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Sheldon et al.

[11] **3,775,842**

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[54] **METHOD FOR CENTERING AND RESTRAINING COILS IN AN ELECTROMAGNET**

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[52] **U.S. Cl.** ..... **29/606,** 29/421, 29/455 R, 29/515, 29/522, 29/602, 264/266, 264/267

[51] **Int. Cl.** **H01f 7/06**

[58] **Field of Search** ..... 29/606, 602, 605, 29/421 R, 455 R, 522, 515; 336/60, 96, 197, 196, 205, 185; 174/52 R, 52 PE; 235/210, 213; 264/266, 267, 245

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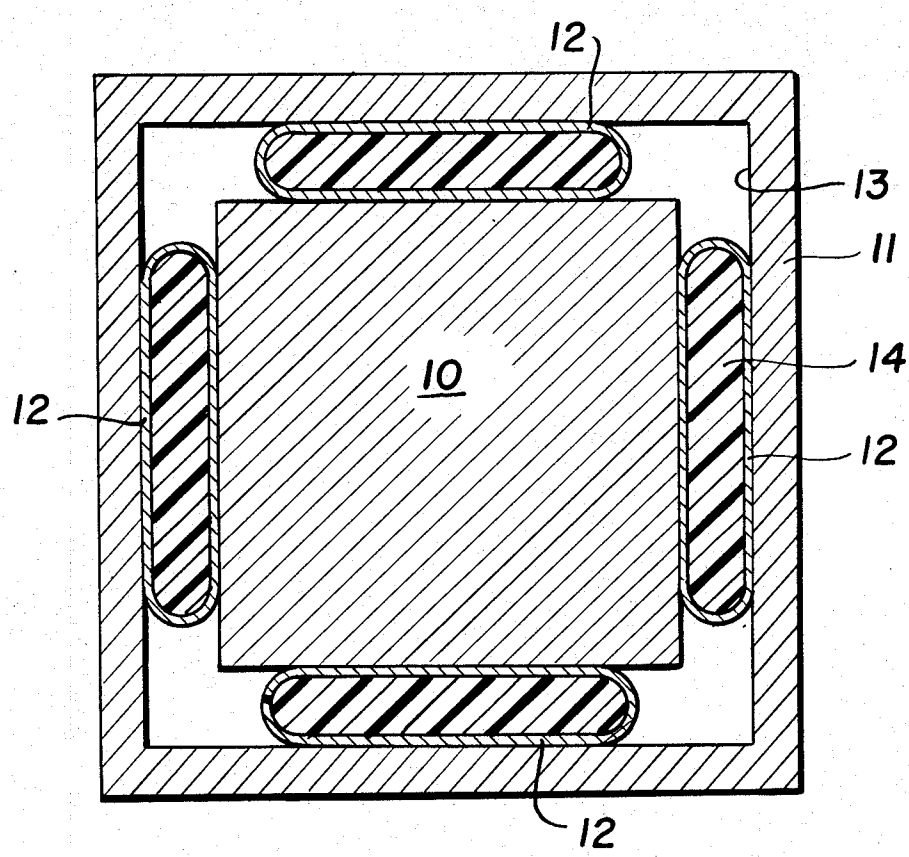
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Assistant Examiner—Carl E. Hall
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[57] **ABSTRACT**

A body is centered within a housing and restrained from moving from such centered position by surrounding the body with a plurality of flattened like tubes positioned between the body and the interior walls of the housing and simultaneously expanding the tubes so as to center the body by filling the tubes with a hardenable material under pressure. Upon hardening of the material, the body is restrained from moving from the centered position. The method is applied particularly to the coils of an electromagnet and the beam tube of a particle accelerator so centered and restrained within a tubular electromagnet housing by hydraulically pumping an epoxy resin under a high pressure into the symmetrically spaced like tubes which are connected hydraulically in parallel and, following curing of the epoxy, capping the ends of the tubes to maintain hydraulic integrity of the system.

9 Claims, 3 Drawing Figures



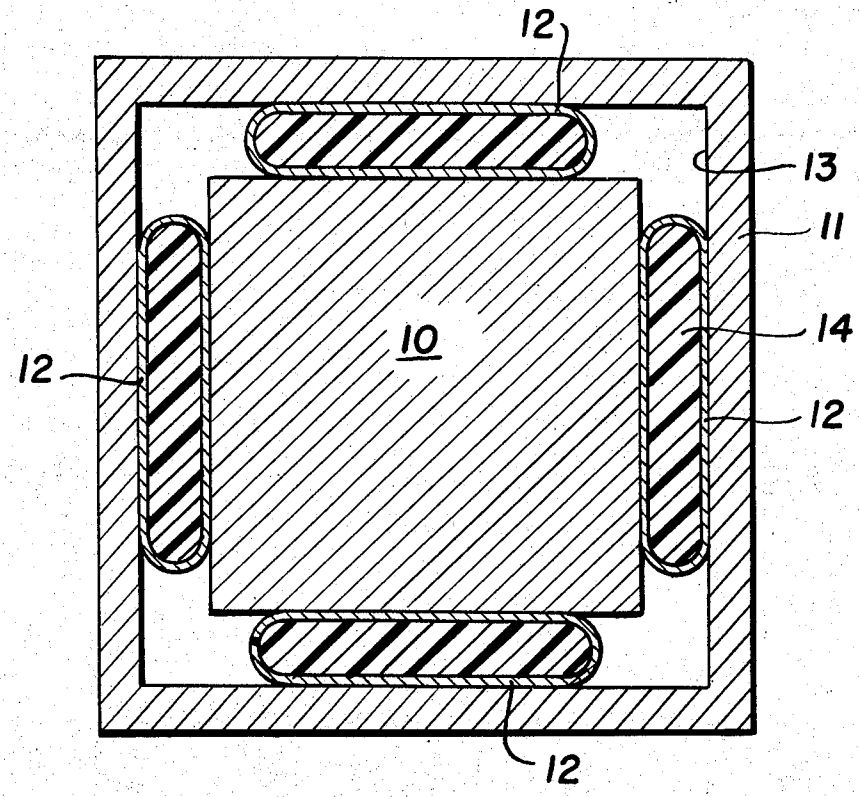

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Fig — 1

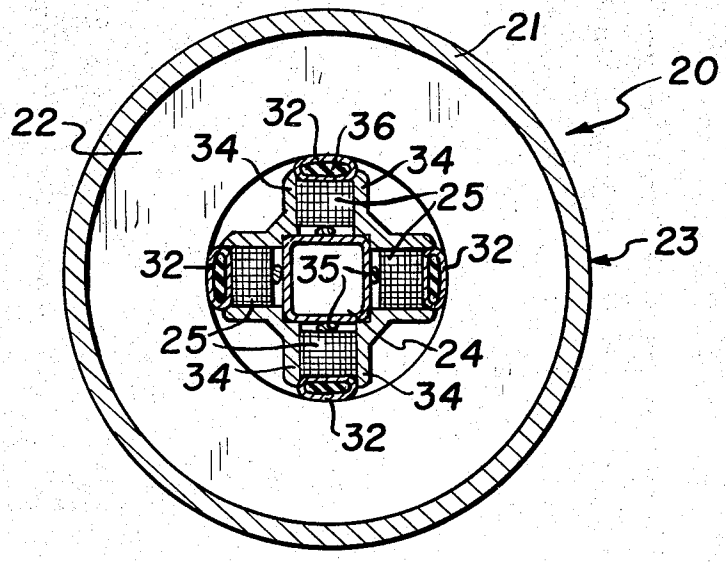

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Fig — 3

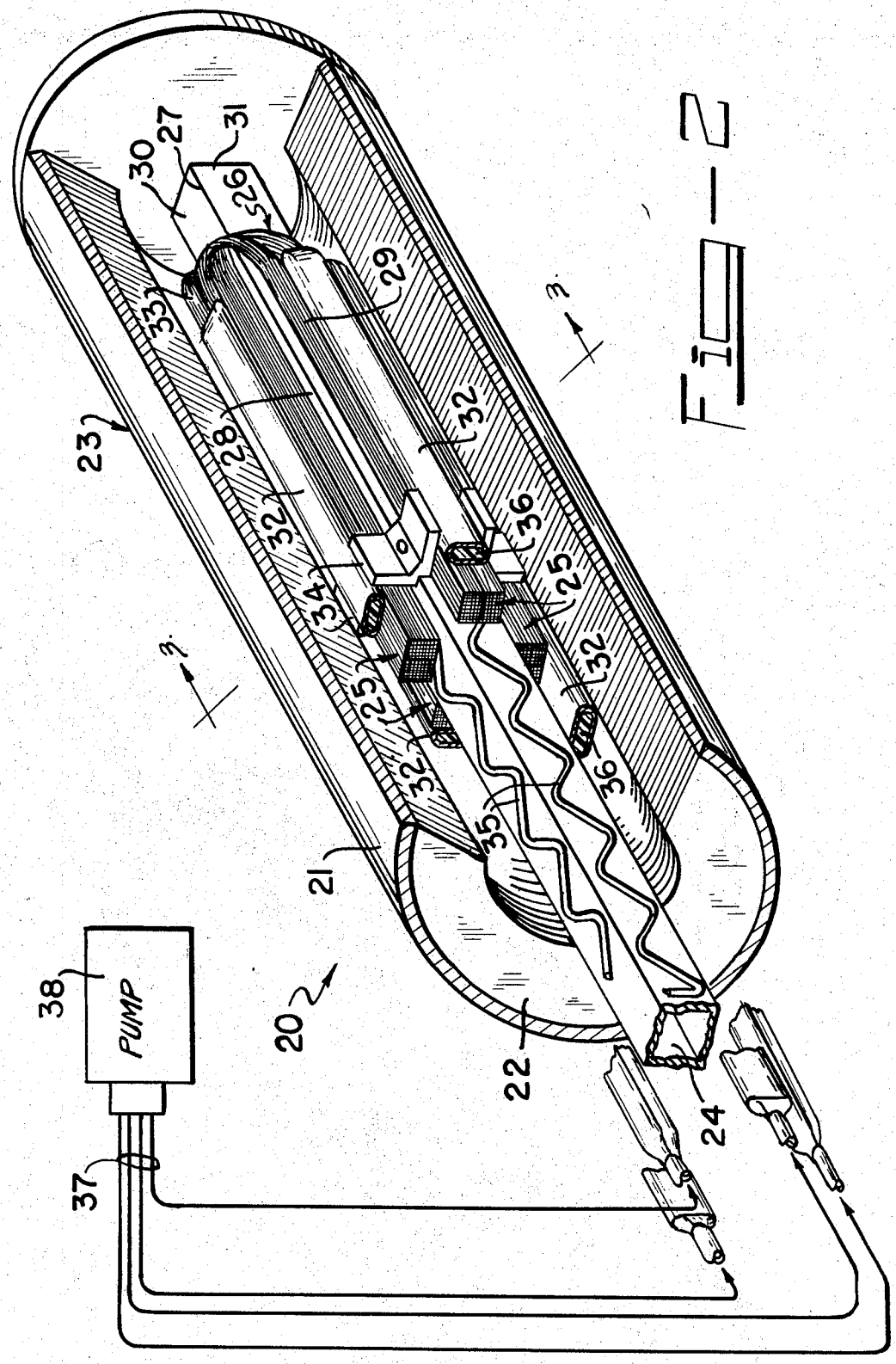


Fig. 2

METHOD FOR CENTERING AND RESTRAINING COILS IN AN ELECTROMAGNET

CONTRACTUAL ORIGIN OF THE INVENTION

The invention described herein was made in the course of, or under, a contract with the UNITED STATES ATOMIC ENERGY COMMISSION.

BACKGROUND OF THE INVENTION

This invention relates to a method of centering a body within a housing and restraining the body from moving within the housing from the centered position. The invention is directed toward a method of centering and restraining the coils about a central member in an electromagnet and is particularly concerned with the centering and restraining of coils about a portion of the beam tube of a particle accelerator in a tubular cryogenic electromagnet housing.

Continuing investigation into the structure of the nucleus and research in the fundamental particles and their interactions require particle accelerators capable of producing particle beams of increasingly greater energies. Concomitant with beams of greater energies is the need for magnets with greatly increased field strengths for use in the construction of the new accelerators. Electromagnets capable of generating the necessary field strengths required in new accelerators demand increasing amounts of electric power for satisfactory operation. The accelerators planned and proposed for future subnuclear investigations will require electromagnets with field strengths so great that the amount of electric power needed to generate these field strengths will be economically prohibitive. A solution to the power demand problem is the use of superconducting electromagnets which enable the attainment of the necessary magnetic field strengths with an economically acceptable electric power demand. The reduction in the electric power demand is occasioned by the very drastic reduction in the resistance in the windings of the coils at extremely low temperatures. To maintain the superconducting properties of the electromagnet during operation, a cryogenic fluid must be continuously passed over the coils and in contact with the windings. Flow paths through the electromagnet immediately adjacent the coils with free access to the surfaces of the windings must be provided in construction of the superconducting electromagnet.

It is also essential in the construction of a superconducting electromagnet that the coils be centered and restrained from moving. This is extremely important in particle accelerator application where the beam tube must be centered within the magnet and the coils properly positioned and centered about the beam tube and restrained from any movement to achieve and maintain the desired magnetic field and its consequent effect on the particle beam within the beam tube. In particular, in a superconducting quadrupole electromagnet for use in a particle accelerator, it is paramount that the coils and beam tube be restrained from any movement as even a slight movement can distort the magnetic field and permit the particles to drift to the walls of the beam tube, negating the effect of the quadrupole magnet as it functions to center the beam within the tube and prevent particles from drifting from the center of the tube.

Since any movement of the coils can cause an undesirable distortion of the magnetic field, the coils must be rigidly restrained along the entire length of the windings. While the coils have been held in position previously with spacing elements such as brackets or braces, these do not provide restraint within acceptable tolerances for high energy accelerator applications. Also it is necessary to include such braces along the entire length of the windings and to position and anchor such braces along such a distance within the small permissible tolerances is extremely difficult. It is also known to restrain movement of coils by encapsulation with epoxy resin, such as in transformers. However, encapsulation with epoxy resin is not adaptable to cryogenic electromagnet applications as encapsulation would prevent flow of the cryogenic fluid over the coils. Also the epoxy resin generally is only poured around the coils and allowed to cure and consequently exerts little force in centering and positioning the coils or preventing movement prior to curing. Consequently, it is an object of the present invention to provide a method for centering and restraining the coils of an electromagnet.

Particularly, it is an object of the present invention to provide a method for centering and restraining the coils of an electromagnet about the beam tube of a high energy particle accelerator.

It is a further object of the present invention to provide such a method wherein the coils will be rigidly restrained along the entire length of the winding.

Specifically it is an object to provide such a method of centering and restraining the coils which will permit the flow of a cryogenic fluid over the surfaces of the coils in contact with the windings so as to permit operation of the electromagnet as a superconducting magnet in extremely high energy particle accelerator applications.

An additional object is to provide such a method for centering and restraining the four coils of a superconducting quadrupole electromagnet used in a particle accelerator.

SUMMARY OF THE INVENTION

In accordance with the present invention a body is centered and restrained within a housing by surrounding the body with a plurality of flattened like tubes positioned between the body and the interior walls of the housing. The flattened like tubes are simultaneously expanded so as to center the body by filling the tubes with a hardenable material under pressure. The hardenable material is subsequently hardened thereby restraining movement of the body from the centered position.

Further in accordance with the present invention, the coils of an electromagnet and the beam tube of a particle accelerator are so centered and restrained within a tubular electromagnet housing. The flattened like tubes are positioned symmetrically about the coils and beam tube between the coils and the interior wall of the housing and are connected hydraulically in parallel. Epoxy resin is hydraulically pumped into the tubes simultaneously under a high pressure and the pressure maintained as the epoxy resin cures. Subsequent to the curing of the epoxy, the ends of the tubes are capped to maintain the hydraulic integrity of the system.

BRIEF DESCRIPTION OF THE DRAWINGS

An understanding of the various aspects of the invention will become apparent upon reading the following description of the invention and with reference to the drawings in which

FIG. 1 is a cross-sectional view of a body centered and restrained within a housing in accordance with the present invention.

FIG. 2 is an isometric view partially broken away of a particle accelerator superconducting quadrupole electromagnet in which the beam tube and coils have been centered and restrained in accordance with the present invention.

FIG. 3 is a cross-sectional view taken along the line 3—3 of FIG. 2.

DESCRIPTION OF THE INVENTION

In order to facilitate an understanding of the basic aspects of the present invention, prior to describing the very important application of the method to the coils of a cryogenic quadrupole electromagnet in a particle accelerator, the method will be described generally in relation to centering a body in a housing and rigidly restraining the body from moving from the centered position. Referring to FIG. 1 for a description of the general application of the method of the present invention, there is illustrated a body **10** which is to be centered and rigidly restrained within a housing indicated generally at **11**. The body **10** is surrounded by a plurality of flattened like tubes **12** which lie between the body **10** and the interior walls **13** of the housing **11**, there being four such flattened tubes illustrated in FIG. **1**. These flattened tubes **12** are filled with a hardenable material **14** which is injected under pressure simultaneously into all such tubes. The like tubes expand under the fluid pressure of the injected hardenable material **14** and as they expand contact both the body **10** and the interior walls **13** so as to center the body **10** within the housing **11**. The hardenable material **14** is subsequently hardened thereby restraining any movement of the body **10** from its centered position within the housing **11**.

While it is preferred that the flattened tubes be spaced about the body symmetrically, it is not essential as other unsymmetrical configurations are possible which will achieve the desired result of centering the body as the tubes expand. The particular spacing arrangement chosen will depend to some extent upon the shape of the body and the shape of the interior walls of the housing. While in FIG. **1** the body is shown to be of a square cross-section as is the interior surface of the housing, the method is equally adaptable to other shapes. By injecting a hardenable material into a flattened tube and thereby expanding the tube, the body is centered and restrained along its entire length. The fluid pressure of the hardenable material is equalized throughout the tube so that the restraining force is equal along the entire length of the tube and the tube expands under the force as a unit so as to center the body within very close tolerances along the entire length. The force exerted to restrain the body is considerable as the hardenable material is injected into the tube under pressure. Injecting the material into the tubes under pressure of course gives much greater restraining force than merely pouring the material into the volume between the body and the housing as would be done in an encapsulation type procedure.

The method of the present invention is adaptable to many and various applications. A very important application is centering and restraining the coils of a cryogenic quadrupole electromagnet about a portion of the beam tube of a high-energy particle accelerator. Referring to FIGS. **2** and **3** for a description of this particular application of the present invention, a cryogenic quadrupole electromagnet is indicated generally at **20**. An outer tubular shell **21** and a series of very tightly compressed washer-shaped laminations **22** composed of a ferromagnetic material form the electromagnet housing **23**. A square beam tube **24** which is a portion of the beam tube of a particular accelerator is positioned so as to extend through the housing **23** along the axis thereof. The four coils indicated generally by **25** of the quadrupole magnet **20** are positioned so as to surround the beam tube **24** and are symmetrically spaced. Each of the coils **25** is flattened and elongated and is positioned about the beam tube **24** so as to be elongated in a direction parallel to the axis thereof. As can be seen by considering a single such elongated coil **26**, the windings of each such coil encircle one edge **27** of the beam tube **24** with the two elongated segments **28** and **29** of coil **26** positioned along adjacent sides **30** and **31**, respectively, of the beam tube **24**, sides **30** and **31** being those adjacent sides which meet to form edge **27**. Since each edge of the beam tube **24** is similarly surrounded by one of the coils **25**, an elongated segment of each of two adjacent coils lies along each side of the beam tube. Flattened stainless steel like tubes **32** are subsequently positioned between the windings of the coils **25** and the interior surfaces of the laminations **22**. The flattened like tubes **32** are symmetrically spaced and extend along the length of the elongated coils parallel to the beam tube **24**. Each flattened tube **32** lies along and firmly contacts the two elongated segments which lie along the same side of the beam tube **24**, such as elongated segments **28** and **33** which lie along side **30**. Optionally, small lateral braces **34** may be used to approximately center the coils **25** on the beam tube **24** and to provide some support for the coils **25** prior to the subsequent steps of the present method, although the braces are not essential. These braces must be small and short so that full flow of cryogenic fluid over the surfaces of the coils will be affected as little as possible. Also optional and for cryogenic electromagnet application, a spacing member such as the serpentine spacer **35** may be inserted between the beam tube **24** and the windings of the coils **25** to permit flow of the cryogenic fluid between the beam tube and the coils. As is seen in FIG. **2**, the flattened stainless steel tubes **32** are parallelly connected by appropriate piping **37** to a hydraulic pump **38**. The flattened stainless steel tubes **32** are connected hydraulically in parallel so that the hydraulic pressure exerted by the fluid pumped into the tubes **32** is equal in all tubes. Epoxy resin **36** is hydraulically pumped through the piping **37** under a high pressure by pump **38** simultaneously into all the flattened stainless steel like tubes **32**. The flattened tubes **32** simultaneously expand under the hydraulic pressure to center the coils **25** and beam tube **24** within the electromagnet housing **23** and prevent and movement of the coils **25** from the centered position. The epoxy resin **36** is cured to hardness while maintaining the hydraulic pressure in the tubes **32**. After the epoxy resin **36** has cured, the ends of the tubes **32** are capped to maintain the hydraulic integrity of the epoxy resin. The hydraulically expanded stainless steel tubes **32** rigidly restrain any movement of the coils **25** about the beam tube **24** from the centered position within the electromagnet housing **23**.

The rigid restraint placed upon the coils about the beam tube by the hydraulic pressure of the cured epoxy

within the stainless steel tubes prevents any movement of the coils or consequent distortion of the magnetic field. Since the tubes extend along the length of the elongated segments of the windings, the pressure and restraint is exerted along the entire length of the coils rather than only at intermittent distances as is the case when braces are used. Since the epoxy is confined to the tubes, ample flow passages for a cryogenic fluid over the coils are provided.

EXAMPLE

A superconducting quadrupole electromagnet prototype for use in a particle accelerator was constructed employing the method of the present invention. The constructed electromagnet was 50 cm in axial length, the housing being formed from a 15 cm outer diameter stainless steel tube having 3 mm thick walls and a series of 0.159 cm thick washer shaped laminations having a 6.8 cm inner diameter and 14.0 cm outer diameter precompressed to a 99.5 percent packing factor inserted into the stainless steel tube and held in the compressed position by 3 mm thick end plates welded to the stainless steel tube. Four flat and elongated coils were wound in appropriate form to insure precise conductor placement and were placed upon a 2.5 cm square beam tube having a serpentine spacer lying along each side to retain flow passages between the coils and the beam tube. The coils were approximately centered by small lateral braces which served to temporarily support the coils in position about the beam tube until final centering and support were provided by subsequent steps. Four flattened like stainless steel tubes were then placed between the windings of the coils and the interior surfaces of the laminations, one flattened tube on each of the four sides of the beam tube. The tubes were connected hydraulically in parallel and simultaneously expanded into place by pumping room temperature curing epoxy resin into the tubes under a pressure of 400 psi. The coils and beam tube were centered and locked firmly in place. The pressure was maintained on the epoxy material throughout its cure cycle thus providing an irreversible hydraulic restraining mechanism, and the stainless steel tubes were subsequently capped to maintain the hydraulic integrity of the system.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method of centering and restraining a body within a housing comprising:

surrounding said body with a plurality of flattened like tubes between said body and said housing;

filling said tubes simultaneously with a hardenable material under pressure whereby the tubes expand to center the body within the housing; and

hardening said hardenable material, thereby restraining movement of said body from the centered position.

2. A method of centering and restraining a body within a housing comprising:

positioning said body within said housing;

positioning a plurality of flattened like tubes between said body and the interior walls of said housing, said tubes being symmetrically spaced about said body;

connecting said tubes together hydraulically in parallel;

hydraulically pumping epoxy resin under pressure into said tubes whereby they expand to center said body within said housing and restrain the body from moving;

curing the epoxy resin to hardness while maintaining the hydraulic pressure; and

capping the ends of said tubes to maintain the hydraulic integrity of the epoxy resin, thereby rigidly restraining movement of said body from the centered position.

3. The method of claim **2** wherein said housing is tubular; said body consists of a central member extending along the axis of said tubular housing and a plurality of peripheral members surrounding said central member and symmetrically spaced about the axis thereof; and said flattened like tubes are positioned parallel to the axis of said central member between the interior walls of said housing and said peripheral members.

4. The method of claim **3** wherein said central member extends through said tubular housing; said peripheral members are elongated flattened coils, said coils elongated in a direction parallel to the axis of said central member; said flattened tubes are positioned along the elongated segments of said coils; and each such elongated segment of each coil is in contact with such a flattened tube.

5. The method of claim **4** wherein said tubular housing is a ferromagnetic material, said coils are the coils of an electromagnet, and said central member is a portion of the beam tube of a particle accelerator.

6. A method of centering and restraining the coils about a central member in an electromagnet comprising:

positioning said central member within the electromagnet housing,

positioning said coils within said housing symmetrically about the periphery of said central member;

positioning a plurality of flattened like tubes between the windings of said coils and the interior walls of said housing, said tubes being symmetrically spaced and each such tube essentially filling the space between the windings and the interior wall of said housing;

connecting said tubes together hydraulically in parallel;

hydraulically pumping curing epoxy resin under pressure into said tubes whereby they simultaneously expand to center the coils within the housing about said central member and restrain the coils from moving;

curing the epoxy resin to hardness while maintaining the hydraulic pressure; and

capping the ends of said tubes to maintain the hydraulic integrity of the epoxy resin whereby the coils are rigidly restrained and centered in the electromagnet about said central member.

7. The method of claim **6** wherein said electromagnet housing is tubular and is composed of a ferromagnetic material; said central member is a square central tube which extends along the axis of said tubular housing; said coils are flattened and elongated windings, said coils elongated in a direction parallel to the axis of said central tube; said flattened tubes are positioned along the elongated segments of said coils; and each elongated segment of each coil is in contact with a flattened tube.

8. The method of claim 7 wherein the electromagnet is a quadrupole magnet having four coils and four flattened tubes; the coils are positioned such that the windings of each of the four coils encircle one of the four edges of the square central tube with the two elongated segments of each coil positioned along adjacent sides of the square tube; and each of said four flattened tubes are positioned so as to contact the elongated segments of two adjacent coils, which two segments lie on the same side of the square tube.

9. The method of claim 8 wherein said square central tube is a portion of the beam tube of a particle accelerator and wherein said electromagnet is cryogenic.

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