DEVELOPMENT OF A SUPERCONDUCTING MAGNETIC SYSTEM OF A PLASMA MASS-SEPARATOR

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The paper presents the design and parameters of a superconducting magnetic system of a mass-separator with a maximum magnetic field value of about 5 and 3 T in the separation area. The magnetic system is designed for a Nb-Ti copper-stabilized superconductor; for current leads HTSC is used. The stored energy is 6 MJ. Heat inputs to the surfaces with T of 4.5 and 40 K are equal to 1 and 50 W, respectively.

PACS: 28.60.+s

1. INTRODUCTION

A problem of producing isotope-pure materials and isotopes as well as developing the methods for their production is the problem of today. Electromagnetic separators (plasma separators being a promising version) and electromagnetic methods of isotope separation are continuously upgrading.

Previous papers [1-3] were devoted to consideration of plasma separators with cyclotron heating of components. In the present paper we continue to consider a superconducting magnetic system (SCMS) of the separator [3] making it possible to reduce significantly the power consumption, mentioned in [1], in the case of using SC magnets. Development of materials and technologies promote the advancement in this field simplifying the conduct of operations and decreasing the cost of magnetic systems developed for different applications, for example, induction linacs, stellarators, torsatrons, separators, etc.

2. SC MAGNETIC SYSTEM

A schematic view of the superconducting system of the plasma mass-separator is presented in Fig.1. A required magnetic field configuration (Fig.2), capable to be modified in the general case, is formed by 5 windings placed, in a special manner, along the field axis. The windings are laying-out in a single cryostat. The walls of a "warm" hole in the cryostat are cooled by a water flow, as they are the walls of the plasma source and of the separator. The superconducting magnetic system wound on the aluminium cylinder, being cooled by the helium flow through pipes welded on the heat contact, is placed inside of the radiation shield with a temperature of 30…40 K. The shield, in its turn, is heat-insulated from the external walls of the vacuum object using a multilayer superinsulation with the heat input of about 1.5 W/m^2 in the temperature difference range from 300 to 40 K.

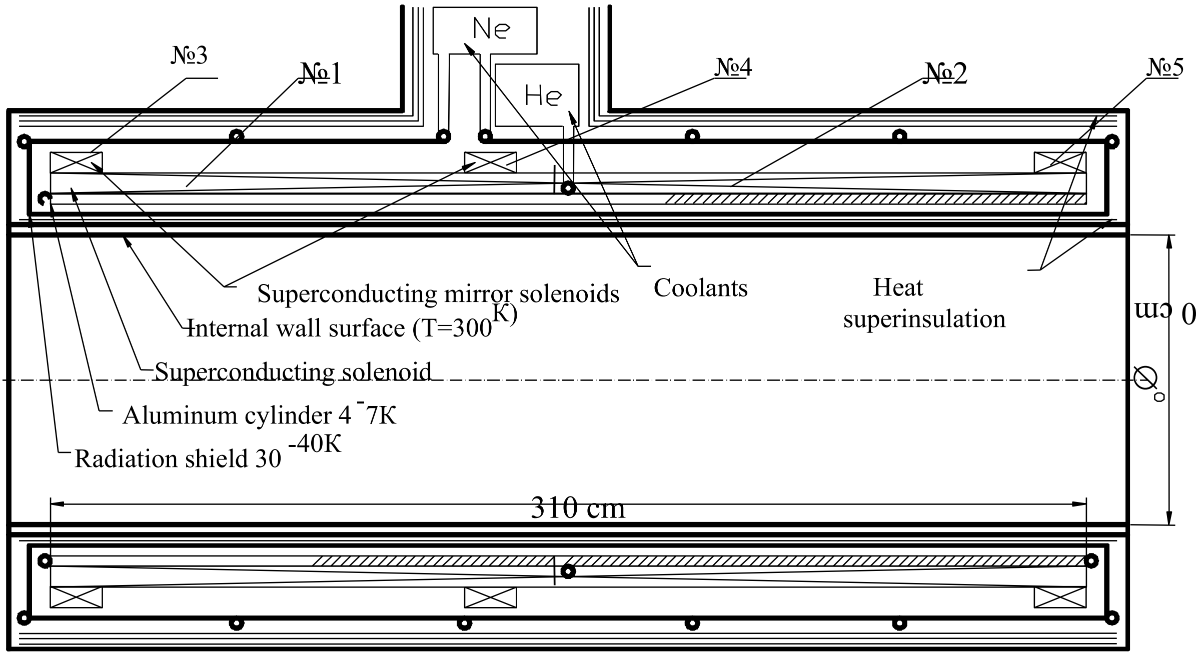

Fig.1. The cross-cut of the superconducting magnetic system

SCMS and the thermal screen are mounted on the thermoforce supports inside the special space in the vacuum chamber interior.

Requirements to the magnetic field homogeneity when conducting operations with heavy isotopes are on the level $\Delta B/B = 10^{-2}...5\cdot10^{-3}$, that is sufficiently simply provided in the system where the winding is applied with turns touching. (The wire diameter/chamber diameter ratio is at a level of $3\cdot10^{-3}$ and the plasma diameter/winding diameter is approximately 0.8). At the same time in the region of the plasma source (PS), in the region of the collisional plasma the homogeneous field is not necessary. Here, the control of output plasma parameters can be performed with the help of high-gradient and periodical magnetic field (Fig.2). It is seen from the figure that the value and topography of the magnetic field in the PS region is controlled by three solenoids №1, №3, №4. The region of the homogeneous magnetic field is controlled, besides the above-mentioned solenoids, by the solenoids №2, №5. In addition, the value of the magnetic moment of ions, contained in the separation area, can be controlled, too [2].

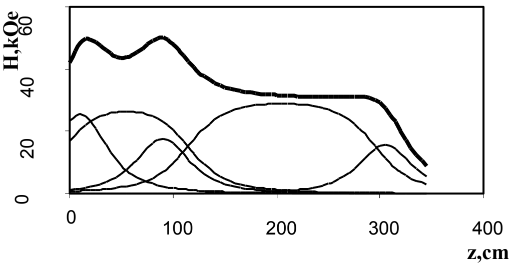

Fig2. The axial topography of the magnetic field of system with 5 solenoids

An important feature in developing SCMS is the current leads which also determine the parameters and operating properties of the system. For our work we select the current leads with the use of HTSC having a critical temperature of 80…100 K. In this case they decrease, almost to zero, the heat input through the current leads to the helium system, as at a temperature of the thermal screen T=30…40 K they are superconducting, not requiring the coolant flow for their operation. They are superconducting up to 80…100 K and, therefore, the heat load to the thermal screen significantly decreases, too. However, it is essential that there is not necessity to lower the values of a transport current along the windings (in order the heat load be decreased).Thus, the inductivities of magnetic system sections, and of the system on the whole, can be decreased. Consequently, it will be possible not only to decrease the voltages at current leads in the case of emergency power release from the solenoids, proportional to U= L dI/dt, but, also, to increase the transport current density in the winding, or the safety factor – the ratio of the transport current in the winding to the current of the short specimen, $I_{t.c}/I_{SS}$.

An important moment for the safe operation of SCMS with high values of the critical current and energy is the system of energy release. Since, while SCMS transition into the normal state, because of low velocities of normal phase propagation, V_φ, V_R, V_Z, are at a level of 20…23 cm/s, 1…3 cm/s and 3…5 cm/s, respectively, the normal phase will occupy an insignificant part of the volume throughout the system at a high temperature values. Indeed, at a given current density values the rate of winding heating is approximately 50 K/s, and the energy, released during the first second, does not reach even 1 kJ. By that time, at this temperature the values of arising thermal stresses do not exceed yet the strength of the winding, however, this value, in the process of making the system, cannot be controlled, and, therefore, a high safety factor is expedient. It is not desirable to exceed the above-mentioned values because then the risk of the system failure can take place. To prevent this, the control and safety system, responsible for the SCMS transition into the normal phase, must connect SCMS in time of about 0.1 s, with the external nonlinear resistance, to which during ~1 s, at a constant voltage, the stored energy is leaded. If the total stored energy is released in the winding, then its temperature increases up to 50 K.

Before we have shown that at rates of energy release of about 1…3 T/s it is possible to lead out up to 80% of the stored energy from the system while the simultaneous transition of the entire SC-winding into the "normal" state. For this purpose the electrical insulation of windings should be performed by 12…15 kV, the energy is leaded out from the windings simultaneously.

For the winding we used a cable having the copper-superconductor ratio at a level of 12, diameter 2 mm, varnish insulation and current-carrying capacity, see Table 1.

***Table 1**. I vs. B of Nb-Ti cable*

I (A)	$1.05\cdot10^3$	$6.5\cdot10^2$	$2.0\cdot10^2$
B (T)	3	5	8

As is seen from Fig.2 a part of the solenoid №2 winding is in the zone of 5 T, therefore the winding of this solenoid can made with cables of variable cross-section for the field region of 3 T and 5 T, respectively. Thus, the saving of the SC cable can be appreciable, as this section of the winding is almost 40% of the total weight of the system and its optimization can decrease its cost.

So, the SCMS parameters should be as follows: length of the system – 310 cm; diameter of the "warm" hole – 60 cm; maximum magnetic filed – 5 T; material of the winding - niobium-titanium with the ratio to copper – 12; stored energy – 6.0 MJ; structural current density – $1.5\cdot10^4$ A/cm^2. The weight of the SC part of the cable winding – 700 kg, of the electric insulation material – up to 80 kg, of the aluminium frame – 180 kg; total summary weight of the cryostat part at 4.5 K – up to 1000 kg.

In calculations for the heat inputs to the cryostat with T=4.5 K we have taken into account the radiating heat input and heat input by the supports. In calculations of heat inputs to the radiation shield the contribution of current leads was also taken into account. The heat input to the cryostat with T=4.5 K is of about 1 W, the heat input to the thermal screen with T=30 K is 50 W.

The axial topography of the magnetic field was calculated by the method of superposition of fields from single-turn solenoids. The parameters of solenoids №1-5 for the maximum filed of 5 T are given in Table 2.

***Table 2**. Parameters of solenoids*

solenoid	№1	№2	№3	№4	№5
N*I, *10^6 (A-turns)	3	4.5	1.625	1.125	1
I(A)	600	600	600	600	1000
L(H)	7.0	11	5.8	2.75	0.75
W (MJ)	1.3	2	1.05	0.5	0.4

Vacuum in the cryostat is maintained due to the use of sorption internal pumps located at the surfaces with T=30 K and 4.5 K. The length of the SC cable is ~23 km. At the cost of the Nb-Ti superconductor of ~2 $/kA•m and the cost of HTSCs of ~100 $/kA•m (length up to 10 m), the cost of the SC winding is estimated at a level of ~$50 thousands.

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СВЕРХПРОВОДЯЩАЯ МАГНИТНАЯ СИСТЕМА ПЛАЗМЕННОГО СЕПАРАТОРА ИЗОТОПОВ

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Представлены конструкция и параметры сверхпроводящей магнитной системы сепаратора изотопов с максимальной величиной магнитного поля ~5 и 3 Тл в области сепарации. Магнитная система рассчитана на Nb-Ti сверхпроводник, стабилизированный медью; для токовводов используется ВТСП. Запасенная энергия составляет ~ 6 МДж. Теплоподводы к поверхностям с температурой 4.5 и 40 К равны 1 и 50 Вт.

НАДПРОВІДНА МАГНІТНА СИСТЕМА ПЛАЗМОВОГО СЕПАРАТОРА ІЗОТОПІВ

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Представлені конструкція та параметри надпровідної магнітної системи сепаратора ізотопів з максимальним значенням магнітного поля біля ~5 та 3 Тл в області сепарації. Магнітна система розрахована на Nb-Ti надпровідник, стабілізований міддю; для струмовводів використовується ВТНП. Запасена енергія становить ~ 6 МДж. Теплопідводи до поверхонь з температурою 4.5 та 40К становлять 1 та 50 Вт.