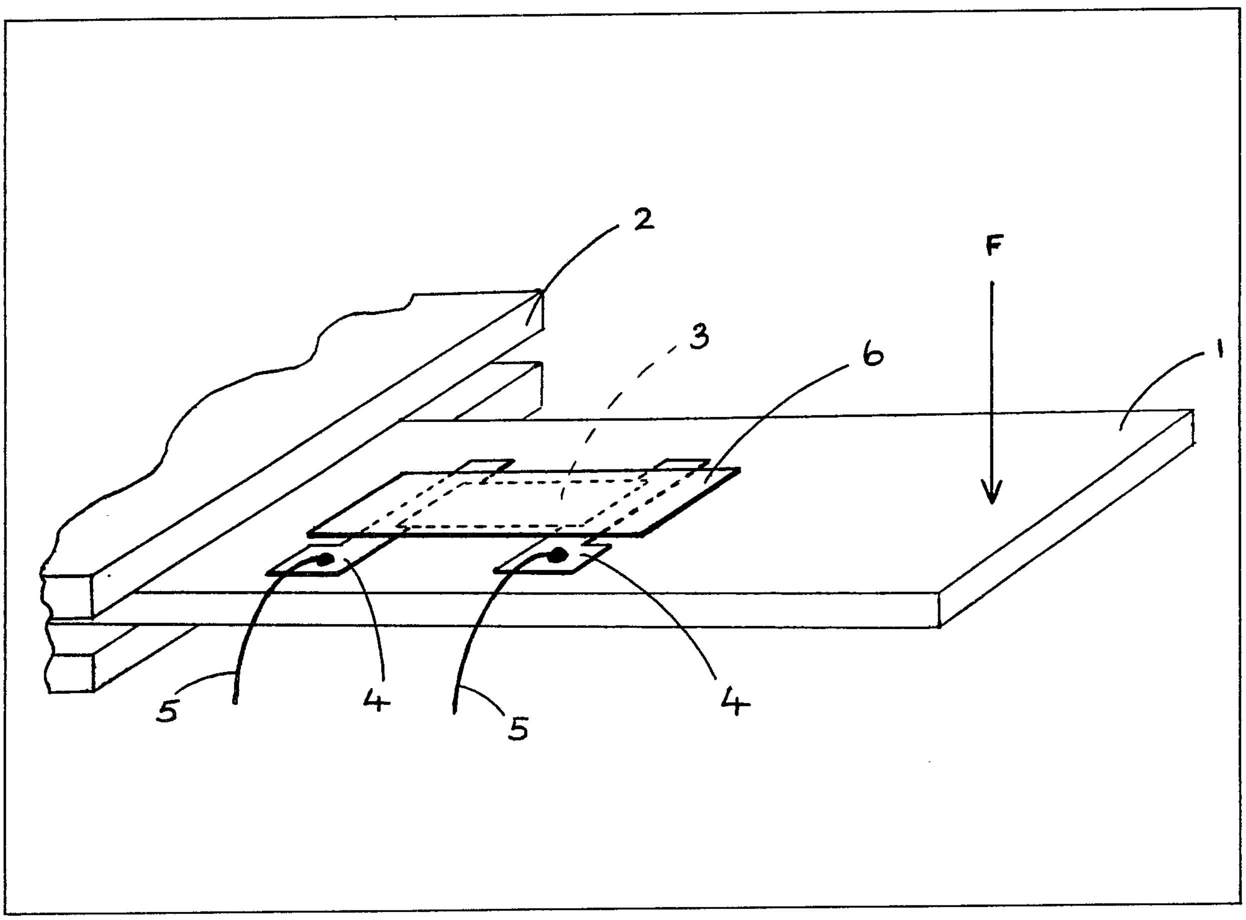
(54) **Electrical strain gauges**

(57) A strain gauge or transducer is provided incorporating a supported film electrical resistance element 3 whose electrical resistnace varies as a function of applied mechanical strain and is provided with electrically conductive terminals 4, the resistance element 3 comprising a dispersion of electrically conductive or resistive particles in an organic polymer together with an optional electrically insulating filler material. The resistance element may be supported on a member 1 of anodised aluminium.



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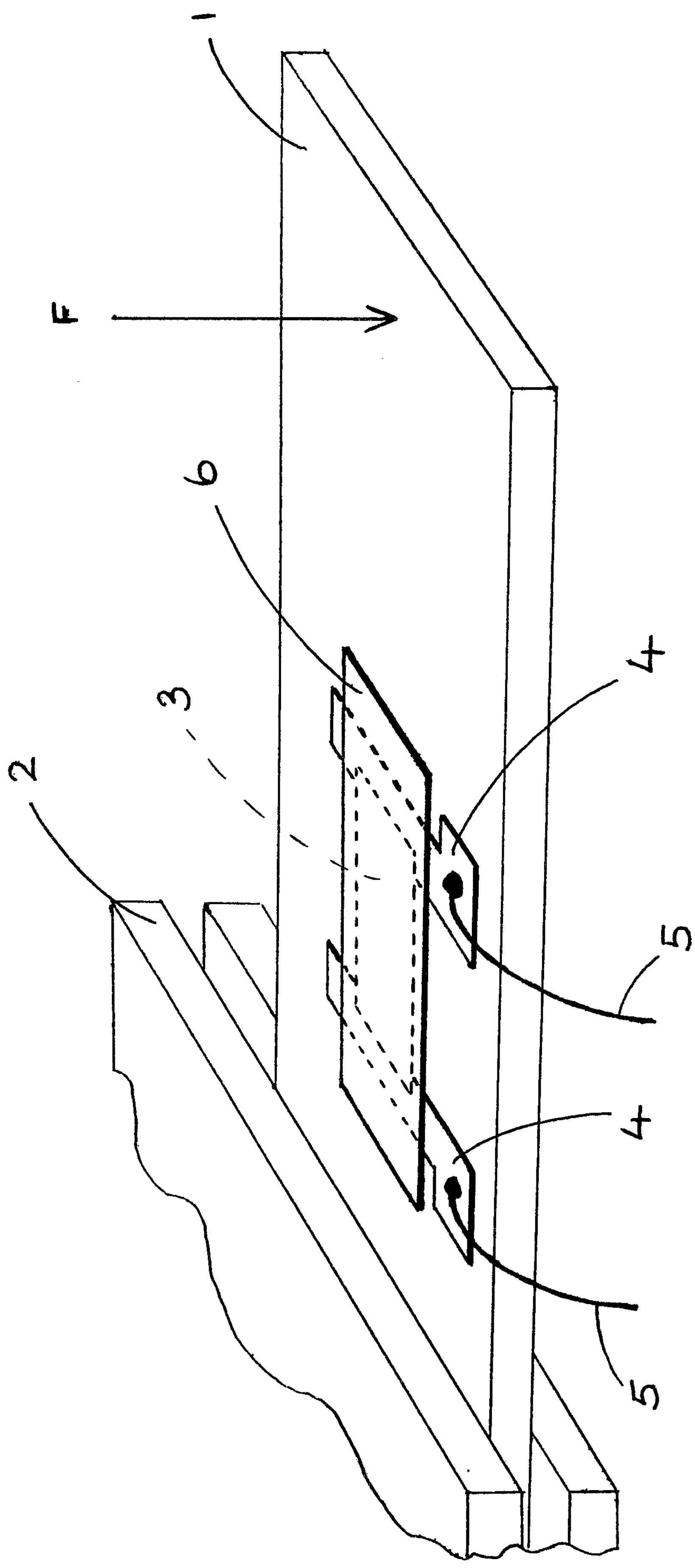
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SPECIFICATION

Strain gauge

This invention relates to an electrical resistance strain gauge or transducer and particularly an electrical resistance element for use therein.

Strain gauges based on the piezo-resistance effect, are well known. Wires of metals and alloys were used as an early form of strain gauge and more recently, thin sheets of metal or foil bonded to the surface of an object in which the strain is to be measured, or thin films evaporated onto the surface of such an object, or thin pieces of semiconductor material bonded onto such a surface have all been used. All of these devices and methods are capable of providing accurate and repeatable indications of the magnitude of both tensile and compressive strain on the surface of the underlying supporting member. Such devices are widely used in the field of precision engineering for strain measurement or stress analysis or in the manufacture of high quality transducers such as load cells or force or pressure transducers for the measurement of force, pressure or weight. Sophisticated industrial weighing systems and weighing platforms and expensive weighing machines or scales used in trade or commerce are provided for by these known devices which can frequently measured to an accuracy of 0.1% or better under all required operating conditions. Such devices do not, however, provided a solution to the need for low cost simple forms of force, load, weight or pressure measuring transducers as are required in units such as kitchen or bathroom scales, or for simple industrial control purposes or various applications in machinery or, for example, in automobiles where accuracies and repeatabilities of the order of 1.0% would generally suffice.

An object of the present invention is to satisfy this need and provide a low cost strain gauge or transducer involving inexpensive materials, simple designs, and non-complex fabrication processes capable of implementation in large volume production. By means of the invention, simple low cost transducers can be provided as may be required in large quantities when available at low prices.

The present invention provides a strain gauge or transducer incorporating a supported film electrical resistance element whose electrical resistance varies as a function of applied mechanical strain and provided with electrically conductive terminals, said element comprising a dispersion of electrically conductive or resistive particles in an organic polymer. A proportion of electrically insulating filler material may optionally be included in said element.

The said conductive terminals are preferably arranged to lie under or over peripheral regions of said element and are preferably of film form. The said film electrical resistance element is suitably supported on and adhered to an electrically insulating or insulated supporting member. The said supporting member may be of thin flexible material, said gauge or transducer being thereby adapted to enable it to be bonded or secured to a structure or component to be subjected to mechanical strain. An adhesive may be used to bond said supporting member of thin flexible material to said structure or component.

Alternatively the supporting member may comprise glass, ceramic or organic plastics or may comprise metal or metal alloy provided with a thin film of electrically insulating material in the region where said element and terminals are supported. The member may be in the form of a diaphragm, beam, bar, cylinder or other complex shape in which mechanical strain induced therein or imparted thereto is to be monitored.

An organic plastics material is especially convenient for use of said supporting member because of the ease with which complex shapes or structures which may be required for various transducer applications can be produced using simple forming or moulding techniques.

When a metal or alloy member is used, this suitably comprises aluminium, bronze or steel.

The said film of electrically insulating material on said metal or alloy member may comprise an organic polymer, lacquer, resin, tape or foil.

Alternatively, when said supporting member comprises aluminium, or an alloy thereof, a preferred film of electrically insulating material is provided in well known manner by anodising the surface of said member at least in the region where the element and terminals are supported. If desired, the anodised surface may be covered with a very thin electrically insulating layer formed by application of a highly fluid organic resin which is subsequently cured or polymerised, said resistance element and terminals being supported on and adhered to the covered surface. By this means, problems arising from any pinholes in the anodised surface are minimised.

Aluminium is advantageous for use as the supporting member because of the ease with which thin adequately insulating layers can be produced by well known anodisation techniques and because the electrical film resistance elements after application to the anodised layer can be stoved and polymerised at a sufficiently high temperature to ensure their maximum stability thereafter as strain sensing devices. The anodised layer will preferably be fabricated free from pinholes and of a thickness such that its electrically insulating strength is sufficient to withstand, and provide an adequate margin of safety over, the level of voltages which will be applied to the electrical film resistance elements and their associated film conductors. It is sometimes considered difficult to ensure absolutely the absence of pinholes in an anodised layer and in this case the application of the very thin layer of organic resin effectively acts as a sealing material to fill in any pinholes which may exist. Such organic resin is applied in a very fluid form in as thin a coating as possible as its purpose is not to increase the average thickness of the anodised insulating layer but only to fill in any imperfections which may exist in that layer.

The electrical film resistance element is, as in the case of bonded foil resistance strain gauges, conveniently but not necessarily attached to a flat portion of the surface of the supporting member.

Electrical resistance elements comprising a dispersion of electrically conductive or resistive particles in an organic polymer are known per se as are compositions intended for use in their manufacture. Such compositions are usually applied to a support as an ink or paste and heated to effect polymerisation. In the present invention an element having a surface resistance of between 100 ohms per square and 10,000 ohms per square has been found to be particularly suitable. Suitably said element comprises from 5 to 60% by weight of said conductive or resistive particles and from 0 to 75% by weight of electrically insulating filler material. A particularly suitable composition of said element is a dispersion of carbon particles in an organic polymer. The said organic polymer is suitably selected from epoxy, alkyd, polyester, acrylic or silicone materials or copolymers thereof.

Suitably said element and terminals have been provided by a screen printing technique or by a technique involving dipping or spraying, a composition suitable for the production of said element and terminals, and which may include a solvent material, having been utilised in such a technique.

The said element has preferably been subjected to a heat treatment to optimise its electrical properties.

The electrical resistance value, measured between the terminals of the resistance element, can be adjusted to a desired value. This is preferably achieved by abrasion or compaction of the outermost surface of the element.

A protective covering of electrically insulating material may also be provided for said element. Such covering conveniently comprises a pressure-sensitive adhesive tape. Alternatively a layer of an organic lacquer which does not significantly interact with said organic polymer may be provided as said protective covering.

An embodiment of the invention is also envisaged in which final trimming to reduce the resistance value of said element has been effected by rubbing the surface of said protective covering to cause permanent compaction of said element.

The preferred compositions used in fabricating the electrical film resistance element have their origins in the mixtures of carbon powder and organic resins used to fabricate early forms of so-called carbon composition resistors. These were hot moulded in the form of solid cylindrical components usually incorporating terminal wires embedded in each end of the cylindrical device. Such components have largely been replaced by improved forms of resistor in which a resistive film is deposited onto the surface of an insulating support. Such films may comprise carbon deposited in a pyrolytic process, tin oxide deposited by thermal hydrolysis or evaporated metal films.

With the growing use of thick film cermet resistors involving particles of resistive material dispersed in a vitreous or glassy matrix which is then fired at a high temperature to bond the materials and the film to an insulating substrate, usually ceramic, attention has also been directed to the use of electrical film resistance elements comprising a dispersion of conductive or resistive particles and possibly particles of a filling material in an organic resin. Such compositions have been utilised for the manufacture of hybrid film circuits in association with conducting films also deposited on and adherent to the insulating substrate. Such electrical film resistance elements have been described as conductive polymer resistors. These resistance elements have also found application as tracks in rotary or linear potentiometers, these being sometimes referred to as conductive plastic potentiometers.

The fabrication of the required compositions is not complex and is well known in the art. The proportions of conducting particles, usually carbon, may range from 5 to 60% by weight. The proportions of insulating filler may range from 0 to 75% by weight and a solvent may be added to facilitate application of the composition. The oganic resin constituting the residual proportion of the composition may be selected from any of the commonly available organic resins including epoxies, alkyds, polyesters, acrylics, silicones etc., or co-polymers thereof, which in fluid form may constitute the carrier for mixing with the conductive or resistive particles, optional insulating particles, and solvent in the production of an ink or paste adapted for application by dipping, spraying or silk screen printing to an insulating substrate. The printed or deposited resistance material is then dried in air, allowing substantial evaporation of the solvent constituent followed by a stoving treatment which may typically occur between 100° and 250°C bringing about a drying, hardening and at least partial polymerisation, of the organic resin. The stoving treatment is continued for a time and at a temperature which ensures that the resultant electrical film resistance element possesses adequate hardness, permanence and electrical stability.

Although the use of such compositions for the manufacture of solid carbon composition resistors, conductive plastic potentiometers and conductive polymer film circuits, is well known and the manufacturers of thick film cermet inks and pastes also supply inks and pastes for the fabrication of conductive polymer resistors, it has not however, been known to use such materials for the fabrication of strain sensitive resistance elements and we have found that by an appropriate selection of materials and processing conditions, these available materials can be fabricated in such a form as to provide low cost strain sensitive elements of sufficient sensitivity and stability to provide useful application in the manufacture of low cost transducers.

We have found that with the use of the said resistance element in strain gauges or transducers of the present invention, gauge factors of between about 2 and 5 are demonstrated. Changes in resistance which are observed in the element have been found to accurately and repeatably provide a measure of tensile and compressive strain occurring in the element and transmitted thereto by the supporting member.

The invention will now be described by way of example with reference to the accompanying drawings which show a perspective view of an embodiment of transducer according to the invention. A supporting member 1 is designed and fabricated in aluminium metal or an alloy thereof, in such a form that it provides the necessary transducer element in an intended force, weight or load transducer. The member is shown to be in the form of a simple beam of rectangular section firmly clamped at one end in a member 2 in a cantilever configuration.

There are, however, many other shapes and configurations for the supporting member well known in the art of transducer design. For example, the member could be in the form of a thin diaphragm arranged to be deflected by applied fluid pressure and forming part of a pressure transducer. The supporting member will be fabricated by conventional casting, extrusion and machining processes which provide the necessary geometrical accuracies required by the purpose to which the transducer is to be put. These metal fabrication processes will include the provision of a sufficiently smooth surface in the region onto which strain sensitive electrical film resistance elements are to be deposited. The aluminium or aluminium alloy supporting member is then subjected to an anodising treatment which may be applied to the whole of its surface but in particular will be directed to the region of the surface onto which the electrical film resistance elements are to be deposited. The anodisation process is well known and will be adapted to provide the necessary degree of electrical insulation between electrical film resistance elements and electrical conductive film elements which are subsequently to be deposited thereon. After anodising the surface may be further treated by the application of a highly fluid organic resin which is subsequently cured and whose purpose is to fill in any pinholes which the anodisation process may leave. An appropriate resin of low viscosity is epoxy AY18 from CIBA in association with hardener H218 mixed in the proportion of 100 parts by weight resin to 75 parts by weight of hardener with the addition of any appropriate required quantity of m.e.k. solvent. Preferably such application of an organic resin is not required and in any case the quantity of any residual organic film must be minimised in order to have the least effect on the total thickness of the anodised layer of aluminium oxide and to have minimum interactive effect with the organic resin materials in the electrical film resistance element to be deposited on the anodised layer. One or more strain sensing elements, each comprising an electrical resistance element 3 whose electrical resistance varies as a function of applied mechanical strain and provided with electrically conductive terminals 4, are provided on the anodised surface of the aluminium member 1. The or each element 3 is arranged near to the clamped end of the member 3 in the region where maximum surface strain is experienced when the member 1 is deflected by application of a force F at or near the free end. The electrical resistance element 3 is in the form of a film and comprises a dispersion of electrically conductive or resistive particles in an organic polymer. Carbon is a preferred material for the conductive or resistive particles.

An appropriate electrical resistance composition comprising, for example, a composition selected according to the resistance value required from the RS-150 series manufactured by Electro-Science Laboratories of Pennsauken, U.S.A., is obtained or fabricated as is well known in the art and applied by the use of an appropriate technique. This may preferably utilise a screen printing process, as is well known, such that the electrical film resistance composition is provided in the form of a screen printable ink which is applied by the action of a squeegee through the interstices of a screen which deposits the electrical film resistance material in defined regions. This process is advantageous in that it facilitates accurate positioning of the resistance element pattern on a selected region of the surface of the supporting member as is required to ensure that the strain to be detected and measured is that which is developed at an appropriate point of the transducer member. Electrical contact to the electrical film resistance element is provided by the application, which may also preferably be carried out by a screen printing process, of the terminals 4 in the form of electrical film conductor elements which may comprise mixtures of conducting powder such as silver and organic resins. Such materials are well known and commonly utilised in conjunction with conductive plastic potentiometer tracks or conductive polymer film resistors and could, for example, be silver-epoxy conductor material type T2100 manufactured by EMD-Cermalloy Inc. of Conshohocken, U.S.A. Lead wires 5 are secured and electrically connected to the terminals 4, e.g. by means of solder. The conductor pattern may be conveniently delineated and registered by the use of screen printing techniques and may abe arranged to overlap the resistance element by deposition either prior to or after the printing of the electrical film resistance element. In either case it is necessary only to dry the first deposited pattern before printing and applying the second deposited pattern whereupon both the conductor and the resistance elements are stoved and partially polymerised in a single heating process. The heating process may involve periods from a few hours to about 24 hours in an oven at temperatures of from 100°C to 250°C. In the case where the supporting member comprises aluminium or aluminium alloy, relatively high temperatures in this range may be selected for the stoving treatment. It must be noted, however, that as higher temperatures are utilised, the stoving process may affect the hardness or elastic parameters of the supporting member 1, and in the case of transducer elements, these are important parameters which may call for the judicious selection of a compromise between the maximised performance of the deposited electrical film resistance element and of the underlying transducer deflection system, as provided by the supporting member. After the stoving and partial polymerisation process, it being noted that polymerisation is a state which can only be approached asymptotically and never finally achieved, attention to the resistance value of the electrial film resistance element is required. The selection of the composition used will have been made to provide resistance values of an appropriate aspect ratio in a convenient range between 100 ohms and 10,000 ohms but the value achieved after printing and stoving will probably not conform sufficiently accurately to the required target value. This will particularly be the case if several resistors are produced on the supporting member in the fabrication of a half bridge or a whole bridge configuration. In these cases some form of trimming or adjustment operation will be necessary to ensure that each element in the half-bridge or bridge is matched to within at least 1%, or in certain cases to within 0.1%, of a common value. Normal methods of trimming film resistors include cutting into the film with an abrasive wheel, a jet of fine abrasive particles or a laser beam. None of these methods are satisfactory when a metal or metal alloy supporting member is adopted as they would inevitably result in a cutting through of the insulating layer and exposing the electrically conducting member to the electrical film resistance element in close approximation to each other. It is therefore preferable to bring about adjustment by an overall abrasion of the surface area of the electrical film resistance element. This can be conveniently carried out using a paste comprising fine abrasive particles dispersed in a fluid medium such as a light oil. This has been found to provide adequate adjustment when applied to film resistors including thick film cermet resistors where such abrasion normally results in an increase in the resistance value. However, in the case of conductive polymer resistors, mild abrasion of this nature is generally found to bring about a lowering of the resistance value. It is believed that this is due to the action of the abrasive on the surface of the conductive polymer resistor in which some of the constituent resistive particles, i.e. the carbon particles, are smeared over the surface of the resinous matrix causing an increased degree of inter-linkage between the constituent carbon particles and thereby decreasing the resistivity of the surface layers of the film. This is not regarded as a disadvantage and results in a technique in which the higher values of the resistance elements in the half-bridge or bridge are adjusted downwards in value until they equate to the resistance value of the lowest value in the configuration. If strain sensitive resistance elements in an appropriate configuration are produced in the aforesaid manner, it will be found that they have gauge factors of between about 2.0 and 5.0 and this provides adequate sensitivity in sensing strain or changes of strain in the supporting member. The temperature coefficient of resistance of the film resistor element may lie between -100 and -200 ppm/°C and these coefficients may track from one element in the configuration to another sufficiently closely so that there is relatively little apparent strain developed when a multi-element gauge or transducer (i.e. incorporating a half bridge or a full bridge) changes temperature. It will, however, be found that the gauges as produced in the aforesaid manner may show some sensitivity to room temperature atmosphere, resulting among other things in an effect due to humidity of the atmosphere. This calls for the application of some protective coating but it has been found that the application of a conventional coating of organic lacquer, followed by its stoving and polymerisation, may affect the underlying electrical film resistance element. The effect is believed to be due to an interaction between the organic protective material and the organic resin constituent of the resistive film, and may cause changes in parametric values, including the resistance value, to an undesirable extent. It has been found that only very small changes are brought about if an adhesive tape 6 is applied to the electrical film resistance element. A suitable adhesive tape is the type Macu-tape P4 manufactured by MacDermid of Telford, England. The application of a pressure sensitive tape does not require any high temperature stoving and relatively small changes in resistance value occur on its application. It has been further discovered that the degree of protection from the surrounding atmosphere which such a pressure-sensitive adhesive tape provides, is sufficient for the purposes required here. Low cost transducers of the type involved would usually not be expected to perform at very low temperatures or very high temperatures and would normally operate within the range 20°C to 40°C. Furthermore, such transducers would generally not be expected to operate in wide ranging atmospheric conditions and particularly not in conditions of high humidity. The use of a readily available pressure sensitive tape 6 is normally found to provide an adequate protection to the resistance film. If, however, a very small resistance change does occur on the application of the tape, and if it is found that the matching of respective resistance elements in a half-bridge or full bridge configuration has varied one to another, a final close tolerance trimming operation can be carried out by the application of local intense pressure to the outside of the applied tape therefore affecting the underlying electrical film resistance element. It is believed that on application of such pressure, the elment undergoes a certain degree of compacting in its structure which brings about a further reduction in resistance value. Such compacting and consequent reduction in resistance value is irreversible and not to be confused with the reversible change in resistance which occurs in the element when subjected to tensile or compressive stress by way of the supporting member. The necessary applied pressure to effect adjustment is suitably achieved by rubbing with a blunt object the outer surface of the protective tape and this process of resistance value adjustment after the application of the protection and the stabilisation of the elements so protected, is a particularly attractive and desirable feature of the present invention.

Instead of using a metal such as aluminium for the supporting member for the resistive element, it may be particularly advantageous for some applications to employ a member of organic plastics material. An example of such an application is in pressure transducers where a supporting member comprising a thin diaphragm, to which fluid pressure is to be applied, and a supporting structure and/or housing therefor may readily be fabricated in organic plastics material by a simple forming process such as transfer moulding.

CLAIMS (Filed on 4 March 1982)

1. A strain gauge or transducer incorporating a supported film electrical resistance element whose electrical resistance varies as a function of applied mechanical strain and provided with electrically conductive terminals, said element comprising a dispersion of electrically conductive or resistive particles in an organic polymer.

2. A strain gauge or transducer according to Claim 1 in which a proportion of electrically insulating filler material is included in said element.

3. A strain gauge or transducer according to Claim 1 or 2 in which said conductive terminals are arranged to lie under or over peripheral regions of said element.

4. A strain gauge or transducer according to Claim 1, 2 or 3 in which said terminals are of film form.

5. A strain gauge or transducer according to any one of Claims 1 to 4 in which said film electrical resistance element is supported on and adhered to an electrically insulating or insulated supporting member.

6. A strain gauge or transducer according to Claim 5 in which said supporting member comprises thin flexible material, said gauge or transducer being thereby adapted to enable it to be bonded or secured to a structure or component to be subjected to mechanical strain.

7. A strain gauge or transducer according to Claim 6 in which an adhesive is used to bond said supporting member of thin flexible material to said structure or component.

8. A strain gauge or transducer according to any one of Claims 1 to 5 in which said supporting member comprises glass, ceramic or organic plastics.

9. A strain gauge or transducer according to any one of Claims 1 to 5 in which said supporting member comprises metal or metal alloy provided with a thin film of electrically insulating material in the region where said element and terminals are supported.

10. A strain gauge or transducer according to Claim 8 or 9 in which said member is in the form of a diaphragm, beam, bar, cylinder or other complex shape in which mechanical strain induced therein or imparted thereto is to be monitored.

11. A strain gauge or transducer according to Claim 9 or 10 in which said metal or alloy comprises aluminium, bronze or steel.

12. A strain gauge or transducer according to Claim 9, 10 or 11 in which said film of electrically insulating material on said metal or alloy member comprises an organic polymer, lacquer, resin, tape or foil.

13. A strain gauge or transducer according to Claim 11 in which said supporting member comprises aluminium, or an alloy thereof, a film of electrically insulating material having been provided by anodising the surface of said member at least in the region where the element and terminals are supported.

14. A strain gauge or transducer according to Claim 13 in which said anodised surface is covered with a very thin electrically insulating layer formed by application of a highly fluid organic resin which is subsequently cured or polymerised, said resistance element and terminals being supported on and adhered to the covered surface.

15. A strain gauge or transducer according to CLaim 14 in which said very thin insulating layer serves only to fill in any imperfections existing in the anodised insulating layer.

16. A strain gauge or transducer according to any one of the preceding claims in which said electrical film resistance element is attached to a flat portion of the surface of the supporting member.

17. A strain gauge or transducer according to any one of the preceding claims in which said film resistance element has a surface resistance of between 100 ohms per square and 10,000 ohms per square.

18. A strain gauge or transducer according to any one of the preceding claims in which said film resistance element comprises from 5 to 60 per cent by weight of said conductive or resistive particles, and from 0 to 75 per cent by weight of electrically insulating filler material.

19. A strain gauge or transducer according to Claim 18 in which said element comprises a dispersion of carbon particles in an organic polymer.

20. A strain gauge or transducer according to Claim 19 in which said organic polymer is selected from epoxy, alkyd, polyester, acrylic or silicone materials, or copolymers thereof.

21. A strain gauge or transducer according to any one of the preceding claims in which said element and terminals have been provided by a screen printing technique or by a technique involving dipping or spraying, a composition suitable for the production of such element and terminals, and which may include a solvent material, having been utilised in such a technique.

22. A strain gauge or transducer according to any one of the preceding claims in which said element has been subjected to a heat treatment to optimise its electrical properties.

23. A strain gauge or transducer according to any one of the preceding claims in which the electrical resistance value measured between the terminals of the resistance element, has been adjusted to a desired value by means of abrasion or compaction of the outermost surface of said element.

24. A strain gauge or transducer according to any one of the preceding claims in which a protective covering of electrically insulating material is provided for said element.

25. A strain gauge or transducer according to Claim 24 in which said protective covering comprises a pressure-sensitive adhesive tape.

26. A strain or transducer according to Claim 24 in which said protective covering comprises a layer of an organic lacquer which does not significantly interact with said organic polymer.

27. A strain gauge or transducer according to any one of Claims 24 to 26 in which final trimming to reduce the resistance value of said element has been

effected by rubbing the surface of said protective covering to cause compaction of said element.

28. A strain gauge or transducer contructed and arranged substantially as herein described with reference to the accompanying drawing.

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