

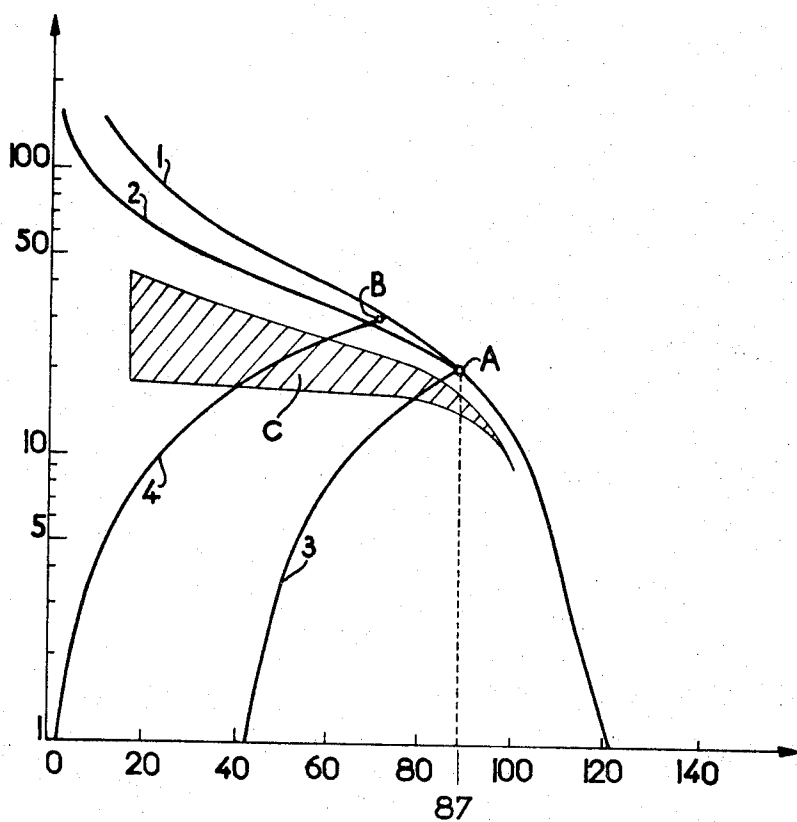
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METHOD FOR FIXING SUPERCONDUCTING MAGNETIC COILS

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METHOD FOR FIXING SUPERCONDUCTING MAGNETIC COILS

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4 Claims

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The present invention relates to a method for fixing superconducting magnetic coils and to coils obtained through said method.

It is known that to a superconducting coil is associated a so-called critical, or quenching, current above which the electrical resistance of said coil is at least partially restored.

The critical currents of superconducting coils have proved to be considerably less than those of uncoiled short samples made of the same wire and submitted to the same tests (externally applied transverse magnetic field). Such a phenomenon is termed current degradation and one usually refers to a so-called "degradation factor" viz the ratio of the critical current of a given coiled wire to that of a short-sample made of the same wire, the upper limit of said factor being therefore unity.

In view of the above definition, the higher the degradation the lower the degradation factor, and conversely.

Since the maximum intensity of the magnetic field obtainable with a superconducting coil increases as said critical current, it is of prime importance to achieve the highest possible value of the latter and, therefore, the highest possible value of the degradation factor of the coil.

Many attempts have been carried out with a view to reducing the degradation of superconducting coils (i.e. increasing their degradation factor) and, in particular, substantial improvements have been obtained by substituting wires coated with a more or less thick copper sheath for the usual uncoated wires. In addition, Professor Louis Weil of the University of Grenoble, France, has achieved further improvements in this respect by more fixing the coil wire through an impregnation of said wire with water, as described in French patent application No. 949,731 dated Oct. 7, 1963, for "A Method for Impregnating Superconducting Coils," in the name of Commissariat a l'Energie Atomique.

It has been made possible through the latter method to raise the value of the critical current of a given superconducting coil from 18 to 25 amperes. However, even under the best circumstances, the values of the degradation factor obtained to this day are always far lower than unity and the most favourable values recorded in the prior art are only of about 0.8, which is not fully satisfactory.

Moreover, it is to be noted that, under given magnetic field conditions and once a superconducting coil has been cooled, the maximum value of its critical current cannot be reached in the course of the first current rise; in fact, the coil has to be brought back to its normal state, then submitted again to a current rise, from zero or nearly zero current, several times in succession until the maximum value of the critical current is reached. This is what is called training. Now, since each time the coil is brought back to its normal state, a certain amount of cooling fluid corresponding to the magnetic energy stored is spent, it is of primary importance to reduce the number of training cycles.

In this connection, further to systematic tests aiming at finding how to best fix the coil, on the one hand, and at

obtaining the best discharge conditions for the heat generated during small flux jumps within the coil, on the other hand, the applicants have devised a method by means of which is obtained a coil having little or no training and the degradation factor of which is very close to unity. It is thus possible to save a large amount of raw material in the manufacture of superconducting coils, while ensuring much more reliable and money-saving operating conditions.

More precisely, the present invention relates to a fixing method by means of which are obtained superconducting coils having substantially no training and the degradation factor of which is substantially unity, said method consisting in introducing, between the successive turns of a wire in the process of being wound into a coil, a heterogeneous fixing mixture constituted by a granulated material having a Young's modulus of at least 11.5×10^6 lbs./sq.in. (8,000 kg./mm.²) in suspension in a material which, whereas it is viscous while said wire is being wound, is brought to the solid state at very low temperatures.

With the method according to the present invention, it is possible to cause the hard granulated material, which may also be a good thermal conductor, to penetrate deeply into the coil when it is most necessary, which is not possible in the case of conventional fixing methods according to which the fixing step does not take place until the coil is formed.

Moreover, if the suspension material used, which is brought to the solid state at very low temperatures, can resume its viscous initial state (in particular through a temperature rise), the method according to the present invention permits to recover the superconducting wire (should, for instance, a breakdown occur), which is most advantageous since superconducting wires are very costly.

The present invention also relates to the superconducting magnetic coils obtained through the above method.

The granulated material of the heterogeneous impregnating mixture used is preferably a substance both hard and a very good conductor of heat: it may be a hard amorphous substance, for instance crushed glass, but it is preferable to resort to a substance in the crystalline state, e.g. silica sand, alumina in powder form or beryllium oxide. At any rate, the heat granulated material used must necessarily have a Young's modulus of at least 11.5×10^6 lbs./sq.in. (8,000 kg./mm.²).

The dimension of the granules is not critical; it is simply required that said granules be small enough in order to avoid an increase of their swelling coefficient, and, on the other hand, that their linear dimension be not much smaller than the mean free path of phonons (viz sound quanta) in the fixing mixture at the temperature of $7.2^\circ = R(4^\circ \text{ K.})$, in so far as it is desired to take advantage of the thermal conductivity of the granulates material.

The granules used will thus have for instance a diameter of from 1 to 2 mils (25 to 50 microns).

Moreover, at the temperature at which the wire is being wound into a coil, the suspension material must both be fluid enough for allowing the addition thereto of the granulated material and have enough consistence to prevent said granulated material from forming a deposit when being applied to the wire. Cup-grease seems to be specially suitable.

One of the main advantages of the method according to the invention as compared to conventional fixing methods, is that, whereas, at the low operating temperatures of superconducting coils, the fixing materials used to this day have a Young's modulus not much higher than 1.4×10^6 lbs./sq. in. (1,000 kg./mm.²), which is for instance the case with ice or frozen oils, the heterogeneous impregnating mixture according to the invention, in view

of its hard granules having a high Young's modulus, enables the superconducting coils to withstand the electromagnetic stresses exerted upon them and which might be the cause of more or less abrupt movements of the coil turns, thus creating flux jumps leading to degradation.

The features of the present invention will be discussed hereafter, reference being had to the accompanying sole figure.

The wire used is a niobium-titanium wire, the characteristics of which (when in the state of a short sample) would be plotted, in the figure, as a curve located between curves numbered 1 and 2, depending upon the manufacturing conditions of said wire.

A coil having a diameter of 1.2 in. (30 mm.) is made with said wire and, according to the invention, a heterogeneous fixing mixture is introduced between the successive turns of the wire in the process of being wound, said mixture being constituted by silica sand granules having a diameter of about 1 mil (25 microns) in suspension in cup-grease.

The coil thus manufactured is cooled down to the temperature of liquid helium and the tests carried out show that this coil exhibits a critical current which provides a magnetic field of 87,000 oersteds along the coil axis (and of about 88,500 oersteds on the first inner layer of the coil), as shown by curve 3 of the chart, where the log of current in amperes is plotted against magnetic fields in kilo-oersteds, it being assumed that the coil is submitted to an outer magnetic field of 40 kilo-oersteds.

The figure shows that the critical current thus achieved is equal to that of the short sample (point A); therefore, the degradation factor of the coil manufactured according to the invention is unity.

Curve 4 and point B correspond to the results obtained with the same coil but with no outer magnetic field.

Hatched area C brings out the advantage of the method according to the invention, since it shows that superconducting magnetic coils according to the prior art exhibit degradation factors which never go beyond 0.85.

It is to be pointed out that, since the method according to the invention permits to reach values of the critical current never reached to this day, it is possible with a coil according to the invention to generate the same magnetic field as that generated by a coil of the prior art of the same volume but with less ampere-turns.

In the above example, for instance, a saving of about 20% ampere-turns is ensured, which corresponds to a wire saving of about 30% by weight.

Moreover, due to the presence of a thermally conductive hard material in the heterogeneous mixture, the coils according to the invention show a better stability when undergoing fluctuations of the magnetic field.

What is claimed is:

1. A method for fixing superconducting magnetic coils comprising the step of introducing between the successive turns of a wire in the process of being wound into a coil, a heterogeneous mixture of a high thermally conductive granulated non-metallic material having a Young's modulus of at least 11.5×10^6 lbs./sq. in. (8000 kg./mm.²) in suspension in a material which is viscous while said wire is

being wound and is solid at very low temperatures, said granulated material providing maximum discharge condition for the heat generated during flux jumps within the coil and said material fixing the turns of the magnetic coil.

2. A method for impregnating superconducting magnetic coils, said method consisting in introducing, between the successive turns of a wire in the process of being wound into a coil, a heterogeneous impregnating mixture constituted by a crystalline granulated non-metallic material, the granules of which have a diameter of from 1 to 2 mils, and having a high thermal conductivity and a Young's modulus of at least 11.5×10^6 lbs./sq. in. (8,000 kg./mm.²) in suspension in a material which, whereas it is viscous while said wire is being wound, is brought to the solid state at very low temperature.

3. A method for impregnating superconducting magnetic coils, said method consisting in introducing, between the successive turns of a wire in the process of being wound into a coil, a heterogeneous impregnating mixture constituted by a granulated non-metallic material, the granules of which have a diameter of from 1 to 2 mils (25 to 50 microns), and having a Young's modulus of at least 11.5×10^6 lbs./sq. in. (8,000 kg./mm.²) in suspension in a material which, whereas it is viscous while said wire is being wound, is brought to the solid state at very low temperature.

4. A method for impregnating superconducting magnetic coils, said method consisting in introducing, between the successive turns of a wire in the process of being wound into a coil, a heterogeneous impregnating mixture constituted by a granulated non-metallic material having a Young's modulus of at least 11.5×10^6 lbs./sq. in. (8,000 kg./mm.²) in suspension in a material which, at the temperature at which said wire is being wound into a coil, is fluid enough for allowing the addition thereto of said granulated material but has enough consistence to prevent said granulated material from forming a deposit when being applied to said wire, and which is brought to the solid state at very low temperatures.

References Cited

UNITED STATES PATENTS

2,167,215	7/1939	Leary.	
2,203,937	6/1940	Barley.	
2,641,879	6/1953	Dalrymple.	
2,841,866	7/1958	Schilling.	
2,914,840	12/1959	Damiano	29—605
3,068,533	12/1962	Raimondi.	
3,078,186	2/1963	Tierney	29—605
3,243,871	4/1966	Saur	29—599
3,264,713	8/1966	Viehe	29—604
3,296,684	1/1967	Allen et al.	29—599
3,322,871	5/1967	Noack et al.	29—604

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