DOWNLOAD PDF SUPERCONDUCTING MACHINES.

Chapter 1 : The Large Hadron Collider | CERN

Superconducting electric machines are electromechanical systems that rely on the use of one or more superconducting elements. Since superconductors have no DC.

Instead, the new materials seem to follow a superconductivity mechanism found previously only in materials that are superconducting at very low temperatures, Chia-Ling Chien and his colleagues at Johns Hopkins University report in an online Nature paper. New superconductors contain alternating layers of iron arsenide orange and red and rare earth metal oxides blue and gray doped with fluorine green. Iron arsenide compounds become superconducting at relatively high temperatures of 55 K, and researchers are now beginning to decipher their superconducting mechanism. The insight is an important step toward understanding how superconductors work, and it could help researchers design even better materials. High-temperature superconductors could lead to cheaper MRI machines; smaller, lighter power cables; and far more energy-efficient and secure power grids. Utilities, for example, could use superconducting magnets to store energy at night, and then use it at peak demand hours in the mornings and evenings. Superconducting materials conduct electric current without any losses when they are chilled below a certain temperature, called the critical temperature. Niobium alloys, used to make superconducting magnets for MRI machines, are superconducting only below 10 K. Copper-oxygen compounds, or cuprates, which were discovered in the late s, are superconducting at much higher temperatures of 90 to K. At these temperatures, cheap, easy-to-use liquid nitrogen can be employed as a refrigerant. Cuprates are not used for MRI magnets because it is difficult and expensive to make wires from them. And some manufacturers are making nitrogen-cooled superconducting cables for transmission lines. But researchers have long tried to find materials with even higher critical temperatures. Superconducting power cables, MRI machines, and energy storage devices would be cheaper and smaller if they did not need cooling. The new iron arsenide superconductors have shown potential for achieving high critical temperatures. Scientists at the Tokyo Institute of Technology first reported in a February paper in Journal of the American Chemical Society that a lanthanum iron arsenide material becomes superconducting at 26 K. Since then, Chinese researchers have pushed the critical temperature up to 55 K. It contains oxides of rare earth metals sandwiched between layers of iron arsenide. Researchers can, for instance, replace the iron, arsenic, or rare earth metals with other elements. In fact, Chinese researchers replaced the lanthanum in the original Japanese material with other rare earth metals, such as samarium, to raise the critical temperature above 50 K. While cuprate power cables have to be fabricated as specially designed flat tapes, it might be easier to make wires from iron arsenide semiconductors. Researchers are also hoping that iron arsenides will help unlock the mystery of how high-temperature superconductors work. That will be key for designing materials with even higher critical temperatures. In superconductors that work at very low temperatures, such as niobium and lead, electrons form pairs below the critical temperature. Atoms or defects in the crystal do not have the energy needed to break the pair and deflect the electrons. So the electron pair zips around the material unimpeded, giving rise to superconductivity. But this pairing theory does not hold for high-temperature copper-oxygen materials. In their Nature paper, Chien and his colleagues show evidence suggesting that the pairing theory might hold for the iron arsenide superconductors. Indeed, while the pairing mechanism of iron arsenides might be different than that of copper-oxygen compounds, the two materials also have similarities. In a recent online paper, also published in Nature , Dai and Lynn showed that the two materials share key magnetic properties. And both materials also have a similar layered structure. It might be too early to say just how useful the iron arsenide superconductors will be. For now, Dai says that researchers are excited about having broken the year monopoly of cuprates and about having a new high-temperature superconductor to play with.

Chapter 2 : Home | Haran Research Group - Illinois

Superconducting Electrical Machines â€¢ Over many decades, various superconducting machines shown to be technically feasible over wide range of power ratings â€¢ First attempted in the s, replacing copper windings with LTS â€¢ Although improved efficiency (about 1%) was expected, the main rationale was the size/weight reduction â€¢ Operated.

In a preferred construction the flux screen is part of an outer rotor cylinder of strong mechanical construction which operates at ambient temperature. The outer rotor cylinder is coupled for rotation with an inner cylinder which carries the superconducting winding, is of relatively light construction to minimize heat inflow and is separated from the outer cylinder by a vacuum space. April 1, An A. Such a machine may be arranged, for example, as an alternating current generator in which the superconducting field winding is a rotor winding supplied with direct current and the stator winding is a multi-phase armature winding such as the conventional three-phase type. In conventional generators having three-phase stator windings and non-superconducting rotor field windings it is known that under conditions of steady operation in which the generator supplies an accurately balanced three-phase load and if undesirable harmonic magneto-motive forces in the stator winding are neglected, then the rotor winding of the machine is not subjected to a time-varying magnetic flux. In practice, however, the operation of such machines involves their supplying power to loads which are rarely, or never, perfectly balanced and which for some periods may be substantially unbalanced. Under such circumstances, the three-phase stator windings may carry substantial negative sequence components of current which subject the rotor winding to a timevarying magnetic flux of considerable amplitude. Whilst in conventional machines the phenomenon described has presented design problems which have been adequately resolved in the production of practical generators, the use of a superconducting field winding presents a further problem when such operating conditions are met since practical superconducting materials exhibit an undesirably high power loss when subjected to time-varying magnetic flux. This loss is known in the art as A. In accordance with the present invention there is provided a dynamo-electric machine having a stator winding and a rotor winding, one of said windings being a superconducting direct current winding, and the other winding being designed to carry alternating currents which in the operation of the machine will tend to produce a magnetic flux pattern varying with respect to the superconducting winding, wherein an electromagnetic flux screen is disposed between the two windings and is rotationally fixed relative to the superconducting winding, the flux screen being designed to shield the superconducting winding from the said varying flux pattern and thereby prevent A. The flux screen has the further advantage of preventing eddy current loss in any electrically-conductive material present in the region protected by the screen, for example in the structure supporting the superconducting winding. Preferably the rotor winding is the superconductingdirect current winding and forms a field winding for the machine and the screen forms part of the rotor of the machine and surrounds the superconducting winding. In a preferred construction to be described in more detail below the screen takes the form of a hollow cylinder carried by an outer part of the rotor and spaced from an inner part of the rotor which carries the superconducting winding. The superconducting winding is located in the surface of the inner rotor part and is held in position by sleeves. A sealed vacuum space is formed between the inner and outer parts of the rotor and a thermal radiation shield is located in the vacuum space. In this construction the screen is non-superconducting material and operates substantially at ambient temperature. The screen is carried by the outer rotor part which bounds the vacuum space which provides thermal insulation for the superconducting winding carried by the inner rotor part. The separation of the rotor into two parts has the further advantage that whereas the outer part can be of sufficiently strong and heavy construction to withstand the mechanical forces to which it is subjected by the varying magnetic fields, the inner part can be of relatively thin construction to minimize the inflow of heat to the superconducting winding. In an alternative construction the screen includes superconducting material and in this case can be carried directly on the outer surface of the rotor in thermal contact with the superconducting winding to ensure the cooling of the screen to superconducting. The superconducting screen should be surrounded by a vacuum enclosure which also surrounds the superconducting winding. In either of the constructions described the superconducting winding can be located in the outer surface of its supporting body and held in place by sleeves or disposed within a hollow supporting body. The superconducting screen can consist of superconducting wire or strip applied to a support. The wire or strip can be composed of niobium titanium, niobium-zirconium alloy or niobium-tin intermetallic compounds and should be stabilized and protected thermally against electrical heating caused by currents flowing therein. In order that the invention may be more clearly understood it will now be further described with reference to the accompanying drawings, in which: Referring first to FIG. I of the drawings, this shows a longitudinal section of an A. The generator comprises a rotor whose inner part 11 supports a superconducting rotor field winding 12 and a stator 13 supporting a non-superconducting winding The winding 14 is a multi-phase A. The inner part II of the rotor comprises a support cylinder Ila of non-magnetic material such as stainless steel, titanium, or material reinforced with carbon fibers, and two hollow conical transition members llb one at each end of the support cylinder. The members llb join the support cylinder to rotor stub shafts 15 which are supported in bearings The rotor winding 12 is cooled by means of a cooling system represented schematically as comprising cooling passages 17 associated with the winding support cylinder 11a and supplied with cryogenic fluid by a refrigeration unit 18 mounted within the support cylinder 11a. The supply of cryogenic fluid to the refrigeration unit 18 is by way of a conduit 19 which enters through a coaxial passage 20 in one of the stub shafts The rotor winding 12 is wound in slots in the outer surface of the support cylinder Ila and is retained in the slots by means of retaining sleeves 21 of non-magnetic material such as stainless steel or aluminum. The support cylinder lla must be capable of withstanding high stress at low temperatures and can, for example, be of stainless steel or titanium alloy. Surrounding but spaced from the superconducting rotor winding 12 and disposed between the rotor winding 12 and the stator winding 14 there is a hollow cylindrical screen 22 of high-conductivity metal, such as aluminum. The screen 22 is strengthened in the radial direction by an outer wall 23 of higher strength material such as titanium alloy and the doublewalled structure composed of the screen 22 and the outer wall 23 is supported by hollow end cones The outer wall 23 is formed of a plurality of rings which are shrink-fitted onto the screen 22 and the cones 24 are bolted to the ends of the screen. The outer ends of the cones 24 are integral with sleeves 25 which are mounted in the bearings 16 and within which the stub shafts I of the inner part of the rotor are located. As shown at the left-hand side of FIG. At each end of the rotor seals not shown are provided between the inner and outer members of the rotor to seal off the space 27 between these parts. At least one of the seals is of bellows type to allow for differential thermal expansion in the two parts. The space 27 is evacuated and a thermal radiation shield 28 is mounted within this space to reduce the inflow of heat to the superconducting winding It is not essential that the screen 22 should be of material of high conductivity and it may be constructed, for example, of aluminum alloys, copper, stainless steels, or titanium alloys, or a combination of these materials. Alternative materials for the outer wall 23 are synthetic plastics materials reinforced with glass fibers or carbon fibers. Whereas in the embodiment of FIGS. I and 2 the conductors of the winding 12 are embedded in the outer surface of the support cylinder Ila and retained by the sleeve 21, as clearly seen in the cross-section of FIG. In each case the cross-section of the conductors varies around the periphery of the rotor to give a sinusoidal flux distribution. Referring now to FIGS. The generator has a structure similar in some respects to the generator of FIGS. As in the embodiment of FIGS. I to 3 the rotor comprises a support cylinder Ila of non-magnetic material such as stainless steel, titanium, or reinforced synthetic resin, and two hollow conical transition members lIb, one at each end of the rotor. The transition members 11b connect the support cylinder 11a to stub shafts 15 which are carried in bearings The rotor carries the superconducting winding 12 which is disposed within the support cylinder 11a. The stator 13 carries an A. Surrounding the support cylinder Ila and transition members is the radiation shield 28 which is in spaced relation to the support cylinder and transition members except at the ends where it comes into contact with the transition members. Surrounding but spaced from the radiation shield 28 is an outer casing The shield 28 is preferably of high thermal conductivity material to facilitate cooling and could, for example, be of aluminum alloy. The casing 29 may be welded to the stub shaft I5 at each end of the rotor. The spaces 30 and 31 between the support cylinder Ila and the radiation shield 28 and between the radiation shield and the casing 29 respectively are under vacuum or at low pressure to reduce heat inflow. Material of low thermal conductivity such as aluminized mylar R. The rotor winding 12 of superconducting material is supported on the inside of the cylinder Ila as shown in FIG. The stator winding 14 is of non-superconducting material and can be of conventional form e. Again the stator winding has not been shown in detail for the sake of clarity. The diameter of the individual wires in the stator winding must be kept small and in a typical case would be of the order of lmm. The outer casing 13 of the stator is spaced from the winding 14 and must act as a magnetic shield for the machine because of the high magnetic fields present. One way of achieving this, is for the casing to be made of laminated magnetic material such as iron or mild steel. Alternatively a separate magnetic shield may be located between the casing and the stator wind? To cool the superconducting winding l2 a cryogenic fluid such as supercritical helium gas is fed through an inlet 32 in the end of the stub shaft 15 at the right-hand end of the machine and passes by way of ducting 33, extending through the passage 20, to the winding The cryogenic fluid leaves the rotor again through an outlet 34 in the stub shaft Depending on the size of the machine, it may be necessary to carry out the final stage of refrigeration inside the rotor itself to reduce the cryogenic fluid to the temperature necessary to maintain the winding 12 in a superconducting state, in which case, a small refrigerating unit could be incorporated in the space within the rotor in addition to the main refrigerator located outside the machine. Alternatively, the whole or the major portion of the refrigeration cycle may be carried out inside the rotor. In the case where the whole of the cycle is carried out inside the rotor the cryogenic fluid would be supplied to the rotor at normal temperatures and several atmospheres pressure, typically 7 ata, and returned from the rotor at near normal temperatures and pressures, typically 1. Excitation current is fed to the rotor winding 12 through slip rings 35 or the stub-shaft l5 and these slip rings operate at normal temperatures. An electromagnetic flux screen 36 is positioned in the airgap between the rotor winding 12 and the stator winding 14 and is carried by the rotor so that it rotates therewith. The screen 36 takes the form of a layer of stabilized superconducting wire or strip wound on to the radially outer surface of the support cylinder Ila. The screen may also extend over the surface of conical transition members Ilb. The superconducting wire or strip may be of niobium-titanium or niobium-zirconium alloy, or of niobium-tin inter-metallic compound. This wire or strip is stabilized and protected thermally against the electrical heating due to currents passing therethrough by associating the superconducting material with a highly thermally conducting, but non-superconducting material, such as copper, which either forms a substrate upon which the superconducting material is carried or a matrix through which filaments of superconducting material pass. Where strip material having e. Where strip or wire material having filaments of superconducting material within a matrix of copper or other suitable material is used, copper may be removed to present the superconducting material at the surface of the strip or wire, the screen again being formed so that the matrix lies in the shielded region. The sectional views of FIGS. The radially outer surface layers of the composite envelope are removed to expose superconducting filaments. It will be appreciated that these filaments are located more adjacent the source of A. The removal of the matrix material may be effected subsequent to the formation of the screen. If a strip-form screen is used, it should be wound over the rotor support cylinder 11a in such a direction as to minimize A. One way of winding includes the provision of strips extending longitudinally over the support cylinder, with one or more circumferential turns of strip at either end of the support cylinder. What is claimed is: A dynamo-electric machine having a stator winding and a rotor winding, said rotor winding being a superconducting direct current winding, and said stator winding being designed to carry alternating currents which in the operation of the machine will tend to produce a magnetic flux pattern varying with respect to said superconducting winding, wherein the rotor structure of the machine includes an electromagnetic flux screen disposed between the two windings and which rotates with said superconducting winding but is fixed relative to said superconducting winding, said flux screen shielding said superconducting winding from the said varying flux pattern and thereby preventing A. A dynamo-electric machine as claimed in claim 1 in which the screen is spaced from the superconducting winding and the space is evacuated to provide heat insulation for the superconducting winding. A dynamo-electric machine as claimed in claim 2 having a radiation shield disposed in the evacuated space and spaced from the screen and from the superconducting winding. A dynamo-electric machine as claimed in claim 1 in which the rotor comprises an inner part carrying the superconducting winding and an outer part carrying the screen, the two parts being supported coaxially and locked against relative rotation. A dynamo-electric machine as claimed in claim 4 in which the outer rotor part has at each end a sleeve shaft supported in a bearing and the inner part has a central section carrying the superconducting winding and end sections of hollow frusto-conical form joining the central section to stub shafts mounted within and coupled for rotation with the sleeve shafts of the outer rotor part. A dynamo-electric machine as claimed in claim 5 in which the outer part is spaced from the inner part throughout the length of the central and end sections of the inner part, the sleeve shafts of the outer part are sealed to the stub shafts of the inner part and the space between the inner and outer parts is evacuated. A dynamo-electric machine as claimed in claim 6 having a thermal radiation shield disposed in the said vacuum space. A dynamo-electric machine as claimed in claim 4 in which the screen comprises a cylindrical wall of metal of high electrical conductivity and a cylindrical supporting wall of higher mechanical strength closely surrounds the screen wall. A dynamo-electric machine as claimed in claim 9 in which the supporting wall is composed of a plurality of elemental rings. A dynamo-electric machine as claimed in claim 1 in which the rotor comprises a supporting body with the superconducting winding located in the radially outer surface of the supporting body. A dynamo-electric machine as claimed in claim 11 having winding retaining sleeves encircling the supporting body. A dynamo-electric machine as claimed in claim 1 in which the rotor comprises a hollow supporting body within which the superconducting winding is mounted.

Chapter 3 : AC Loss in Fully Superconducting Electric Machines â€“ Grainger CEME

A superconducting magnet is an electromagnet made from coils of superconducting wire. They must be cooled to cryogenic temperatures during operation. In its superconducting state the wire has no electrical resistance and therefore can conduct much larger electric currents than ordinary wire, creating intense magnetic fields.

Cooling[edit] During operation, the magnet windings must be cooled below their critical temperature , the temperature at which the winding material changes from the normal resistive state and becomes a superconductor. Two types of cooling regimes are commonly used to maintain magnet windings at temperatures sufficient to maintain superconductivity: Liquid cooled[edit] Liquid helium is used as a coolant for most superconductive windings, even those with critical temperatures far above its boiling point of 4. This is because the lower the temperature, the better superconductive windings workâ€"the higher the currents and magnetic fields they can stand without returning to their nonsuperconductive state. The magnet and coolant are contained in a thermally insulated container dewar called a cryostat. To keep the helium from boiling away, the cryostat is usually constructed with an outer jacket containing significantly cheaper liquid nitrogen at 77 K. Alternatively, a thermal shield made of conductive material and maintained in 40 K K temperature range, cooled by conductive connections to the cryocooler cold head, is placed around the helium-filled vessel to keep the heat input to the latter at acceptable level. One of the goals of the search for high temperature superconductors is to build magnets that can be cooled by liquid nitrogen alone. At temperatures above about 20 K cooling can be achieved without boiling off cryogenic liquids. In general two types of mechanical cryocoolers are employed which have sufficient cooling power to maintain magnets below their critical temperature. The Gifford-McMahon Cryocooler has been commercially available since the s and has found widespread application. The G-M regenerator cycle in a cryocooler operates using a piston type displacer and heat exchanger. Alternatively, marked the first commercial application using a pulse tube cryocooler. This design of cryocooler has become increasingly common due to low vibration and long service interval as pulse tube designs utilize an acoustic process in lieu of mechanical displacement. In use, the first stage is used primarily for ancillary cooling of the cryostat with the second stage used primarily for cooling the magnet. Materials[edit] The maximal magnetic field achievable in a superconducting magnet is limited by the field at which the winding material ceases to be superconducting, its "critical field", Hc, which for type-II superconductors is its upper critical field. Another limiting factor is the "critical current", Ic, at which the winding material also ceases to be superconducting. Advances in magnets have focused on creating better winding materials. The superconducting portions of most current magnets are composed of niobium-titanium. This material has critical temperature of 10 kelvins and can superconduct at up to about 15 teslas. More expensive magnets can be made of niobium-tin Nb3Sn. These have a Tc of 18 K. When operating at 4. Unfortunately, it is far more difficult to make the required filaments from this material. This is why sometimes a combination of Nb3Sn for the high-field sections and NbTi for the lower-field sections is used. Vanadium-gallium is another material used for the high-field inserts. The wire or tape itself may be made of tiny filaments about 20 micrometers thick of superconductor in a copper matrix. The copper is needed to add mechanical stability, and to provide a low resistance path for the large currents in case the temperature rises above Tc or the current rises above Ic and superconductivity is lost. These filaments need to be this small because in this type of superconductor the current only flows skin-deep. See Skin effect The coil must be carefully designed to withstand or counteract magnetic pressure and Lorentz forces that could otherwise cause wire fracture or crushing of insulation between adjacent turns. Operation[edit] Seven Tesla horizontal bore superconducting magnet, part of a mass spectrometer. The magnet itself is inside the cylindrical cryostat. Power supply[edit] The current to the coil windings is provided by a high current, very low voltage DC power supply , since in steady state the only voltage across the magnet is due to the resistance of the feeder wires. Any change to the current through the magnet must be done very slowly, first because electrically the magnet is a large inductor and an abrupt current change will result in a large voltage spike across the windings, and more importantly because fast changes in current can cause eddy currents and mechanical stresses in the windings that can precipitate a quench see below. So the power supply is usually microprocessor-controlled, programmed to accomplish current changes gradually, in gentle ramps. It usually takes several minutes to energize or de-energize a laboratory-sized magnet. Persistent mode[edit] An alternate operating mode used by most superconducting magnets is to short-circuit the windings with a piece of superconductor once the magnet has been energized. The windings become a closed superconducting loop, the power supply can be turned off, and persistent currents will flow for months, preserving the magnetic field. The advantage of this persistent mode is that stability of the magnetic field is better than is achievable with the best power supplies, and no energy is needed to power the windings. Since the winding itself has no resistance, no current flows through the switch wire. To go to persistent mode, the supply current is adjusted until the desired magnetic field is obtained, then the heater is turned off. The persistent switch cools to its superconducting temperature, short-circuiting the windings. Then the power supply can be turned off.

Chapter 4 : Super Conducting Generators

The 10 MW superconducting generator concept will be experimentally validated with a small-scale magnetic machine, which has innovative components such as superconducting coils, modular cryostats and cooling systems, and will have similar size and characteristics as the 10 MW generator.

The superconducting rotating machine includes a stator assembly, a rotor assembly configured to rotate within the stator assembly and having at least one HTS superconducting winding assembly which, in operation, generates a magnetic flux linking the rotor assembly to the stator assembly, and a refrigeration system for cooling the at least one superconducting winding. The superconducting rotating has a gap shear characteristic greater than 10 psi. The use of superconducting windings in these machines has resulted in a significant increase in the field magnetomotive forces generated by the windings and increased flux and power densities of the machines. The field windings were cooled with liquid helium from a stationary liquifier. The liquid helium was transferred into the rotor of the machine and then vaporized to use both the latent and sensable heat of the fluid to cool the windings. This approach proved to be viable for only very large synchronous motors and generators. In effect, the construction provides a superconducting rotating machine having an increased power density characteristic. The superconducting rotating machine is of the type having a stator assembly and a rotor assembly which rotates within the stator assembly and is spaced from the stator assembly by a gap. For example, in one embodiment, the superconducting rotating machine e. Gap shear stress is an effective measure of the torque density of a machine. It relates machine performance to the surface area in the gap between the rotor assembly and stator assembly. In particular, gap shear stress is numerically equivalent to the machine torque divided by the area and radius of the gap. If the rotor experiences a surface shear stress equal to the gap shear stress, a torque equal to the design torque would be transmitted to the shaft of the machine. Embodiments of this aspect of the invention may include one or more of the following features. The superconducting rotating machine has a specific power in a range between 1. The superconducting rotating machine has a power density in a range between 1. It is appreciated that as the speed of the rotating machine becomes larger or smaller, the specific power and power density will become proportionally larger or smaller as well. The superconducting winding assembly includes a superconducting coil having a superconductor tape wound about and disposed along an axis of the winding assembly to provide a plurality of concentric turns defining an opening. The opening has a dimension which gradually decreases, in the direction along the axis, and from a first end to a second end of the winding assembly. Each turn of the superconductor tape has a broad surface maintained substantially parallel to the axis of the winding assembly. The decreasing dimension opening defined by the winding configuration of the coil provides a coil having a tapered profile. The advantages of a tapered superconducting coil having this arrangement are numerous. For example, the tapered superconducting coil is well-suited for use in applications where the coil is to be positioned in annularly-shaped volumes, such as those commonly found in rotating electric machines. In general, the tapered arrangement eliminates stepped profiles, common with other stacked arrangements. In particular, the tapered superconducting coil requires relatively fewer stacked individual coils to fill annularly-shaped volumes. This is in contrast to other superconducting coil assemblies, which require stacking of many more thin, individual coils to fill an annularly-shaped volume. Moreover, reducing the number of individual coils, in turn, reduces the number of electrical connections between the individual coils, thereby increasing the overall performance and reliability of a coil assembly using tapered coils. In addition, the superconductor tape of the present invention is wound with its broad surface maintained substantially parallel to the axis of the coil as well as to adjacent turns. This feature is particularly advantageous when the tape is formed of less flexible, brittle materials, such as ceramic-based high temperature superconducting materials. Furthermore, the tapered configuration provides better critical current Ic retention characteristics and allows for better coil grading. In certain embodiments, the superconductor tape is wound in a racetrack shape defining a pair of opposing arcuate end sections and a pair of opposing substantially straight side sections. The superconductor tape includes a multi-filament composite superconductor having individual superconducting filaments which extend the length of the multi-filament composite conductor and are surrounded by a matrix-forming material. The superconductor tape includes an anisotropic high temperature superconductor, for example, Bi2Sr3Ca2Cu3O. Alternatively, the anisotropic high temperature superconductor is a member of the rare-earth-copper-oxide family. The rotor assembly includes a cylindrical support member for supporting the superconducting winding assembly. The cylindrical support member is formed of a high strength, low thermal conductivity composite material, for example, a G phenolic or woven-glass epoxy. Thus, the low thermal conductivity composite material thermally isolates the cryogenically-cooled superconducting coils from the outside ambient temperature world. The rotating machine further includes an axially compliant member for radially supporting an end of the cylindrical support member. The refrigeration system includes a cryocooler located in a stationary reference frame, and a closed circulation system external to the cryocooler interfacing the stationary reference frame with a rotating reference frame in which the superconductor winding assembly is located. Among other advantages, the refrigeration system of the invention permits the cryocooler to remain stationary while eliminating the need for an extensive sealing system needed to flow coolant through an open circulation system. The closed circulation system includes a heat transfer assembly located in the rotating reference frame and a heat transfer gap defined between the cryocooler and the heat transfer assembly. The heat transfer assembly transfers heat from the superconducting winding assembly to the heat transfer gap. Thus, the heat transfer gap provides an efficient structure for transferring heat from the superconductor winding to the cryocooler. In one embodiment, the rotating heat transfer assembly includes a heat pipe having a first fluid path for directing a flow of liquid coolant from a cold end to a warm end of the heat transfer assembly, and a second fluid path for directing a flow of gas coolant from the warm end to the cold end of the heat transfer assembly. The superconducting rotating machine further includes a warm end conduction block and a cold end conduction block, which define the warm end and cold end of the heat transfer assembly, respectively. The warm end conduction block and cold end conduction block are both mounted to the heat pipe. The warm end conduction block is further mounted to the superconducting winding assembly. The cold end conduction block includes first fins and the cryocooler includes second fins rotatable with respect to the second fins and intermeshed with the first fins. The space between the intermeshed fins define the heat transfer gap. The rotor assembly includes induction structure for carrying current at levels sufficient to allow a transient induction mode of operation. Because induced currents are generated in the rotor assembly in the induction mode, a structure for supporting these currents is necessary. Further, the induction structure is configured to allow the superconducting motor to generate a peak torque breakdown torque which is at least twice the rated torque in the induction mode of operation. In one embodiment, at least a portion of the induction structure is spaced from the at least one superconducting winding by a thermal isolation vacuum region. That is, a portion of the induction structure is in the warm region of the rotor assembly, such as an electromagnetic shield member. The electromagnetic shield member includes a conductive, non-magnetic material e. The induction structure can also include a cryostat positioned between the thermal isolation vacuum region and the electromagnetic shield member. Thus, the cryostat not only serves to cool the superconducting windings of the rotor assembly, but also serves to support induced currents when the motor operates in the induction mode. The cold cylindrical support member which supports the at least one superconducting winding can also serve as part of the induction structure. In certain embodiments, the superconducting electric motor also includes an adjustable speed drive for providing an adjustable frequency electrical signal to the stator assembly. The superconducting rotating machine also includes an exciter, having a radially laminated rotatable disk including AC windings, and a stationary disk also including AC windings. The stationary disk is axially spaced from the radially laminated, rotating disk to form a gap therebetween. In essence, the rotating disk and stationary disks and coils together provide a transformer to induce AC voltage and current in the rotating coil. The exciter further includes a rectifier coupled to the AC windings in the rotor and having an output coupled to the DC windings. The superconducting rotating machine further includes a frame for supporting the stationary disk, rectifier and current regulator. The stator assembly includes a cylindrical support tube having a bore extending along a longitudinal axis of the support tube and a single-layer winding wound along the axis of the support tube. The cylindrical support tube is formed of an electrically resistive composite material including, for example, glass and epoxy. The stator assembly further includes a cooling member e. The cooling member includes helically wound tubes, a first one of the helically wound tubes disposed between the outer surface of the support tube and an inner surface of single layer winding. A second one of the helically wound tubes is thermally coupled to an outer surface of one of the single layer windings. The windings of the stator are radially spaced from a longitudinal axis of the stator and are circumferentially spaced from each other, with alternate ones of the windings having end regions which extend radially away from the axis. The cooling member further includes an end region helically wound tube that is thermally coupled to the radially-extending end regions. The helically-wound tubes are formed of a non-magnetic material. The stator assembly includes an outer banded member disposed around the superconducting winding and formed of a high permeability material. In one embodiment, the outer banded material is a steel wire wound around the at least one superconducting winding. This banded member is wound under tension to load the stator assembly against the stator bore tube. The stator assembly includes an outer housing for enclosing the cylindrical support tube, the single-layer winding, and the outer banded material. The stator assembly also includes an encapsulating material e. Other advantages and features of the invention will become apparent from the following description and the claims. As will be described in greater detail below, each of these components and assemblies have features which contribute toward both increasing the overall performance, as well as reducing the overall size of motor In particular, superconducting synchronous motor 10 has been shown to have a greatly improved gap shear stress characteristic in a range between 30 psi and psi. For example, for a superconducting synchronous motor rotating at rpm, the gap shear stress around 45 psi and have a power density in a range between 1. Such a motor can have a specific power in a range between 1. In this embodiment, cryostat 25 is approximately 42 inches in length and has a diameter of about 19 inches. Disposed within cryostat 25 is a cold support member 20 fabricated from a high-strength and ductile material e. Cold support member 20 includes an outer surface upon which four HTS superconducting coil assemblies 26 are mounted and epoxy impregnated. Cold support member 20 also includes an inner bore 23 within which a heat transfer assembly 24 is positioned. As will be described in detail below, heat transfer assembly 24 is used to conduct heat transfer to and generated by coil assemblies 26 to cryocooler 14 where the heat can be dissipated. In particular embodiments, cryostat 25 includes an outer cylindrical wall which, for reasons discussed below, serves as an electromagnetic shield. Rotor assembly 12 also includes a torque tube 22 for transferring the rotational forces of rotor assembly 12 to shaft Torque tube 22 is formed of a high strength, low thermal conductivity composite material, such as a G phenolic or woven-glass epoxy. In one embodiment, end rings not shown with circular grooves are bolted to opposing surfaces of the end bell 27 and cold support member Torque tube 22 is then adhesively attached e. The opposite, non-driven, end of the rotor assembly 12, includes a disk-shaped support plate 51 to support and center cold support member 20 within rotor assembly Support plate 51, which may be a solid member or have a spoked arrangement, is formed of a composite material, such as that used for torque tube The material is selected to be compliant in the axial direction and relatively stiff in the radial direction. For reasons discussed below, bearings 52 are positioned between cryostat 25 and cold support member 20 of rotor assembly 12 so that the coldhead remains stationary when the cryostat rotates. As shown more particularly in FIG. As will be described immediately below, superconducting coils 26 have a tapered construction which, among other advantages, allows the coils to conform to the outer surface of cold support member 20, thereby providing a more compact and integrated structure. As will be described below in conjunction with one fabrication approach, each coil of coil assembly 26 is wound about an axis 32 of the coil assembly from a continuous length or series of lengths of superconductor tape, thereby forming a number of windings or turns 34 of the coil see FIG.

Chapter 5 : Focus on Superconducting Rotating Machines - Superconductor Science and Technology - IOP

Some of the large scale devices and systems such as superconducting generators, motors, power transmission, large magnets, high speed ground transportation and industrial processing clearly speak directly to improved efficiencies of generation and utilization of energy.

Lack of DC resistance in super conductors contributes much to its greater efficiency. In a super conducting machine very high magnetic field is produced otherwise impossible in a conventional machine and is the main characteristic of super conductors. High magnetic field results in lesser motor volume and ultimately more power density. Cryogenics are highly used in super conductors to maintain a specific temperature which is less than the room temperature upto hundred degrees, super conducting transition temperature Tc , at which the superconductors reach the zero resistance. Superconducting AC synchronous electric machines which include alternators and synchronous motors have become more common nowadays than before. The rotor or the rotating member of the machines has an electromagnetic field winding on itself for direct current which employs superconductors. The stationary member or stator of the machines however utilizes the same old conductors constituting of copper conductors which undergo normal conduction. An attempt to reduce the resistive loss of the stator conductors they are cooled but the loss is not permanently removed. Principle The working principle previously used in old electric generators which included synchronous permanent magnet generators or motors and the induction machines is also being used nowadays in the superconducting generators. The only difference between the two is the windings of the superconducting generator. These windings are able to support a more powerful magnetic field as compared to that of conventional generators. Using this coil in other various rotating machines will also improve their efficiency; make them more compact and eco-friendly. The superconducting generators have a coil cover for the coil to support it when under centrifugal force and a damper for protection against high frequency magnetic field. A cooling chamber to maintain ultra-low temperature is also present along with a rotary seal which is a rotary room to provide the cryogenic coolant from. The core is made of non-magnetic stator core plus a stator coil made of copper. The current is applied to the super conducting coil, made of superconducting material, through the slip ring. Three insulations are also present, first is the shield to protect the release of magnetic field to the surrounding, second is the vacuum jacket which forms the vacuum insulation layer and last is the torque tube which is the insulating structure. The magnetic resonance imaging techs in medicine and super-colliders or particle physics analysis done in research are a few beneficial outcomes of this technology which clearly are upgrading different areas of our society. The size, cost and efficiency of the production and usage of electricity will also be greatly affected by super conductors. The results obtained from the comparison show that the conventional technology costs cheaper when dealing with low power levels. This is so because the cost of copper cable used in the conventional machines is much less than that of the superconducting cable. The cost of superconducting generators also increases because of the use of cryogenics to cool the machine up to a specific temperature while the cooling cost of old generators is much less. The case is reverse when talking about high power levels. Super conductors become more cost effective at this point because the power per unit of increase becomes more favorable. The break-even point for both generators comes out to be between the ranges of MWatt. It is expected in future that further research and improvement in superconductor production tech and the cooling method through cryogenics will decrease the cost a great deal. The cost utilized for superconducting power generation will also decrease. The break-even point mentioned earlier will also reduce. If it decreases up to 2 MWatt, competition for superconducting generators will also decrease. Positive and negative points of superconducting electric machines First a few of its positive points as compared to conventional tech are being highlighted. The rotor electromagnet is subject to less resistive loss. The size and weight per power capacity is also decreased regardless of the cooling equipment. Some negative points of this machine are as follows: The cooling system has greater cost, size, weight and also complications. Once the superconductors exit their superconductive state the generator at once stops working. Chances for instability of the rotor speed are also greater. Lack of the characteristic damping usually found in conventional generators may cause the synchronous speed of the superconductor generator to fluctuate. Either the motor bearings should be separate from the cold rotor or it should be able to tolerate the decreased temperature. To operate a synchronous machine such as the superconductor generator practically, it is important to have access to electronic control. This electronic control leads to harmonic loss in the super cooled rotor of the generator to great extent. The coils used in the superconducting generators or motors have electric resistance to a zero unlike that of the copper coil used in old generators leading to less loss of electrical resistance and so greater efficiency. As the electrical resistance loss is decreased so the heat produced by the machine is also less. This reduces the size and the quantity of the material used for production. Advanced heat and electric insulation along with cryogenic refrigeration technology is required by the superconducting generators plus motors to maintain the low temperature requirement and the functionality of the superconducting coil. Leading future market is expected from superconducting generators and motors because of its characteristic high energy efficiency and better resource utilization ability.

Chapter 6 : Superconducting electric machine - Wikipedia

A superconducting electrical machine includes a rotor and a stator. The rotor includes rotor windings configured to superconduct when cooled in a rotor cryostat to a temperature no greater than a rotor superconducting temperature.

A superconducting rotary electrical machine, comprising: A superconducting rotary electrical machine according to claim 1, in which the cooling system is adapted to change between the first and second modes by changing the total flow rate of the coolant. A superconducting rotary electrical machine according to claim 2, in which the outer rotor is a vacuum chamber configured to be under vacuum during operation of the cooling system in the second mode. A superconducting rotary electrical machine as claimed in claim 1, wherein the inner rotor includes a rotary shaft having a chamber for receiving a flow of coolant in the first mode. A superconducting rotary electrical machine as claimed in claim 3, wherein the outer rotor further comprises a radiation screen which partitions so as to provide an inner region and an outer region, the inner and outer regions providing fluid paths for a flow of coolant. A superconducting rotary electrical machine as claimed in claim 5 wherein the inner region and outer region are in fluid communication via an opening in the radiation screen. A superconducting rotary electrical machine as claimed in claim 6, wherein the openings include a cover portion which substantially obstructs the openings from a generally radial direction. A superconducting rotary electrical machine as claimed in claim 7, wherein the covers are integrally formed with the shield. A method of operating a superconducting rotary electrical machine comprising a two-part rotor having an inner part and an outer part, both parts configured to receive a flow of coolant and the inner part including at least one superconducting component requiring cooling for its operation; and, a cooling system configurable to provide coolant to the two-part rotor in a first mode and a second mode, the method comprising: A method according to claim 9, in which the change from the first mode to the second mode is achieved by changing the total flow rate of a coolant. A method according to claim 9, in which the region inside of the outer rotor is evacuated so as to be under vacuum during the second mode. A method according to claim 9 in which the outer rotor includes an inner region and an outer region separated by a radiation screen, the radiation screen providing a flow path for coolant, the method further comprising the steps of: A method according to claim 9, in which the temperature of the coolant differs between the first mode and the second mode. A method according to claim 9, in which, in the first mode, a different or additional coolant is used, relative to that used in the second mode. A method according to claim 9, in which the said predetermined temperature is higher than a steady-state temperature of the component during operation of the machine. This invention relates to superconducting machines, and more particularly to such a machine having a cooling system and to a method of operating such a machine. Superconducting electrical machines require a cryogenic cooling system to keep at least one of their major components i. The cryogenic system is usually sized to remove the steady-state heat load i. Superconducting electrical machines of large power and low speed e. In consequence the superconducting machine takes a long time to cool down from ambient to the temperature required for the superconducting state. This cool-down period is of the order of days in machines rated as above. Compared to a conventional i. This arises because the superconducting electrical machine cannot be used until its relevant major component has been cooled to the required cryogenic temperature, but it is uneconomic to keep it cooled permanently. Simple analysis shows that the time to cool down a body of mass M, initially at temperature Thot and subsequently at temperature T after time t, is given by equation 1: Similarly, the cool-down period is reduced if the temperature of the coolant Tcool is reduced. The above formula can be recast in dimensionless form as: However, a colder coolant is obviously more expensive. In general terms, for maximum cooling it is desirable i to increase the body area A which is exposed to the coolant, ii to increase the heat transfer coefficient h from the body to the coolant, and iii to reduce the coolant temperature Tcool , but all these measures are likely to involve increased expense. According to the invention there is provided a method and apparatus as provided by the appended claims. In one aspect there is a provided a method of operating a superconducting rotary electrical machine comprising a two-part rotor having an inner part and an outer part, both parts configured to receive a flow of coolant and the inner part including at least one superconducting component 15 requiring cooling for its operation; and, a cooling system configurable to provide coolant to the two-part rotor in a first mode and a second mode, the method comprising: The change from the first mode to the second mode may be achieved by changing the total flow rate of a coolant. The outer rotor may be evacuated so as to be under vacuum during the second mode. The outer rotor may include an inner region and an outer region separated by a radiation screen, the radiation screen providing flow paths for coolant, the method further comprising the steps of: The temperature of the coolant may differ between the first mode and the second mode. A different or additional coolant may be used in the first mode relative to that used in the second mode. The said predetermined temperature may be higher than a steady-state temperature of the component during operation of the machine. In a second aspect the invention provides a superconducting rotary electrical machine, comprising: The cooling system may be adapted to change between the first and second modes by changing the total flow rate of the coolant. The outer rotor may be a vacuum chamber configured to be under vacuum during operation of the cooling system in the second mode. The inner rotor may include a rotary shaft having a chamber for receiving a flow of coolant in the first mode. The outer rotor may further comprise a radiation screen which partitions so as to provide an inner region and an outer region, the inner and outer regions providing fluid paths for a flow of coolant. The inner region and outer region may be in fluid communication via an opening in the radiation screen. The openings may include a cover portion which substantially obstructs the openings from a radial direction. The covers may be integrally formed with the shield. In another aspect there is provided a method of operating a machine having a superconducting component requiring cooling for its operation and including a cooling system, the method comprising: The mode of operation of the cooling system can be changed by changing the speed of circulation of the coolant, or changing its temperature, or by circulating the coolant in additional regions during cooling, where it does not circulate during operation; a further option is to use a different or additional coolant for the cool-down phase. Combinations of these possibilities can be used. In one embodiment, the coolant is circulated during cool-down in addition to circulation in the normal operational region in regions that during normal service operation are under vacuum. Another aspect of the present invention provides a machine having a superconducting component requiring cooling for its operation and including a cooling system, in which the cooling system is operable in first and second modes, in which the heat transfer from the superconducting component is higher in the first mode than in the second mode. For example, if the machine is a superconducting motor for a ship or other watercraft, normal service operation is operation of the motor to drive the vessel. For a better understanding of the invention, embodiments will now be explained with reference to the attached drawings, in which: It will be understood, however, that the same principles can be applied to a superconducting stator winding or indeed both, in the case where stator and rotor carry superconducting windings. The inner rotor 13 is driven by, or drives, a shaft 20 mounted on bearings 22, the drive end being indicated as 20a. A superconducting field winding 15 surrounds the inner rotor and is cooled by a cooling system which in the embodiment described is a cryogenic system. The inner rotor carrying the superconducting winding 15 is fed with cryogen along the axis. In order to reduce the ingress of heat to the superconductor, known as heat in-leak, the inner rotor 13 is surrounded by a region 16 which is maintained under vacuum. As a further measure to keep the rotor cold, a cylindrical radiation screen 17 located within the vacuum space surrounds the inner rotor Seals 24 provide a hermetic seal between the outer rotor 11 and the shaft The cryogenic system of the machine is operable in first and second modes, as will be described below FIG. The cryogenic system 40 comprises a cryostat 41 in which a cooler 42 is mounted. Coolant passes to the interior of the inner rotor 13 via a lance It takes a long time to cool such a system from ambient temperature to the very low temperatures required to enable superconducting operation. Examples of such systems will now be described. In one type of embodiment of the invention there are two such cryogenic supplies, and in many cases their circulation path is the same during cool-down as during steady-state operation. Such a novel cryogenic system is shown schematically in FIG. V1 also has a closed position such that no cryogen can flow to the rotor from either supply. The cryogen supply for the steady state is shown at Css, and an additional supply of cryogen used specifically to reduce the cool-down period is shown at Ccd. Note that the pumps to drive the cryogen s around the cooling circuit are not shown. Again, superconducting-rotor types are envisaged, but not exclusively. Cryogen in the cool-down supply Ccd can be either: This amounts to increasing the heat transfer coefficient h of the cryogenâ€”see equation 1; or b a different and colder cryogen than that in Css. In this case only the colder cryogen Ccd is used during cool-down and, being colder than that in Css, it reduces the cool-down period as explained above. In a variant of a there is only one cryogen supply, but the corresponding pump is run at a higher power during cool-down, giving rise to a faster circulation and hence increased heat transfer. In those cases where there are one or more vacuum spaces within the superconducting machine, that are normally maintained in the evacuated state by continuous vacuum pumping, the vacuum can be relaxed during the cool-down period by correct operation of the valves, so as to allow access by the cool-down cryogenic fluid to the designated vacuum space s. This also shortens the cool-down period. A setup of this kind is shown in FIG. This diagram shows a partial section through the system. The region 16, normally under vacuum, comprises an outer region 52 and an inner region 54, which are separated by a radiation screen The regions 52 and 54 communicate with each other through an opening 58 in the radiation screen A return line 47 for cryogen is connected by a branch line 48 to the inner region A vacuum line valve V is shown, on the pump side of the branch line connection, as is a valve V2 on the branch line In the first mode of operation, during cool-down, the vacuum line valve V is closed and, while the cryogen is flowing through the inner rotor, as indicated by arrows, and returning to the cryogen supply via the valve V1 FIG. Cryogen is then drawn into the vacuum spaces 16 under the residual vacuum in them, so providing an enhanced cooling effect on the inner and outer rotors 11, 13 as a whole. The possibility of passing coolant via the branch valve V2 into the vacuum space 16 in the initial cool-down phase exposes more of the surface area of the rotors 11, 13 to the cryogenic coolant and thereby reduces the cool-down period in accordance with equation 1. Here there need only be one supply of cryogen, but two may be used, as shown in FIG. Once cool-down has been achieved, the following actions are then performed: In another embodiment, cool down is achieved using an iron lung approach whereby the vacuum spaces are flooded with coolant and V2 is closed while vacuum pump removes the coolant via valve V. Once a substantial portion of the coolant has been removed, V can be closed and V2 reopened to admit more coolant. This cycle can be repeated until sufficient cool down has been achieved. The iron lung approach would be preferable if minimising the number of pipes connecting with the vacuum space is desirable to simplify sealing arrangements. In some circumstances, the rotors 11, 13 are not cooled down in the first mode of operation completely to the desired target temperature T. This is because heat may be transferred to the region of the superconducting winding 15 by conduction and convection through the cool-down cryogen occupying the spaces 16 in which a vacuum is established during steady-state operation. Hence, the point at which the vacuum pump starts to re-establish a vacuum in the regions 16 is at a temperature Thi which is slightly higher than the target temperature T. The final cool-down to temperature T is then achieved using the steady-state cryogen in Css. The temperature Thi will be chosen so as to optimise the cooling process, taking account of: Heat transfer is increased by increasing the heat transfer coefficient to the cryogen from the body of the electrical machine or, in the case of the flooding of additional regions of the machine, by increasing the area of surface exposed to the cryogen. Embodiments of the invention can thus make maximum use of the existing cooling and electrical machine systems with minimal additional equipment. The present invention can be applied to superconducting machines with a superconducting rotor, or where both the stator and the rotor carry superconducting windings. The process described with reference to FIG.

Chapter 7 : Machine Shop Department | Applied Physics and Superconducting Technology Division

The paper contains a review of recent advancements in high temperature superconducting (HTS) machines. With the discovery of HTS cuprate-perovskite ceramic materials in , the United States.

History[edit] DC homopolar machines are among the oldest electric machines. Michael Faraday made one in In the General Atomics company received a contract for the creation of a large low speed superconducting homopolar motor for ship propulsion. However, homopolar machines have not been practical for most applications. In the past, experimental AC synchronous superconducting machines were made with rotors using low-temperature metal superconductors that exhibit superconductivity when cooled with liquid helium. These worked, however the high cost of liquid helium cooling made them too expensive for most applications. More recently AC synchronous superconducting machines have been made with ceramic rotor conductors that exhibit high-temperature superconductivity. These have liquid nitrogen cooled ceramic superconductors in their rotors. The ceramic superconductors are also called high-temperature or liquid-nitrogen-temperature superconductors. Because liquid nitrogen is relatively inexpensive and easier to handle, there is a greater interest in the ceramic superconductor machines than the liquid helium cooled metal superconductor machines. Present interest[edit] Present interest in AC synchronous ceramic superconducting machines is in larger machines like the generators used in utility and ship power plants and the motors used in ship propulsion. American Superconductor and Northrup Grumman created and demonstrated a Because they are light-weight and therefore offer lower tower and construction costs they are seen as a promising generator technology for wind turbines. With super conducting generators the weight and volume of generators could be reduced compared to direct drive synchronous generators, which could lead to lower costs of the whole turbine. Reduced resistive losses but only in the rotor electromagnet. Reduced size and weight per power capacity without considering the refrigeration equipment. There are also the following disadvantages: The cost, size, weight, and complications of the cooling system. A sudden decrease or elimination of motor or generator action if the superconductors leave their superconductive state. A greater tendency for rotor speed instability. A superconducting rotor does not have the inherent damping of a conventional rotor. Its speed may hunt or oscillate around its synchronous speed. Motor bearings need to be able to withstand cold or need to be insulated from the cold rotor. As a synchronous motor, electronic control is essential for practical operation. Electronic control introduces expensive harmonic loss in the supercooled rotor electromagnet. High-temperature superconductors versus Low-temperature superconductors[edit] High-temperature superconductors HTS become superconducting at more easily obtainable liquid nitrogen temperatures, which is much more economical than liquid helium that is typically used in low-temperature superconductors. HTS are ceramics, and are fragile relative to conventional metal alloy superconductors such as niobium-titanium. Ceramic superconductors cannot be bolted or welded together to form superconducting junctions. Ceramic superconductors must be cast in their final shape when created. This may increase production costs. This could be a problem during transient conditions, as during a sudden load or supply change.

Chapter 8 : SUPERCONDUCTING MACHINES - ROLLS-ROYCE PLC

A superconducting rotating machine has a relatively compact construction while still providing a relatively high output power, thus the superconducting rotating machine has an increased power density characteristic.

Chapter 9 : USB1 - Superconducting rotating machines - Google Patents

Superconducting AC synchronous electric machines which include alternators and synchronous motors have become more common nowadays than before. The rotor or the rotating member of the machines has an electromagnetic field winding on itself for direct current which employs superconductors.