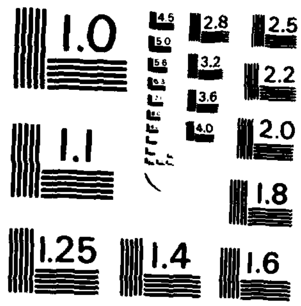
AD-A136 488 THE POSSIBILITIES OF APPLICATION OF SUPERCONDUCTORS IN ELECTRONICS(U) FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OH Y Y KAZOVSKIY ET AL. 05 DEC 83 1/1

UNCLASSIFIED FTD-ID(RS)T-1323-83 F/G 9/5 NL

END
DATE
FILMED
1 84
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

FTD-ID(RS)T-1323-83

FOREIGN TECHNOLOGY DIVISION

THE POSSIBILITIES OF APPLICATION OF SUPERCONDUCTORS IN ELECTRONICS

by

Ye.Ya. Kazovskiy, V.P. Kartsev

84 01 04 047

EDITED TRANSLATION

FTD-ID(RS)T-1323-83 5 December 1983

MICROFICHE NR: FTD-83-C-001478

THE POSSIBILITIES OF APPLICATION OF SUPERCONDUCTORS IN ELECTRONICS

By: Ye.Ya. Kazovskiy, V.P. Kartsev

English pages: 24

Source: Elektronika, Nr. 1, 1964, pp. 22-26

Country of origin: USSR
Translated by: Robert Allen Potts
Requester: FTD/TQTD
Approved for public release; distribution unlimited.

THIS TRANSLATION IS A RENDITION OF THE ORIGINAL FOREIGN TEXT WITHOUT ANY ANALYTICAL OR EDITORIAL COMMENT. STATEMENTS OR THEORIES ADVOCATED OR IMPLIED ARE THOSE OF THE SOURCE AND DO NOT NECESSARILY REFLECT THE POSITION OR OPINION OF THE FOREIGN TECHNOLOGY DIVISION.	PREPARED BY: TRANSLATION DIVISION FOREIGN TECHNOLOGY DIVISION WP.AFB, OHIO.

U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*<u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this translation were extracted from the best quality copy available.

THE POSSIBILITIES OF APPLICATION OF SUPERCONDUCTORS IN ELECTRONICS

Doctor of tech. sciences Ye. Ya. Kazovskiy, engineer V. P. Kartsev

Investigations of the properties of frozen mercury near absolute zero revealed that beginning from some temperature, its electrical resistance drops to a value, which it is impossible to measure even with the aid of the most perfect instruments. It turned out that some other metals, alloys and compounds possess a similar property [1].

The electrical resistance of superconducting compounds is so low in comparison with the resistance of metals ordinarily used as conductors that the latter can be used as electric insulation coatings for superconducting conductors [2].

One more inportant property of superconductors is experimentally established: the electromagnetic field penetrates it only to a depth on the order of 10^{-5} cm; in the surface layer of the same thickness through the superconducting elements pass electric currents. The admissibility of the creation of high current densities in the superconductor and the actual passage of currents only in the surface layer opens the possibility of the use of superconducting printed electrical circuits. This is especially expedient as with decrease of the thickness of superconducting films one of the very important parameters is improved - the critical field, i.e., the amount of the magnetic field intensity, with which the superconductor again acquires its resistance, despite the low temperature.

The critical field of a thin film can exceed the critical field of a massive sample by more than 50 times [4]. In superconducting printed circuits it could be possible to achieve current densities 1000 A/mm², whereas for ordinary conductors this value does not exceed 3-12 A/mm².

The absence of a magnetic field in the thickness of superconductor ("Meissner effect") [1] makes it possible to create a so-called "Mohammed coffin" - a body, being supported in space without support by forces of ejection of the field from superconductor or the superconductor from the field (Fig. 1). Such ideal diamagnetism of some superconductors gave the possibility to create models of bearings without friction. Their lifting force reaches 300 gf/cm², if niobium is used as superconductor [3].

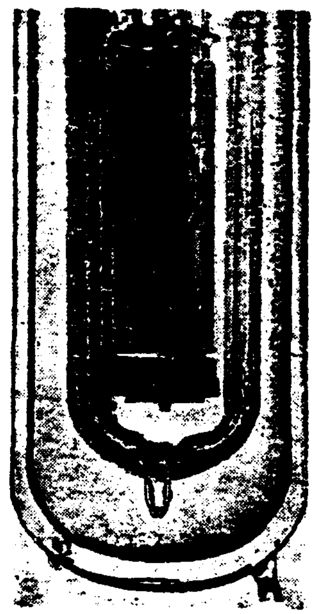


Fig. 1. Test, illustrating the ideal diamagnetism of a superconductor. Cylinder 4.8 kg is secured freely suspended by flow, created by a lower cylinder.

A significant obstacle to the path of use of properties of superconductors is the presence of their critical magnetic field.

The critical fields of the majority of superconductors are small (on the order of hundreds of gauss); current, passing through the superconductor, can cause loss of superconductivity, if the field, created by it, exceeds critical. One of the methods of raising the values of critical field and current is lowering the temperature. However, such a method does not make it possible to significantly increase the critical field even at very low temperatures. Small values of critical field of the majority of superconducting elements for a long time did not give possibilities in practice to use the properties of superconductors.

In recent years new materials, preserving superconductivity at higher magnetic fields and temperatures, have been found (Fig. 2).

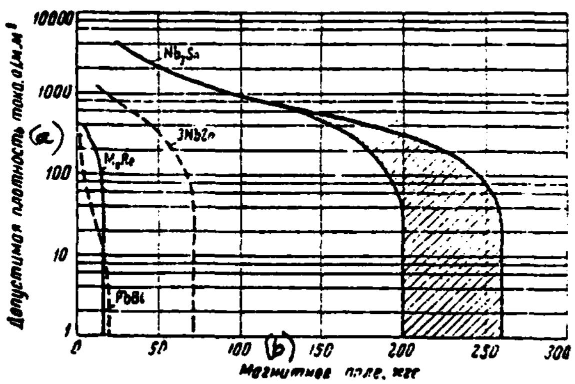


Fig. 2. Curves of critical inductions in the function of allowable current density for some superconductors.

Key: (a) Allowable current density, A/mm². (b) Magnetic field, kG.

In the table are presented parameters of new superconductors. These materials (rigid superconductors) have some differences from ordinary superconductors (for example, their Meissner effect is observed only in very weak fields; current passes through the entire section of conductors, more precise, through a multitude of superconducting fibers, arranged in the thickness of ordinary nonsuperconducting alloy).

(a) Химическое соединение	(b) Критическая температура, °K	(c) Критическое поле, кгс
Nb_3Sn	18,06	183
Nb_3Ga	14,5	—
Nb_3Al	17,5	—
V_3Ga	16,5	350
3NbZr	11	77
2NbTi	9,1	82
PbBi	8,2	16
V_3Si	17	156
M_nRe	12,6	27

Key: (a) Chemical compound. (b) Critical temperature, °K. (c) Critical field, kG.

Let us examine some regions of application of superconducting materials.

Electromagnets with superconductors. The electrical power, expendable for heat losses, depending on the amount of volume, in which this field needs to obtain with the aid of magnetic field intensity and ordinary coils, is determined from equality [5]

$$H = G\left(\frac{W\lambda}{\rho r_1}\right)^{\frac{1}{2}}.$$

where H - magnetic field intensity, Oe; G - coefficient, depending on the shape of coils; ρ - specific electric resistance of material of coil, Ω/cm; λ - space factor of the volume, occupied by coil; r_1 - internal radius of coil, cm; W - expended power, kW.

From this formula we see that increase of the magnetic field intensity in the given volume n times leads to increase of heat losses n^2 times. If we take into account the considerable difficulties, connected with the removal of heat, then it is obvious that the use of material with specific resistance ρ=0 as winding conductor is very effective.

Numerous works showed the expediency of use of superconducting coils for creation of large magnetic fields in considerable volumes.

It is interesting to compare a magnet with superconducting windings and a magnet, having the same field, with copper windings, cooled by water. With induction 88 kG, created in cylindrical volume 5 cm in diameter and 10 cm high, an ordinary electromagnet requires 1500 kW of power input, 4000 l of water per minute for cooling of windings, large area for placement of the magnet itself and the distributing device for it.

The corresponding magnetic system, using superconductor as material of windings, has (without cooling device) the shape of a cylinder 0.5 m in diameter and 1 m high, is portable and according to the calculations of specialists costs 10 times less, including the cost of the cooling device. The daily requirement of liquid helium is 2-3 liters [6].

Progress in the technology of manufacture of superconducting alloys will make it possible, in the opinion of researchers, in the near future to create electromagnets, possessing induction up to 500 kG.

At the present time are constructed superconductor electromagnets, creating a field with intensity 101 kG in a volume of several cubic centimeters [14] and a field with intensity 30 kG in a volume of several liters [5].

A deficiency of devices with superconductors is the high cost of materials. Therefore in some cases during calculation of the technical and economic effectiveness of the introduction of superconductors it is necessary to consider only the gain from substantial reduction of dimensions and the rise of efficiency of the installation. The cost of the installation itself remains commensurate with the cost of ordinary equipment. So, an MHD generator w. h powe' .0 MW with copper field winding and working induction 40 kG costs, according to data of [7], 250000 pounds sterling (600 thousand rubles). As much again will cost an installation with superconductors, since the price of 1 kg of wire from material 3NbZr is 140 pounds sterling (800 rubles/kg). However, the gain is determined by the large economy in dimensions and in the consumption of power for cooling (50-100 kW for operation of cooler instead of 15 MW losses in winding) [7].

Power transformers with superconducting windings. A transformer with lead superconducting windings with power 15 kW is described in [8]. The windings of the transformer are placed in a vacuum tank and cooled by liquid helium; their construction is such that the layers of windings of high and low voltage are alternated, as a result of which the powerful counter magnetic fields created by them completely destroy each other, and the noncompensated magnetic flux is too small to cause the disappearance of superconductivity.

The magnetic circuit of the transformer is made of burdened steel and operates at room temperature (with its placement beside windings at 4.2°K the losses escaping in steel cause vigorous evaporation of liquid helium, for compensating which are required too powerful and expensive cooling installations).

Calculation of the transformer with superconductors with power 300 MW [8] showed that even in this case the power consumed by cooler becomes only 50 kW, whereas losses in the windings of an ordinary transformer reach ~1000 kW. The total weight of the transformer (without taking into account the weight of protective devices) is 10 times less than the weight of a transformer of ordinary construction, and taking into account the weight of protective devices - 2 times.

During designing and testing of transformers with power 15 kW there are revealed basic difficulties of their use and manufacture, and the range of voltages, for which it is expedient to apply such transformers, is also investigated.

Fig. 3 depicts curves of dependence of losses in the core and power, consumed by cooler, on the voltage (with lowering of voltage the losses in the cooler rise in connection with increase of losses I^2R in the conducting ends of the winding).

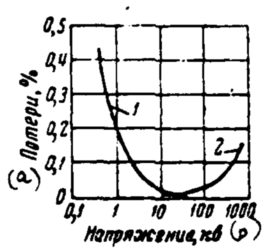


Fig. 3. Curves of losses of superconductor transformer in the function of voltage. 1 - power of cooler; 2 - losses in steel.

Key: (a) Losses, %. (b) Voltage, kV.

A comparison of allowable current densities for ordinary and superconducting transformers in a function of voltage is also made (Fig. 4), from which we see that the greatest gain in weight of the winding is given by the application of a superconducting transformer at comparatively low voltages.

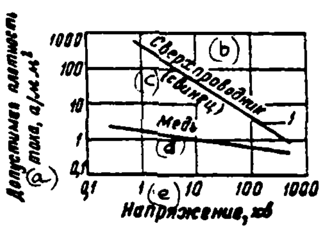


Fig. 4. Curves of current densities of ordinary and superconductor transformers in a function of voltage. 1 - superconductor (lead); 2 - copper.

Key: (a) Allowable current density, A/mm². (b) Superconductor. (c) (lead). (d) Copper. (e) Voltage, kV.

In the work on the creation of superconductor transformers an important problem is the question of sudden short circuiting of the transformer. It is known that with the achievement of some surface of current density (pertaining to the perimeter of the cross section of conductor), determined as

$$I_{c.n} = H_c,$$

the superconductor acquires normal resistance. In this case the windings are rapidly heated and the transformer stops functioning until the windings will again be cooled. The time, necessary for cooling the transformer, is several minutes. Therefore, one must either provide for the appropriate protection (better also on superconducting principle), or work with values I and H, far from critical level, and provide such reactance of transformer x_K, which could limit the currents of short circuiting to a safe level. So, if we work at level 0.1 I_c and provide reactance 12.5%, the current during short circuiting will be equal to 0.8 of critical and not be a hazard for the transformer.

The installation of external reactors, which can limit the necessary thickening of insulation of extreme turns of high-voltage transformers, providing protection from overvoltages with steep front, is also possible.

The magnetic field, created by magnetizing current, can induce different-valued voltages in parallel-connected windings, which in some cases leads to the formation of circulation currents inside the winding and must be considered when designing the transformers.

The leakage inductance of alternating windings is rather low due to decrease of the scattering field intensity. However, increase of the current density of superconducting windings creates the reverse effect, leading to increase of scattering. In the experimental model the reactance of scattering was 0.5% (since lead was used, possessing small critical field).

Losses on eddy currents in superconductors are relatively great, which forces the use of fiber or laminated conductors for transformer windings.

Transformers with rigid superconductors will possess high values of scattering reactance, since each turn is permeated by considerable flow of scattering. If induction in the winding is 30-40 kG with 10-20 kG in the core, then reactance will be on the order of 100%. Such high values of scattering reactance require the taking of special measures for its compensation [9].

The scattering coefficient of superconductor transformer with core can be tentatively estimated by formula

$$\varepsilon_{T} = \frac{2 B_{\Omega} A_{f}}{B_{c} A_{c}},$$

where ε_{T} - is expressed by the relationship of voltage, induced by scattering flow, which is caused by the load current, to voltage, created by the magetizing flux in the magnetic circuit; aB_Q - allowable induction of material of winding; A_f - cross section of the channel of scattering; B_c - induction in magnetic circuit; A_c - section of magnetic circuit.

Losses of superconductor transformers (including power of cooling installation) can be determined in fractions of nominal power of the transformer by formula

$$\varepsilon \approx \frac{1}{V} + G(V^{\frac{9}{8}} P^{\frac{1}{4}}),$$

where V - highest voltage used, kV; P - power of transformer, MW; G - coefficient depending on the material of winding.

The relative losses of the transformer with superconductor windings with power on the order of hundreds of megawatts are minimum in the voltage range 100-500 kV.

Losses in helium liquifier are determined mainly by heat inputs into the cryostat through the electric leads of the transformer. In [10] is given analysis of determination of the diameter of the optimum lead, i.e., lead, introducing minimum of losses into the cyrostat. The heat, introduced into the chamber through such a lead (in a unit of time), is equal to:

$$Q = I\left[\frac{\lambda}{\sigma}(T_3 - T_{\text{н}}\right]^{\frac{1}{2}}.$$

where I - current, passing through the lead; λ, σ - coefficient of heat conductivity and specific electric conductivity of the material of lead; $T_{\text{в}}, T_{\text{н}}$ - materials of "hot" and "cold" sides of the lead.

The providing of mechanical strength of the structural elements, considering the application of large inductions, is of considerable difficulty.

Thus, the main problems, appearing during the use of superconducting transformer, are:

1) the necessity of limitation of jumps of current to a level, allowed by conditions of transition to nonsuperconducting state;

2) decrease of circulation currents, caused by different position of parallel-connected turns relative to magnetic flux. This current, being added to the current of load (if special measures are not taken), can reach critical value;

3) reduction of losses in input buses;

4) limitation of scattering of transformer;

5) compensation of mechanical forces during high inductions.

Applying superconducting windings, in principle it is possible to construct an economical and transportable transformer of 1 million kW [11].

Synchronous electric motors with superconducting rotor, bearings and winding of stator. Superconducting bearings (supports) give the possibility to liquidate the main source of friction in the electric motor. If the windings of the stator of electric motor, as also the rotor and bearings, are made from superconductor, then the motor would have efficiency close to 100%. However, in this case the rotor must not have cylindrical shape, as usual, since repulsive forces, caused by the interaction of currents of stator windings and counteracting currents, directed by alternating flow of stator in cylindrical rotor, are directed through the axis of rotation and do not create torque.

If we give the rotor the shape of a polygon, the direction of repuslive forces no longer occurs through the axis of rotation and torque is created (Fig. 5).

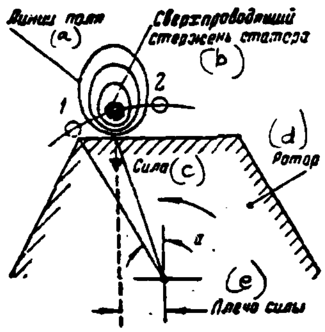


Fig. 5. Diagram of action of synchronous superconductor electric motor with polygonal rotor.

Key: (a) Lines of field. (b) Superconducting stator rod. (c) Force. (d) Rotor. (e) Arm of force.

With the action of rotating magnetic field of three-phase stator of the motor the rotor starts to rotate on its magnetic supports; with increase of the frequency of feeding current the speed of rotation increases.

In the laboratory of the firm "General Electric" was constructed a model of a motor, operating on this principle; its rotating speed reached 20000 rpm and was limited to this figure only because the rotor was not designed for large centrifugal force (Fig. 6). The rotor was made in the form of a hexahedral can, the bottom of which from the inside was repulsed from the winding, placed inside; the interaction of its inside walls with this same winding did not permit the rotor to accomplish oscillations in the horizontal plane. Thus, it hung in a vacuum without contact with supports. The angular moment of the rotor (weighing 26 g) was $2 \cdot 10^5$ gf·cm²/s at 20000 rpm [12].

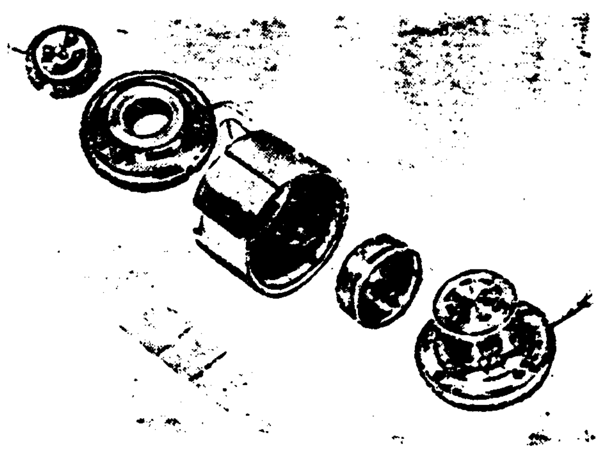


Fig. 6. Synchronous superconductor motor with "magnetic lubrication" and round rotor. Asymmetry of magnetic resistances is created due to the presence of special recesses in the rotor.

The torque, developed by the motor with polygonal superconductor rotor depending on the stator current, can be determined from the following expressions:

$$M = \frac{1}{2} I^2 \frac{dL}{dx}$$

or

$$\frac{2}{\pi}\int_{1}^{2} M\,d\pi = \frac{1}{\pi}\int_{1}^{2} I^2\,dL.$$

The average torque in interval 1-2 (Fig. 5) is equal to 1/2 $I^2/a(L_1-L_2)$. From these expressions ensue the inportance of maximum change of inductance of stator windings with change of the position of the rotor. The torque of the machine is proportional to the square of the stator current. With constancy of stator current the machine operates in mode M=const.

In the described machines for the creation of rotating field there were used direct current pulses running through the stator or voltages shifted to some angle in two phases.

A deficiency of electric machines of similar construction is the complexity of their mechanical coupling with devices, being at normal temperature. The shaft, connecting the motor (operating at 4.2°K) to the device, being at 300°K, would cause insurmountable boiling up of helium due to heat transfer through this shaft. Therefore the region of application of similar machines at present is narrow, this is drive of low-temperature devices, pumps, and also high-precision gyroscopes.

In order to avoid difficulties of coupling the low-temperature rotor of a machine with devices, being at normal temperature, constructions of electric machines were proposed, for which only the stator is located in conditions of superconductivity. The rotor at this time operates at normal temperature and can be connected with the working mechanism or turbine in the ordinary manner.

Some large rotating electric machines, for example synchronous compensator, do not require their connection by a shaft with some other machines or mechanisms. This makes it posssible to make the stator and rotor of such machines superconducting.

Electric machines with superconductor excitation. Superconductor windings with constant magnetic flux "frozen" in them are ideal for purposes of excitation of electric machines. Such windings create the same magnetic flux outside the dependence on the armature current, provide self-regulation of excitation and ideal operating stability of the machine. Furthermore, they occupy small places, are able to create very high magnetic fields (i.e., to lower the overall dimensions of the machine) and do not require outside any energy (except power of cooler, which with thorough heat insulation can be extremely small).

An example of the design of the machine, for which one winding (stator winding, being the field winding) is superconducting, and the other ordinary, is the design of a turbogenerator with power 600 thousand kW, described in [8].

Since the electromagnets, using superconductors, make it possible to create inductions, significantly higher than the induction of saturation of steel, then for the described turbogenerator there is no steel as magnetic circuit; thus, the body of the rotor should be made of nonmagnetic material. Large inductions lead to high values of induced voltage; the absence of steel in the rotor makes it possible to use the freed place for additional copper conductors. As a result of this the electric power, being realized in limited dimensions of the machine, significantly rises.

Superconductor solenoid made of alloy Nb_3Sn, not requiring feed of energy, creates a field of 100 kG (Fig. 7) (in ordinary machines the induction does not exceed 20 kG), in which is rotated a rotor with length 2 and diameter 1 m (in ordinary large turbogenerators the active part of the rotor has length 5-6 and diameter on the order of 1.1 m). The emf induced in the rotor is removed from the rotating rotor to the fixed buses with the aid of baths with liquid metal [7].

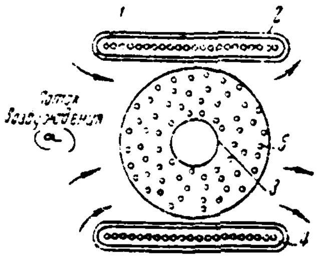


Fig. 7. Diagram of magnetic circuit of turbogenerator with superconductor field winding. 1 - superconductor field winding; 2 - heat insulation; 3 - shaft; 4 - liquid helium (T=4.2°K); 5 - copper conductors of rotor (T=300°K).

Key: (a) Excitation current.

The density of current in the turbogenerator rotor is 0.5 A/mm², voltage, induced in 1 linear meter of rotor conductor 1000 V; overall losses in the rotor 60 kW; power of cooler, necessary for compensation of heat inputs through the heat insulation (there are no input buses in the stator - it is short-circuited), is very low.

The possibilities of use of superconductor excitation are available also in magnetohydrodynamic and unipolar generators, direct-current machines and machines with claw-shaped poles. In all these cases it will become possible to provide constant flow of excitation without losses and to reduce to minimum the effect of load on voltage or speed of rotation of the machine.

Conclusions

1. At the present time are found superconductors, not losing their properties in fields with inductions 100 kG and maintaining currents with density 10^3 A/mm^3. This opens wide possibilities for reducing the overall dimensions and weight of electric machines. An ordinary synchronous machine with power 130 kW has an armature with length 400 mm and diameter 300 mm. In superconductor electric machine with the same volume of armature it would be possible to raise the current density 200 times and field intensity 25 times [13].

2. Superconductor electromagnets, not using energy, are able to create magnetic fields, which with usual methods can be obtained only with great difficulty. At the present time the inductions of magnetic field of superconductor electromagnets reach 100 kG.

3. The use of superconductors in transformers makes it possible to reduce their losses, overall dimensions and weight. Superconductor transformer with power 1000 MW will be transportable and more economical than ordinary. It is most suitable to use superconductors

for the construction of transformers of high power and high voltages.

4. The complete absence of electric resistance and ideal diamagnetism of superconductors make it possible to create electric machines with minimum losses, self-regulation of excitation and high static and dynamic stability. The losses of superconductor machine are determined mainly by power, used by helium cooler; this power for rather large machines comprises fractions of a percent; for synchronous machine with power 20 MW the power of the cooler is 400 kW [13].

REFERENCES

1. K. Mendelsohn, Cryophysics, 1960.
2. Kunzler, Superconducting Magnets, Scientific American, July, 1962.
3. T. Buchhold, Applications of Superconductivity, Scientific American, May, 1960.
4. J. Bremer, Superconductive Devices, 1961:
5. High Magnetic Fields, 1962.
6. Kunzler, Superconductivity in High Magnetic Fields at High Current Densities, Review of Modern Physics, 1961, v. 33, № 4.
7. Symposium on MPD Electrical Power Generation. Newcastle, 1962.
8. R. McFee, Applications of Superconductivity to the Generation and Distribution of Electric Power, Electrical Engineering, 1962, № 2.
9. R. McFee, The Feasibility of Superconducting Power Transformers, Electrical Engineering, 1961, № 10.
10. R. McFee, Optimum Input Leads for Cryogenic Apparatus, Review of Scientific Instruments, 1959, № 2.
11. See million kw. Superconductor Transformer, Electrical world, 1961, v. 56, № 11.
12. Advances in Cryogenic Engineering, 1961, v. 6.
13. STZ, 1962, № 19.
14. Electrical Engineering, № 8, 1963.

DATE

FILMED

8