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EUROPEAN PATENT APPLICATION

21 Application number: **83307923.9**

51 Int. Cl.³: **H 01 B 3/00, H 05 K 7/20**

22 Date of filing: **22.12.83**

30 Priority: **11.01.83 US 457199**

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43 Date of publication of application: **25.07.84**
Bulletin 84/30

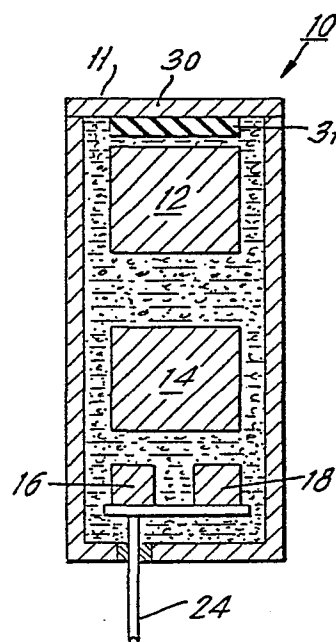
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84 Designated Contracting States: **DE FR GB SE**

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54 **Thermally conducting filler for enclosing electrical components.**

57 A slurry of particles of thermally conductive but electrically insulative material is suspended in a dielectric fluid such as silicone oil and is capable of freely flowing to fill the irregular interior volume of a housing containing electrical components. The particles are compacted, by settling and centrifuging, to form a compact, relatively non-flowable paste in which the dielectric fluid is present only to the extent that it fills the interstitial spaces between particles. The thermal conductivity of the compacted particles is close to that of the bulk material. The free volume within the housing may be reduced by adding relatively large blocks of solid electrically insulative but thermally conductive ceramic before filling with the slurry of particles which are to be compacted.



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THERMAL CONDUCTING FILLER FOR
ENCLOSING ELECTRICAL COMPONENTS

BACKGROUND OF THE INVENTION

This invention relates to a novel thermally conductive filler for insulating the interior of a housing containing electrical components and to a method of filling the housing and
5 encapsulating the electrical components with the thermally conductive medium.

It is well known that heat produced by electrical components contained within a housing should be removed by conducting the heat to the exterior of the housing. When the
10 electrical components within the housing are relatively high voltage components and the housing has a relatively small volume, it is not feasible to employ conventional air cooling or liquid cooling systems. Moreover, it is frequently desirable that the housing be filled with a medium which will encapsulate
15 and protect the individual components therein against relative movement due to shock forces and the like, and against chemical attack or contamination by environment influences. Consequently, electrical equipment including such assemblies as high voltage power supplies which produce output voltages of the
20 order of thousands of volts, are conventionally potted by a potting material which is typically a polymerized resin.

These potting resins provide mechanical protection of the potted components but the thermal conductivity of such resins is relatively poor. For example, the thermal
25 conductivity of typical potting material now used is of the order of 0.0005 cal. per second cm °C. Therefore, heat generated by the electrical components within the housing is not easily conducted to external surfaces of the housing.

It is known that thermally conductive particles can be
30 added to polymerized potting resins in order to increase the thermal conductivity of the potting material. These thermally conductive particles are generally electrically insulative ceramics which have good thermal conduction characteristics and typically may be beryllium oxide, aluminium oxide, boron nitride
35 or some types of silicon carbide. These thermally conductive

particles are normally stirred into the potting resin just before the resin is poured into the interior of a housing.

It has been found that the volume of the insulation particles loaded in this way can rarely exceed 50% of the total resin volume. Consequently, the thermal conductivity of the insulation medium with the particles in place is usually only about twice that of the resin itself. Thus, while aluminium oxide, for example, has a bulk thermal conductivity of 0.084 cal. per second cm °C. when particles of the ceramic consist of about 50% of the total volume of a conventional polymerized potting resin, the thermal conductivity of the ultimate material will be increased from about 0.0005 cal. per second cm °C. to about 0.001 cal. per second cm °C.

BRIEF DESCRIPTION OF THE INVENTION

In accordance with the invention, the interior of an electrical housing filled with heat-generating devices, such as transistors, transformers, resistors and the like, having irregular volumes and shapes, is filled with an easily flowing slurry consisting of a mixture of more than 50% by volume and preferably more than 70% by volume of heat-conductive, electrically insulative particles, suspended in a dielectric fluid, which preferably is a liquid such as silicone oil. The thermally conductive particles typically may be aluminium oxide particles or the like having a particle size which is preferably distributed about a mean diameter of about 150 microns. Beryllia can also be used, but it is more expensive than aluminium and is very toxic in powdered form.

The slurry is first mixed at room temperature by pouring the particles into the dielectric fluid and agitating this mixture. The slurry is then poured into a filler column which, in turn, is connected to the open top of the electrical housing. The filler column and housing are sealed to be air-tight so that the slurry cannot freely escape from the interior of the housing. The slurry is then subjected to vacuum to remove trapped air bubbles therefrom and the slurry is permitted to settle into the housing interior under the force of gravity. During the settling period, the assembly is tilted in

different directions to eliminate Rankine slope effects. Oil appearing at the top of the column is decanted and replaced by additional slurry during the settling process. The volumetric packing density after settling for about 36 hours will often

5 exceed 80% of particles by volume.

The slurry particles are then further compacted against one another to form a relatively non-flowable paste. this further compacting can be carried out by a centrifugal process. Thus, the entire housing is spun at moderate "g" force for about two hours in a suitable fixture. The insulation particles, which are more dense than the suspending liquid, tend to compact in one direction relative to the housing due to centripetal force effects to form a paste-like consistency in which silicone oil fills the interstices between

10 particles. The paste now forms an almost solid continuous body which encapsulates the components and extends between the components and to the interior of the surrounding walls of the housing. It has been found that the final highly compacted mass has a thermal conductivity close to that of a solid block

15 of the insulation material which is employed.

The filler column is then removed and the paste, which extends above the top of the open housing end, is sliced off to be flush with the housing top. A housing lid is then sealed over the housing top to complete the enclosure.

25 Preferably, the housing is made of conductive material to act as a heat sink to heat conducted from internal potted components through the encapsulant.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a cross-section taken through a housing which has been filled with thermally conductive insulation in accordance with the invention.

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Figure 2 is a cross-section view of Figure 1 taken across the section line 2-2 in Figure 1.

DETAILED DESCRIPTION OF THE DRAWINGS

35 Referring to the drawings, there is shown in generalized form a housing 10 which may be of a good thermal conductor, preferably of aluminium, and which may have any

desired thickness. Housing 10 has a top lid 11 attached and sealed thereto in any desired manner. The housing 10 can typically have dimensions of 2 inches by 4 inches by 5 inches but it will be obvious that the invention can apply to any
5 housing size which contains any type of component.

Various heat-generating electrical components are mounted within the housing and are schematically illustrated as the heat-generating components 12, 14, 16, 18, 20 and 22. These components can be of any desired nature. By way of
10 example, component 12 could be a bridge-connected rectified circuit which might produce 4.8 watts during its operation. Component 14 could be an inverter transformer which produces 25 watts during its operation. Components 16 to 22 could be the elements of a bridge-connected rectifier which produces 1.2
15 watts. Components 16 to 22 can be carried on a common circuit board with other components, not shown. An electrical connector shown in the form of a multi-conductor ribbon 24 carries suitable wires from the interior electrical components of housing 10 to the exterior where the wires can be connected
20 to other circuits. A suitable insulation seal can enclose and seal ribbon 24 as it passes through the wall of housing 10. Alternatively, a multi-pin connector can be formed in the wall of housing 10 and individual wires from the components within housing 10 can be connected to the multi-pin connector.

25 In order to prevent an excessive temperature rise of components 16 to 22 and their connecting leads or wires during their operation without complicating the housing design with metal heat sinks, and without having to enlarge the housing, the components can be thermally connected to the exterior walls of
30 housing 10 by the novel heat conductive insulation of the invention which encapsulates the electrical components.

The housing 10 is provided with an open top (lid 11 is removed) and the electrical components to be mounted therein are fixed in place. A filler column (not shown) which has a volume
35 larger than that of housing 10, is sealed to the open top of housing 10.

In accordance with the invention, an insulation medium is prepared as a relatively non-viscous slurry of particles of a material having good thermal conductive properties but which are electrically insulative, suspended in an insulation fluid.

5 Typical particles may be of aluminium oxide, beryllium oxide, boron nitride and certain types of known silicon carbides. The particle size employed for these particles is not critical. Good results have been obtained with particles distributed about a mean diameter of less than about 300 microns which ensures
10 uniform and homogeneous filling of the particles within housing 10 and into very small irregular crevices or the like, in the interior of housing 10.

The particles are loaded into a suitable dielectric fluid as silicone oil at room temperature and stirred to ensure
15 thorough mixing and uniform distribution of the particles into the oil. There should be sufficient oil present in the mixture to ensure that the slurry will flow easily into the interior of housing 10. Generally, the particles should occupy more than one half by volume of the slurry.

20 In an illustrative embodiment of the invention, aluminium oxide particles have a size distributed around a mean diameter of about 150 microns are stirred into a silicone oil carrier. The powder and oil are in a ratio of about 70% to 30%, respectively, by volume. The slurry is very easily
25 flowable in this condition. Other stable dielectric fluids can be used in place of silicone oil.

The slurry is then poured into the filler column connected to container 10 of Figure 1 and 2, with the filler column and container under vacuum. The alumina containing
30 slurry is then permitted to settle into container 10 for a given settling period, for example, 36 hours. During this settling period, the unit and column are tilted to different orientations to eliminate Rankine slope effects. During the settling period, oil at the top of the column is decanted and is replaced
35 with the 70% to 30% by volume slurry.

At the end of the settling period, the alumina particles will reach a packing density in excess of 80% by volume of the slurry.

The assembly is then placed in a centrifugal apparatus and is rotated at a moderate "g" force to cause the aluminium oxide particles to compact further. The compacted particles now form an almost solid paste-like body which adheres to all
5 exposed surfaces within housing 10 and which encapsulates all components within the housing.

Thereafter, excess silicone fluid is drawn off from the top of the column and the column is removed. The paste, which extends above the top of container 10, is sliced through at the
10 column to container joint.

A conductive lid 30 is then fastened to the top of housing 10. A compressible synthetic rubber pad 31 is fixed to the interior of lid 31 to keep the paste under positive pressure within housing 10.

15 Paste compacted in this way and employing aluminium oxide particles has a thermal conductivity of the order of 0.07 cal. per second cm °C. as compared with a thermal conductivity of 0.084 cal. per second cm °C. for the solid material.

After filling, small cavities may appear within the
20 paste as a result of thermal movement. These cavities are not important to thermal behaviour, but they could be significant in terms of formation of corona discharge. However, oil in and around the alumina will fill these cavities as they form to prevent electrical breakdown within the cavities.

25 If the interior of the volume contains large voids, a relatively large volume of powder would be needed to fill the interior free volume. This interior volume can be reduced by filling with solid filler blocks such as filler blocks 34 and 26 in Figure 1. These blocks can have any desired shape and
30 reduce the volume of compacted particles needed to fill the housing interior. The filler blocks 34 and 36 may be of the same ceramic material as the particles of the slurry and, in the preferred example, are of aluminium oxide.

In a specific example of the invention, the electrical
35 components 12 through 22 were capable of having a working surface temperature of 220°C. The mean free path distances from the surfaces of components 12 and 14 and of components 16,

18, 20 and 22 collectively was 25mm (1 inch), 10mm (0.375 inch) and 25mm (1 inch) respectively, and their effective areas were 13 square cm (2 square inches), 52 square cm (8 square inches) and 26 square cm (4 square inches) respectively. The novel thermally paste of the invention encapsulated and coupled these components to the surfaces of housing 10 so that the housing 10 had a temperature of about 210°C., indicating a temperature differential across the thermally conductive insulating material of only 10°C.

In another example, a magnetic/rectifier module of a 550 watt inverter, working at 1 watt per cubic cm (16 watts per cubic inch) had an internal dissipation of the order of 30 watts. The steady state temperature difference between the center of the module and the outside walls was less than five centigrade degrees.

It is important to examine the variation of thermal conductivity for the encapsulating material with the proportion of filler. This is tabulated in the following table for two theoretical materials, one a thermally conductive powder and one a fluid. The thermal conductivities are shown for three alternative thermal conductivity ratios of the powder to fluid of 10:1, 100:1, 1000:1.

	Volumetric Proportion of higher thermally conductive powder	Proportioned Thermal Conductivity for 10:1	Proportioned Thermal Conductivity for 100:1	Proportioned Thermal Conductivity for 1000:1
	0	1	1	1
	50%	1.82	1.98	1.99
	60%	2.17	2.46	2.49
30	70%	2.9	3.26	3.33
	80%	3.5	4.8	4.98
	90%	5.26	9.2	9.9
	92%	5.8	11.2	12.3
	94%	6.5	14.4	16.4
35	96%	7.3	20.2	24.4
	98%	8.5	33.6	47.6
	100%	10	100	1000

It is seen that for proportions of the higher thermal conductivity material, up to about 70% by volume, there is no significant difference in the achieved thermal conductivity, irrespective of whether the conductivity ratios are 10:1, 100:1
5 or 1000:1. This result covers the range of proportions which can be obtained with loaded encapsulating resins (due to limitations in pour and infill), and shows the restriction imposed by the resin itself.

The table also shows that it would be valuable to
10 achieve volumetric fill proportions of the more conductive material of greater than about 80%, and specifically in the range from 90% to 96%, and thereby obtain a significant proportion of the available benefits of the material with a ratio of 100:1. The table also shows that the benefits of a
15 1000:1 material cannot be obtained until a loading of virtually 100% has been achieved.

Although a preferred embodiment of this invention has been described, many variations and modifications will now be apparent to those skilled in the art, and it is therefore
20 preferred that the instant invention be limited not by the specific disclosure herein, but only by the appending claims.

What we claim is:-

1. A thermally-conducting filler for enclosing electrical components contained in a housing, characterised by an easily-flowing slurry comprising at least 50% by volume of thermally-conducting electrically-insulating particles suspended in a dielectric fluid.
2. A filler as claimed in Claim 1 characterised in that said particles have a mean diameter of 150 microns.
3. A filler as claimed in either of Claims 1 or 2 characterised in that the particles are formed from a ceramic material.
4. A filler as claimed in Claim 3 characterised in that the ceramic material is selected from the group comprising metal oxides, metal nitrides and metal carbides.
5. A filler as claimed in any one of Claims 1 to 4 characterised in that the dielectric fluid is a silicone oil.
6. A method of filling a housing containing electrical components characterised by the steps of filling the interior of the housing with a filler as claimed in any one of the preceding claims, and compacting the suspended particles to form a non-flowable but deformable paste.
7. A method as claimed in Claim 6 characterised in that the filler material is initially compacted by gravitational settling.
8. A method as claimed in Claim 7 characterised in that the filler is subsequently compacted by being subjected to centrifugal force.
9. A method as claimed in Claim 8 characterised in that the non-flowable paste comprises at least 80% by volume of said particles.
10. A method as claimed in any one of Claims 6 to 9 characterised in that spaces within the housing are partially filled with homogeneous solid blocks of thermally-conducting electrically-insulating material prior to filling the remaining space with said filler.

FIG. 2

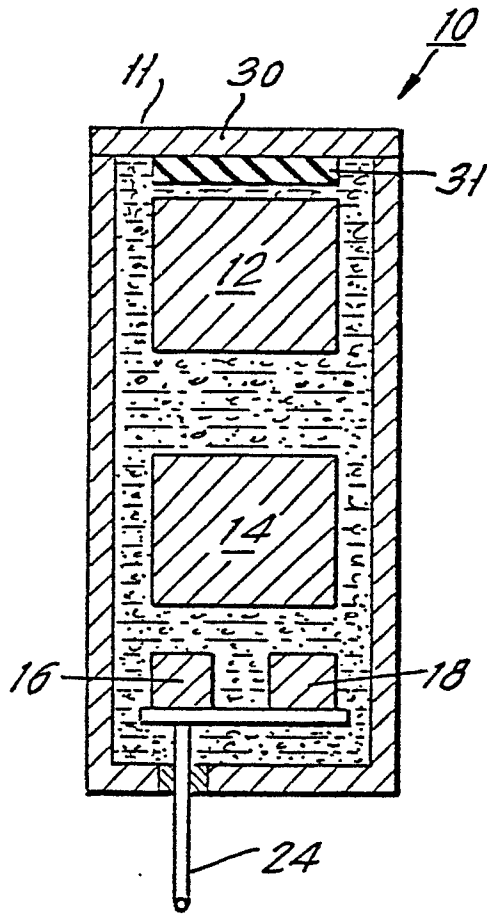
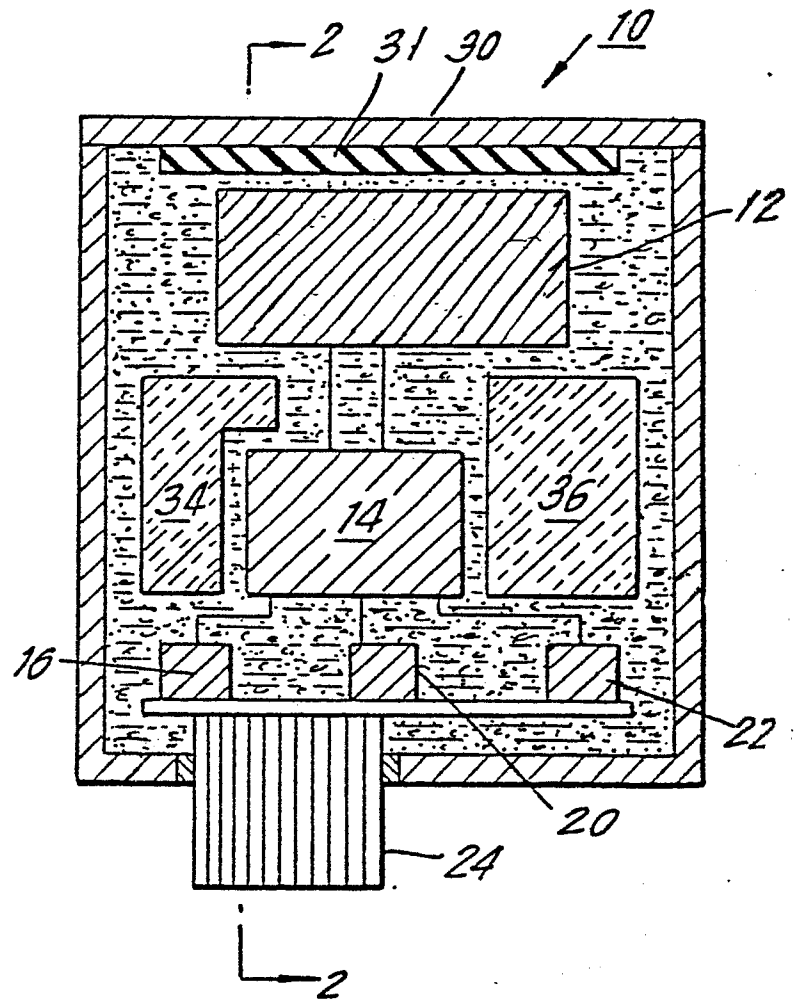


FIG. 1





European Patent
Office

EUROPEAN SEARCH REPORT

0114000

Application number

DOCUMENTS CONSIDERED TO BE RELEVANT			EP 83307923.9
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)
X	US - A - 3 885 984 (WRIGHT) * Abstract; column 4, line 42 - column 6, line 61 *	1,3-5	H 01 B 3/00 H 05 K 7/20
X	US - A - 3 137 665 (RETFORD) * Column 1, lines 10-15; column 3, lines 34-47; examples *	1-5	
X	DE - B2 - 1 913 675 (SIEMENS) * Totality *	1-6 9	
X	GB - A - 874 801 (PHILIPS) * Totality *	1,3-8 9,10	
Y	DE - A1 - 1 439 456 (SIEMENS) * Page 5, last paragraph - page 6, last paragraph *	10	TECHNICAL FIELDS SEARCHED (Int. Cl. 3) H 01 B 3/00 H 05 K
X	US - A - 4 265 775 (AAKALU et al.) * Claims 1-5 *	1,3-5	H 01 L 23/00 H 02 K C 09 K 5/00
X	US - A - 3 754 071 (ERNST et al.) * Abstract; example 1 *	1,3,4,6-9	C 08 L 83/00 C 08 K 3/00
The present search report has been drawn up for all claims			
Place of search VIENNA		Date of completion of the search 11-04-1984	Examiner KUTZELNIGG
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			



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EUROPEAN SEARCH REPORT

0114000

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DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int. Cl.)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
L	W. BATEL "Einführung in die Korngrößenmeßtechnik", 2nd edition, 1964 SPRINGER, Berlin Zur Praxis der Kennzeichnung einer Korngrößenverteilung pages 21-23, 56, 57 -----	2	
			TECHNICAL FIELDS SEARCHED (Int. Cl.)