Cryogenic system of the cyclotron MSC 230

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The MSC230 cyclotron cryogenic system is designed for creating a magnetic field in the cyclotron magnet yoke structure. Its main components are shown in Fig.1.

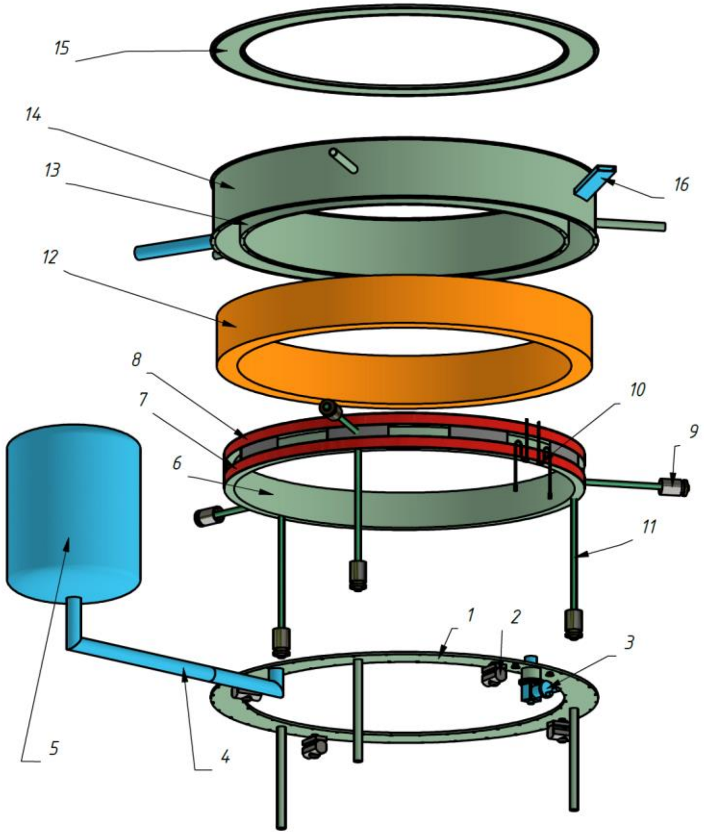

Fig.1.

The vacuum vessel consists of a bottom cover (1), top cover (15), inner (13) and outer (14) cylindrical shells bolted to each other. The distinctive feature of the chosen design concept is detachable top and bottom covers that allow accessing the cryostat internal space for repair and maintenance purposes. The cryostat vacuum space is separated from the cyclotron and the beam output pipe (16) space.

The solenoid structure consisting of the stainless steel base structure (6), two superconducting coils (7,8), and HTSC current leads (10) is placed in the copper heat shield (12) and rests on the support system including three axial (11) and three radial rod supports. Each rod support is equipped with a differential thread adjusting device (9) and an electrical actuator as an option. The heat shield is cooled down to the liquid nitrogen temperature by four cryocoolers (2) and by liquid nitrogen as a standby support system. The current leads are cooled by the cryocooler (3).

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Table 1. Cryogenic system main technical characteristics

Parameter name	Unit	Value
Solenoid inner diameter	m	2.55
Solenoid outer diameter	m	2.70
Number of coils	pcs	2
Distance between coils	m	0.1
Solenoid height	m	0.28
Maximum magnetic field induction in the aperture gap	T	2
SC coil conductor	Cu + Nb-Ti	
Insulating vacuum space pressure	Pa	$\leq 1 \times 10^{-3}$
Operating current	A	500
Interaction force between coils	kN	420
Axial support load	kN	100
Radial support load	kN	50

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The refrigerator (5) provides both solenoid and heat shield cooling systems supply with liquid helium and nitrogen. The liquid helium and liquid nitrogen supply pipelines, as well as the return ones, are placed in the vacuum tunnel (4) equipped with an internal heat shield cooled by liquid nitrogen (see Fig.1).

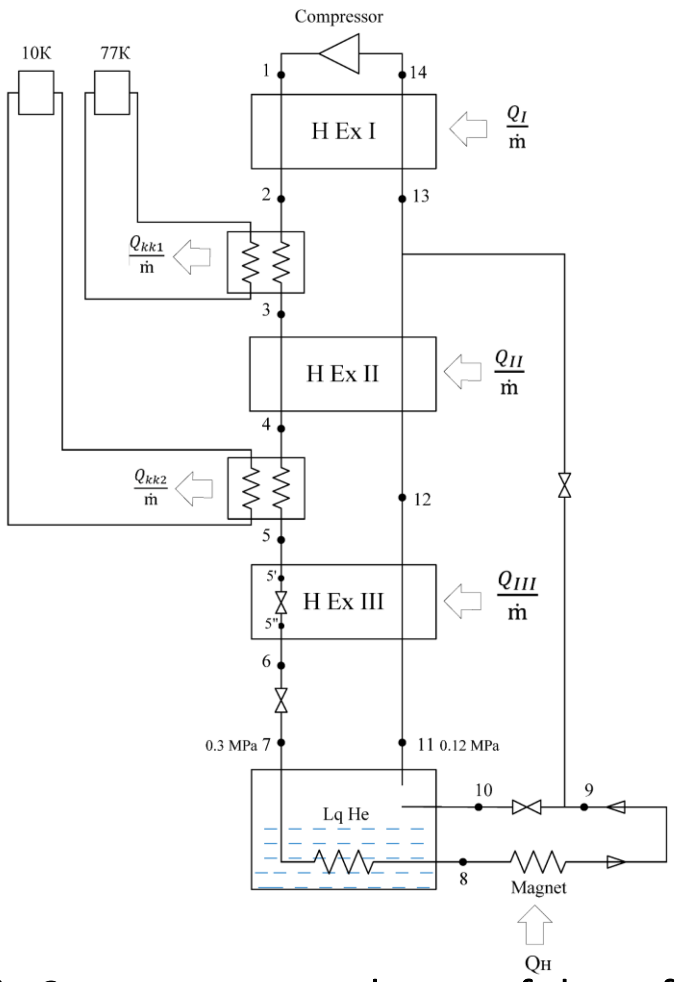

Fig.2. Technological scheme of the refrigerator

Table 2. Main technical characteristics of cooling system

Parameter	**Unit**	**Value**
Total design heat load to helium @ 5.5 K	W	3.35
Heat gain to the solenoid thermal shield	W	51.4
Heat gain to HTS CL @ 60 K	W	50
Heat gain to the thermal shield of the refrigerator	W	9.7
Nominal refrigerator capacity @ 5.5 K	W	6.0
Cold mass of the magnet	kg	550

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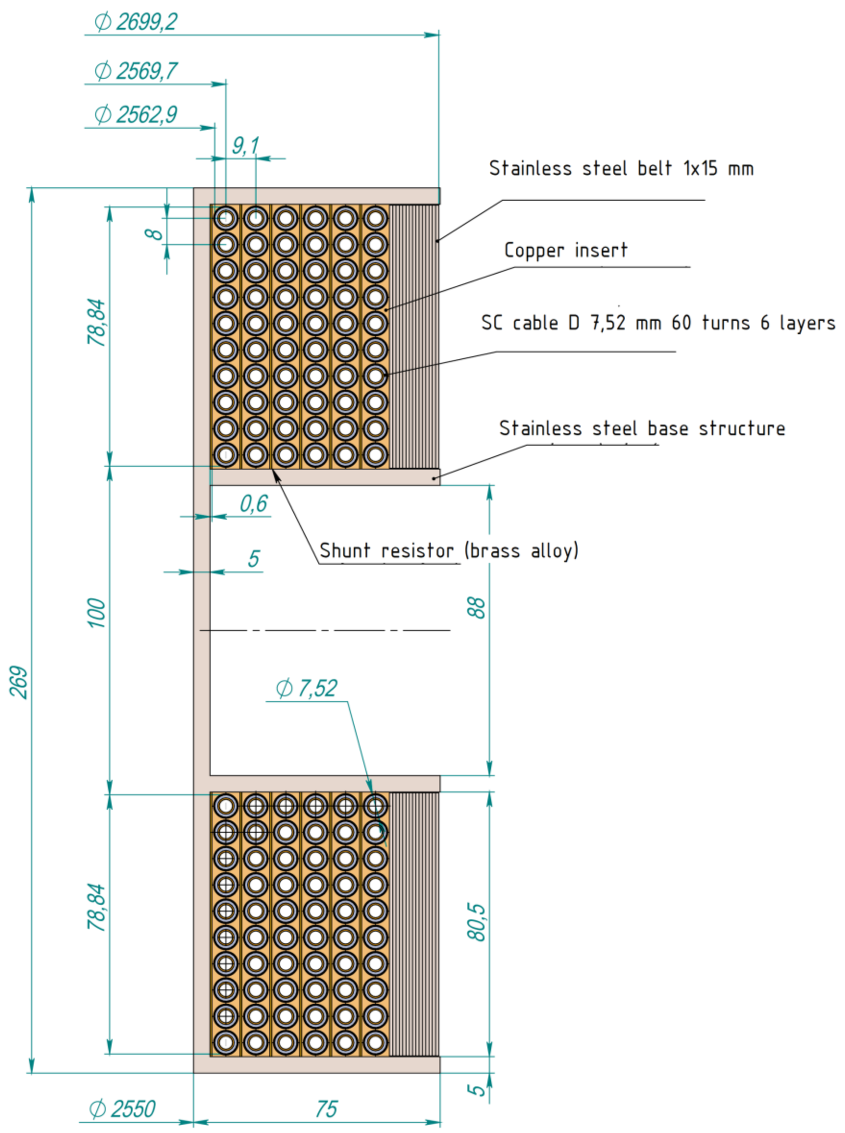

Fig. 3. Solenoid structure cross-sectional view

The protection of the magnet from overheating during quench is solved by sectioning the solenoid and uniform energy release throughout the winding. For this, the winding is electrically divided into sections. The energy stored in the magnet is dissipated both on the external resistance and on 36 shunts - heaters located between the winding layers of the upper and lower coils. The external resistance Re = 0.509 Ohm limits the maximum voltage to ground to ± 250 V.

The maximum calculated winding heating temperature as a result of quench is 97 K.

The time constant of the energy evacuation process will be 17.9 s.

Thank you for your attention