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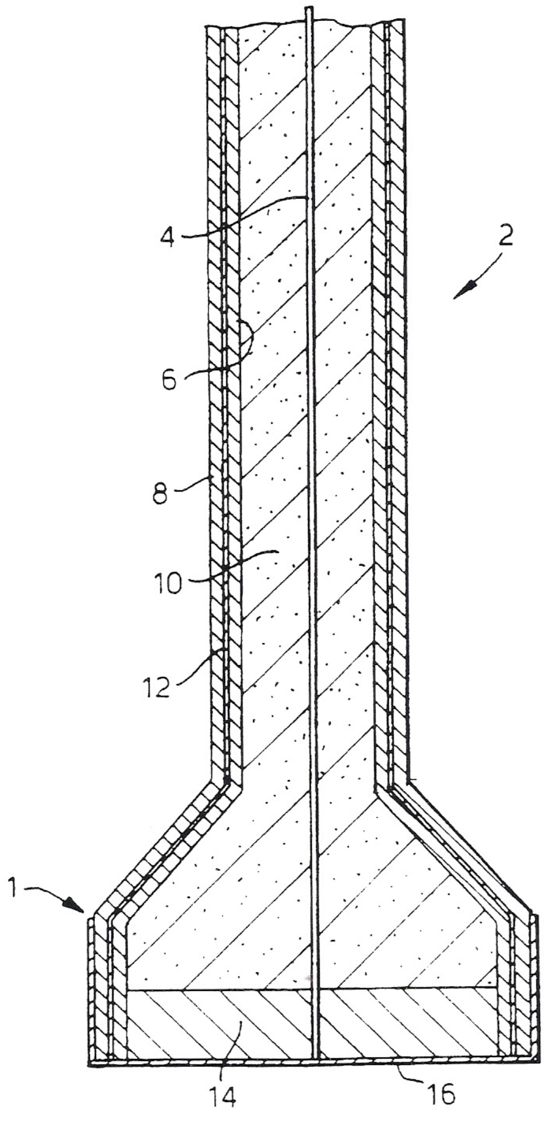

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CAPACITIVE GAP MEASUREMENT DEVICE

This invention relates to the measurement of gaps, and especially to the measurement of gaps in gas turbines, for example the measurement of gaps from a probe to a solid object such as a shaft, disc, or to an intermittent object such as a turbine blade or the like.

In many fields, and especially in the case of gas turbines, there is a need for a gap measurement probe that is able to function at very high temperatures, for example in the order of 1000°C or more, and indeed, in order to improve the thermodynamic efficiency of such engines, work is being conducted to increase the working temperature, for example to 1200°C or higher, for example to 1500°C or above. In such environments it is not possible to employ probes that rely on permanent magnetism of materials, and also it is important to ensure that all materials used to manufacture the probe can withstand the temperatures that will be experienced. For this reason, capacitance probes have been proposed for use in turbines.

One use of such probes in the case of turbines, is to measure the clearance between the tips of the turbine blades and the housing. It is highly desirable to minimise this clearance in order to maximise the efficiency of the turbine, and a gap of

1mm would be typical of current turbines although it is desired to reduce this further. In order to achieve such small clearances, it is necessary to provide probes that are located in the housing and detect the presence of the turbine blades as they pass the probe. Such a probe typically will comprise an electrode that will couple capacitively with the turbine blade, a shield that is located between the electrode and the turbine casing, a probe body that surrounds the shield and enables the probe to fit precisely in the recess that is provided for it in the casing, and insulation provided between the electrode and shield and also between the shield and retainer in order to electrically isolate the electrode and shield from the casing. The electrode is connected to the centre conductor of a triaxial cable, and the shield to the intermediate screen of the cable while the retainer or the housing is connected to the outer screen of the cable which removes the signals from the probe from the vicinity of the turbine. The signal from the electrode is passed to the shield via a unity gain amplifier so that the electrode signal is screened from ground (the casing) by means of a buffered version of itself.

Such a probe will function quite satisfactorily to enable a blade - casing gap to be maintained at about 1mm, but it is extremely expensive to manufacture: The probe will be expected to operate at a temperature in the order of 1000°C which means that the insulating elements must be manufactured from machined ceramics. Furthermore, the insulating elements, which are in the form of rings, will have as small a wall thickness as possible in order to be able to maximise the size of the electrode (which increases the sensitivity of the probe), thereby increasing the difficulty and cost of manufacture. In addition, the assembly of the probes is a highly skilled operation which adds to the cost of the final product, especially since the probes must be installed in a turbine and tested at the normal operating temperature of the turbine.

According to the present invention, there is provided a method of forming a probe for capacitively measuring the distance to an object together with a composite cable, which comprises the steps of:

(a) providing the interior of a metal tube with a longitudinally extending conductor and a mineral insulant (normally in the form of a compacted powder) so that the interior is substantially filled with the conductor and insulant;

(b) locating the metal tube within the bore of a larger tube after the exterior surface of the metal tube and/or the interior surface of the larger tube has been provided with a deposited layer of insulating material;

(c) drawing the assembly of tubes so formed through a reducing die with the exception of one end thereof to form a cable part of smaller diameter than the said one end; and

(d) providing an electrode at the said one end of the assembly to form the probe, which electrode extends over substantially the entire surface of exposed mineral insulant and is in electrical contact with the conductor.

The method according to the invention has the advantage it enables a gap measurement probe to be manufactured at significantly reduced cost due to the removal of two physical components (the ceramic insulating rings) that are difficult to machine, and their replacement with mineral insulant and a deposited layer of insulation. The composite probe and cable manufactured in accordance with the invention has the further advantage that the various component parts of the probe will suffer from differential thermal expansion in operation to a lesser extent than conventional probes. If a conventional probe were to be used for turbine blade tip clearance measurement, differential thermal expansion of the metal and ceramic parts could cause them to become loose to some degree when the probe is heated up to the normal operating temperature of about 1000°C. Also, the difference in pressure on either side of the turbine blades as they pass the probe applies a vibrating force on the electrode at a frequency up to 6000 Hz or higher, normally from 1000 to 6000 Hz, which causes the probe electrode to apply a vibrating shearing force on the ceramic insulating rings. In some instances, for example with certain turbochargers, the vibrating force can have a frequency as high as 100 kHz. This shearing force could, after a prolonged operation time, cause damage to the ceramic rings which would lead to catastrophic failure of the system if the probe became detached from the casing.

The steps may be conducted in any appropriate order, for example, steps (a) and (b) may be performed in either order: the inner tube, conductor and mineral insulant may be assembled, and may then be located in the metal tube, or alternatively, the relevant surface of either tube may first be coated with insulant, the two tubes assembled, and only then the conductor and mineral insulant be introduced into the inner tube. It is possible for either the interior surface of the metal tube or the exterior surface of the inner tube to be provided with the deposited layer of insulating material, although it is normally preferable, for ease of processing, for the exterior surface of the inner tube to be provided with the insulation.

It is possible for the initial, undrawn, assembly of tubes to have the appropriate diameter for the probe, in which case the only drawing step(s) required are to reduce the diameter of that part of the assembly that will become the cable (step (c)). However, in most cases, the process will require an initial drawing step in which the diameter of the assembly of tubes is drawn down to substantially the intended final diameter of the probe. Such a method has the advantage that it may be employed to manufacture a range of different sizes of probe, the only difference being the size of the drawing die. In addition, the initial drawing step may be used for accurate dimensioning of the probe diameter after the various component parts of the assembly (i.e. the tubes, conductor and mineral insulant) have been assembled.

At some stage in the manufacturing process, it is preferable to seal the two tubes together at the end thereof that forms the probe, in order to prevent any escape of insulating material from between them. This may be achieved in a number of ways, and at different steps in the process, but preferably it is performed by a glass/ceramic sealing step in which the material composition has been chosen such that the material has a softening or melting point sufficiently high to withstand further processing or service conditions needed to complete the manufacture of the composite structure and to which the probe will be subjected to in service.

A suitable material for such a seal is glass powder, or preform of the necessary dimensions, having a melting point at least 100°C above the subsequent maximum temperature. In addition the material is advantageously impervious to and unreactive with moisture and should has sufficient adhesion to the components of the composite structure (tubes in particular) to withstand the dynamic (vibration and shear) forces applied in the balance of the manufacturing process. Adhesion/sealing mat be improved by, for example, producing a thin oxide layer on the tubes using a controlled oxidation treatment.

The sealing step is preferably performed after the assembly of tubes has been drawn down, but before application of the electrode.

Normally a recess is provided in the exposed surface of the mineral insulant after the drawing step (and sealing step, if any) and a layer of ceramic material deposited on the end of the assembly in order to isolate the interior of the tube forming the guard or screen from the electrode before the electrode is provided. After the layer of ceramic has been deposited, the exposed end of the conductor is cleaned and the recess is filled with metal to form the electrode. The electrode may be formed as a separate component that is inserted into the recess, or it may be provided in any other appropriate way. For example, it may be deposited.

The layer that is formed by deposition, i.e. the layer of insulating material between the tubes, and any other layer that may be formed by deposition, may be formed by any method that will generate a layer that has the necessary adhesion and thermal stability to enable it to operate at the relevant temperature, for example or 1000°C, 1200°C or 1500°C. The layers may, in principle, be formed by deposition in the condensed phase, for instance by sol-gel methods, but preferably the layers are formed by other deposition techniques, for example by vacuum deposition methods such as plasma assisted chemical vapour deposition, by sputtering or, preferably, by plasma deposition, all of which processes are well known and commercially employed for a number of purposes. In the case of plasma deposition, the component is spun in a vacuum while a ceramic or metal powder is sprayed through an arc or flame that flashes it into a plasma. As the plasma hits the cold spinning part, it condenses, forming a layer of ceramic or metal. Each layer of insulation or metal may be formed as a single layer only, or if desired may be built up from a number of layers. For example, one or more keying layers may be provided in order to improve the adhesion between the top layer and the substrate, the keying layer(s) being formed, for example by a different vacuum deposition process and/or having a different composition or stoichiometry from that of the top layer so that the properties of the layers are graded over the total thickness. The insulating layers that are deposited by these methods are generally oxides and nitrides of metals or metalloids, for example oxides and nitrides of aluminium, titanium, tantalum and silicon, or mixtures thereof with themselves or with other oxides or nitrides. Thus, the use of mixed metal oxides for the layers is also envisaged. It should be appreciated, however, that the invention, at least in its broadest aspect, is not limited to any particular deposition technique.

The layers may be formed to any thickness that is appropriate to the function of the layer. For example, in the case of the electrode, a thickness of from 0.01 to 1 micrometres, preferably from 0.1 to 0.2 micrometres will be appropriate in order to provide the necessary electrical conductivity, while for the layer of electrical insulation, thicknesses of from 0.2 to 0.5 micrometres will be appropriate. However, according to a preferred aspect of the invention, the electrode may be formed with a significantly greater thickness, for example with a thickness greater than 0.5 mm, preferably in the range of from 0.5 to 2mm, and especially from 0.75 to 1.5mm. This is especially useful where the probe is intended to be used to measure turbine blade tip clearance. Such a layer can be formed so that the layer is softer than the material forming the turbine blade, and so be abradable by the turbine blade, thereby ensuring a very small and controllable gap between the blade and the front face of the electrode. Although the probe could be manufactured in its entirety before installation in the casing, it is possible to form the probe without the front face of the electrode, to install the probe in the casing and only then to deposit the front face of the electrode. The front face of the electrode can then be machined back to the required level, leaving the probe flush with the inside of the casing. During operation of the engine, a blade tip could erode the casing liner and the front face of the probe, but still leave the probe operational. This would result in the probe giving an output of true tip clearance after a rub as the probe tip would still be flush with the casing inner diameter. In contrast, conventional probes are not abradable, and are recessed in the casing. After the first rub, the distance from the probe front face to the casing inner diameter changes, and all clearance readings are incorrect from that point on.

According to another aspect, the present invention provides a device for capacitively measuring the distance to an object comprising an assembly having a probe and a cable formed integrally with the probe, the assembly including a triaxial cable having a solid central conductor, a shield that surrounds the conductor and is insulated therefrom by means of a mineral insulant, and an outer metal tube that surrounds the shield and is insulated therefrom by means of a solid insulating material, the triaxial cable having a generally constant diameter, but having an increased diameter at one end part thereof which forms the probe, and having an electrode that extends over the end face of the probe which is electrically connected to the central conductor and is electrically isolated from the shield and from the outer metal tube.

Although described principally with reference to turbines (since such engines generally provide the most demanding environment), the probe formed according to the invention can be used for gap measurement in general and can function at temperatures up to the limit of the materials from which it is formed. It can be employed anywhere in a gas turbine, stream turbine or other turbomachinery, reciprocating engine or other equipment requiring measurement of gap size.

One form of probe according to the present invention will now be described by way of example with reference to the accompanying drawing which is a schematic section through the probe and part of the composite cable.

Referring to the accompanying drawings, a composite probe and cable for capacitively measuring a clearance to a turbine blade comprises a probe 1 and a triaxial cable part 2 formed integrally therewith. The probe 1 and cable part 2 each comprise a central conductor 4 that is located centrally along the length of an inner tubular part 6 that forms a screen and which is located within an outer tubular part 8 that forms a guard. The interior of the inner tubular part 6 that is not occupied by the conductor 4 is filled with a mineral insulant 10, for example magnesium oxide or silica. The guard 8 is intended to be located in a recess in the housing of a turbine, and is electrically insulated from the screen by means of a deposited layer of ceramic insulant 12. A recess is provided in the end surface of the mineral insulant 10 in which is located an electrode 14 connected to the central conductor 4. A thin layer 16 of ceramic covers the end of the assembly forming the probe 1.

The composite assembly is formed by first forming a preform comprising a hollow stainless steel tube 6 of outer diameter about 8mm, which contains a central nickel or stainless steel conductor rod 4 and mineral insulant 10 by methods that are conventional for forming mineral insulated cable. The preform will have a length in the range of from 1 to 10 metres depending on the dimensions and geometry of the turbine in which the assembly is intended to be fitted. A ceramic insulating layer 12 about 0.1mm in thickness is then deposited on the outer surface of the hollow tube 6 by means of a flame-spraying method, and the tube is then slid into a tube 8 whose internal diameter is such as to enable the coated tube 6 to fit snugly.

The assembly is passed through one or more die drawing steps until the outer diameter of the tube 8 corresponds to the intended final diameter of the of the probe 1 (other than any changes that will be caused by coating the probe), for example about 6mm. The assembly is then subjected to a further drawing step in which the part of the assembly that are intended to constitute the cable, i.e. the entire of the assembly with the exception of one end thereof which will form the probe, is drawn down further to a diameter of about 3mm.

After the assembly has been drawn to the required size, the end of the tubes 6 and 8 are sealed by means of fused glass or silica in order to seal the insulating layer 12 between the tubes. A recess is then formed in the end of the probe 1 by removing all the mineral insulant therefrom to a depth of about 0.5mm, and a thin layer of ceramic is flame sprayed over the recessed end in order to coat the exposed internal surface of the tube 8. The end of the central conductor 4 that has been exposed by forming the recess in the mineral insulant is cleaned to remove the flame sprayed ceramic, and an electrode is formed by flame spraying a 0.5mm thick layer of metal (e.g. nickel) into the recess. Finally, the entire end and side face of the probe 1 is flame sprayed with a ceramic in order to protect the underlying metalwork.

Claims:

1. A method of forming a probe for capacitively measuring the distance to an object together with a composite cable, which comprises the steps of:

(a) providing the interior of a metal tube with a longitudinally extending conductor and a mineral insulant so that the interior is substantially filled with the conductor and insulant;

(b) locating the metal tube within the bore of a larger tube after the exterior surface of the metal tube and/or the interior surface of the larger tube has been provided with a deposited layer of insulating material;

(c) drawing the assembly of tubes so formed through a reducing die with the exception of one end thereof to form a cable part of smaller diameter than the said one end;

(d) providing an electrode at the said one end of the assembly to form the probe, which electrode extends over substantially the entire surface of exposed mineral insulant and is in electrical contact with the conductor.

2. A method as claimed in claim 1, wherein the exterior surface of the metal tube is provided with the insulating material in step (b).

3. A method as claimed in claim 1 or claim 2, which includes an initial drawing step in which the diameter of the assembly of tubes is drawn down to substantially the intended final diameter of the probe.

4. A method as claimed in any one of claims 1 to 3, wherein the inner tube is located within the outer tube before the conductor and the mineral insulant are located in the inner tube.

5. A method as claimed in any one of claims 1 to 4, wherein the electrode is provided by a vacuum deposition method.

6. A method as claimed in any one of claims 1 to 5, wherein a recess is formed in the exposed mineral insulant at the said one end of the assembly in order to accommodate the electrode.

7. A method as claimed in claim 6, which includes depositing a layer of insulating material on the said one end of the assembly after formation of the recess in the mineral insulant in order to isolate the electrode from the inner tube.

8. A device for capacitively measuring the distance to an object comprising an assembly having a probe and a cable formed integrally with the probe, the assembly including a triaxial cable having a solid central conductor, a shield that surrounds the conductor and is insulated therefrom by means of a mineral insulant, and an outer metal tube that surrounds the shield and is insulated therefrom by means of a solid insulating material, the triaxial cable having a generally constant diameter, but having an increased diameter at one end part thereof which forms the probe, and having an electrode that extends over the end face of the probe which is electrically connected to the central conductor and is electrically isolated from the shield and from the outer metal tube.