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Rutherford Laboratory Report

The Construction of Magnets for Particle Accelerator Physics using Cementatious Aggregates

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Science Research Council

Engineering Division
Rutherford High Energy Laboratory
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THE CONSTRUCTION OF MAGNETS FOR PARTICLE ACCELERATOR PHYSICS USING CEMENTATIOUS AGGREGATES

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ABSTRACT

The paper proposes a technique for constructing synchrotron and other high energy physics magnets in an integral form using concrete both as an electrical insulator and as a mechanical support. These structures will overcome the radiation problems encountered in synchrotrons and should prove to be economically attractive.

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1. INTRODUCTION

A major problem to be overcome in constructing particle accelerators is in the selection of materials which will withstand damage by high intensity ionising radiation. A requirement for insulation and good structural integrity has invariably led to a choice of some plastic (organic) material reinforced with a fibrous or particulate material. Materials of this nature showing good resistance to radiation degradation have been uncovered by us,[1] and have been used with success in many accelerator applications. Consideration, however, must be given to future accelerator projects involving considerably increased energies and intensities of ionising particles. With this consideration in mind we have given attention to the use of inorganic structural materials.

One of the major applications of such materials in nuclear apparatus lies in the construction of magnets. Magnets are specially sensitive to damage since the coil (normally located and insulated with epoxy resin, glass fibre composite) is usually extremely close to the particle beam or experimental position. Damage to the coil insulation by radiation is serious since this will lead to a fall in insulation by moisture absorption and dimensional changes caused or accelerated by gas evolution within the plastic coil matrix.

The purpose of this report is to describe the use of an inorganic binder (or cement) to be used instead of epoxy resin, together with suitable inorganic reinforcement (fibrous and aggregate). This inorganic cement will not suffer the radiation degradation exhibited by the organic resins and in addition the proposed constructional technique should result in other advantages, in cost, improved geometric shielding factor and improved thermal conductivity at very low temperatures.

2. CONVENTIONAL TECHNIQUES

Conventional techniques of magnet coil manufacture have been described elsewhere and only a brief summary need be given here.[2, 3]

Copper conductor, usually of rectangular cross-section with an axial cooling hole, is wound onto a former appropriate to the design of the magnet. During the process of winding the copper, glass tape is wound onto the conductor, the glass tape would be either preimpregnated with a suitable epoxy resin formulation or wound dry. When the conductor has been fully wound and bonded with glass tape the coil is placed in a mould for the final form and, in the case of the preimpregnated tape, heat is applied and the resin cured. If the coil has been bound with dry glass tape, the coil (positioned in the mould) must be vacuum impregnated with liquid resin and hardener and then finally cured using an appropriate temperature cycle.

These techniques are only applicable to the conventional resins currently used for coil manufacture. In order to use an inorganic cementatious material, a complete departure from these techniques is indicated.

3. CONSIDERATION OF MATERIALS

Conventional concrete comprises graded stone aggregates of various ranges bonded together with a suitably hydrated binder such as Portland cement. These concretes while exhibiting good compressive strength show weakness in tension, but can give fair electrical insulation.[4] However, a system analogous to concrete indicated to us an avenue for consideration.

Materials we have given consideration to are as follows:-[5,6]

3.1 Binder. We have studied the use of an aluminous binder (ciment fondu) in addition to conventional Portland cements with particular reference to iron free materials.

3.2 Aggregate. We have examined a variety of graded aggregates such as ground sieved siliceous material to spherical fillers such as ballotini. The current status of the work suggests that graded fragmented alumina provides a very suitable aggregrate giving good initial drying shrinkage and improved crack resistance when oven dried.

3.3 Primary insulation of coil. A problem to be overcome in designing a technique with cement aggregates is the need to insulate between conductors during the initial winding of the coil. This problem is not significant when using conventional insulation techniques since the copper conductor is prewound with glass cloth. This technique has been tried with cementatious material, but difficulty was found with fully impregnating the cloth tape. This difficulty was to some extent overcome by preimpregnating the cloth tapes with the cement before winding. However, it was thought that the complications of the process made it worthwhile to consider other methods of achieving the same object.

The most promising techniques so far tried involve either precoating the conductors with a thin film of flame sprayed alumina or egg-crating between conductors with strips of ceramic material. After the coils have been firmly located in the magnet yoke the filling with concrete may be commenced.

4. APPLICATION OF TECHNIQUE USING CEMENTATIOUS MATERIALS [7]

In applying the materials described in the novel way of insulating coils, it must be borne in mind that some more original design approach to magnet coils should be made. Therefore, the cement composite material is not seen only as an alternative to epoxy resin in making coils, but is regarded as part of a new concept in magnet coil design. This suggests that a "concrete" magnet could be constructed integral with the rest of the function with which it is used. This will be illustrated by the ensuing example of application.

The photograph (figure 1), shows a model which was constructed to incorporate the principles which would be required in an integral beam bending magnet. The magnet is built round a stainless steel beam pipe. The copper coil is formed around the beam pipe concurrent with being flame sprayed with alumina or egg-crated with alumina strips to provide inter-turn and outerground insulation. The coil is temporarily located with a support jig until the two halves of the steel yoke end plates are placed in position. The end plates are clamped in position by means of tie-bars which pass outside the coil and yoke structures but axially to the beam-pipe. The tie-bars are tensioned to give limited compression to the coil and yoke assembly, additional tension to the tie-bars is obtained by compression of an external jig assembly. The final stage of the operation is boxing in of the coil and yoke assembly to provide a mould for the concrete filling. The whole of the assembly is vibrated to compact the cementatious material and then set aside to harden. After hardening, brought about by oven drying, the tie-bar nuts are run down on the end plates, and the external jig assembly removed. This leaves the tie-bars in position under tension giving the whole structure added strength in tension. It is desirable to give the finished structure a coating treatment with a suitable silicate solution to reduce moisture absorption by the concrete.

5. CONCLUSIONS

The foregoing illustrates the technique of using inorganic cementatious material for encapsulating magnets for use in high energy particle accelerators. The basic material is cheap, high density, low activation cross-section with relatively short half-life yields, is refractory and is very strong in compression. The model magnet was successfully powered in October, 1968.

The techniques and materials described indicate the current status of work. Further work is in hand to refine the materials and mode of application and further, to provide more suitable conceptual designs leading to prototype manufacture and test.

6. ACKNOWLEDGEMENTS

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TABLE 1

Samples oven dried 3 days at 130°C	Initial ρΩ cm after cooling to room temperature	
	DC measurement	AC measurement (1600 Hz)
1. Secar (aluminous cement) 1:2 alumina aggregate	$> 1 \times 10^{13}$	2×10^{9}
2. Secar 1:4 alumina aggregate	$> 1 \times 10^{13}$	5×10^{9}
3. White Portland Cement 1:2 alumina aggregate	1×10^{12}	5.5×10^{8}
4. White Portland Cement 1:2 alumina aggregate	1×10^{11}	2×10^{8}

Some typical resistivity results obtained under practical conditions

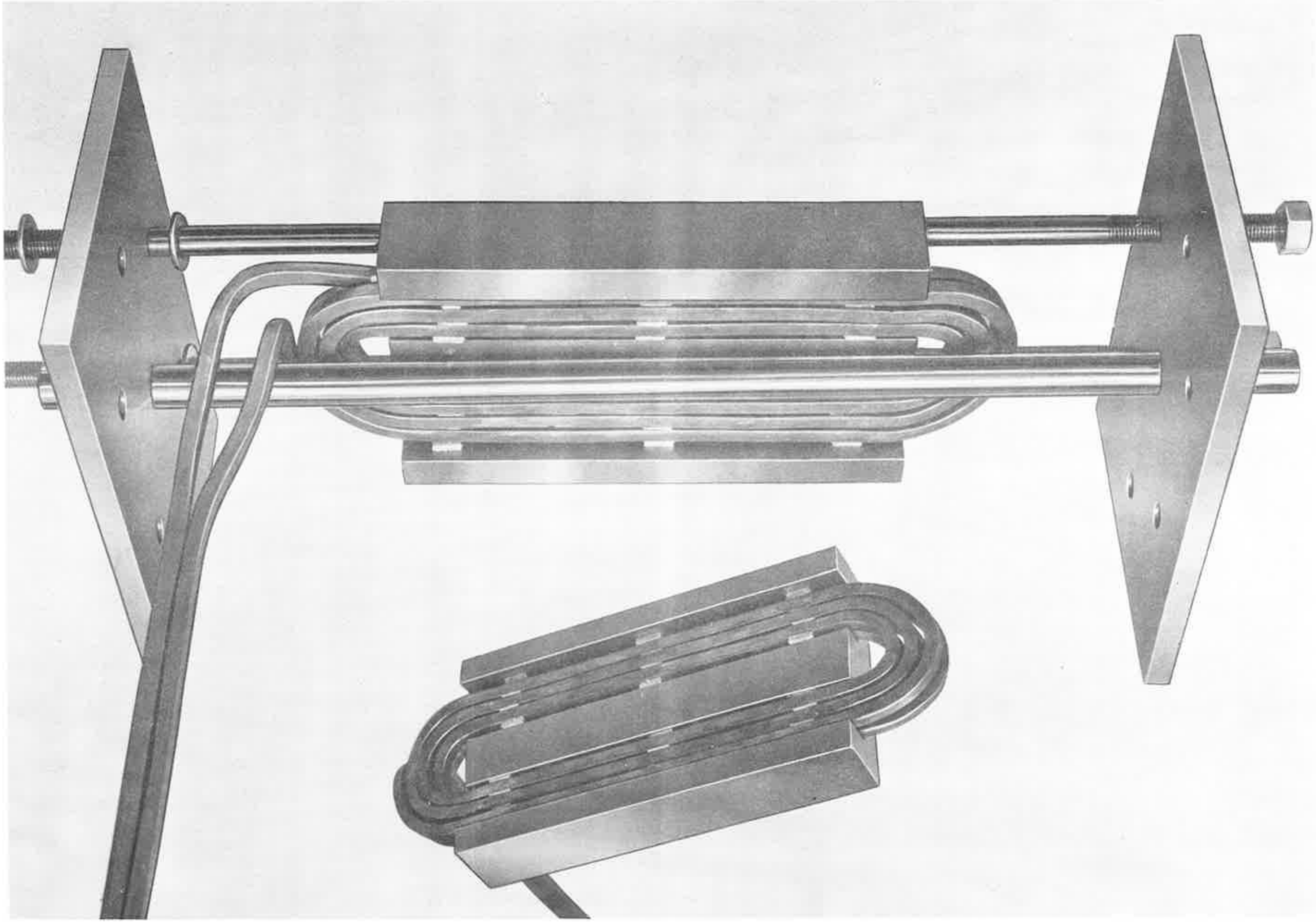

FIGURE 1

Model magnet prior to filling with concrete

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