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HIGH MAGNETIC FIELD UNIFORMITY SUPERCONDUCTING MAGNET FOR A MOVABLE POLARIZED TARGET

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The superconducting polarizing magnet was constructed for movable polarized target (MPT) with working volume 200 mm long and 30 mm in diameter [1]. The magnet provides a polarizing magnetic field up to 6 T with the uniformity of 4.5×10^{-4} in the working volume of the target. The magnet windings are made of a NbTi wire, impregnated with the epoxy resin and placed in the horizontal cryostat with «warm» aperture diameter of 96 mm. The design and technology of the magnet winding are described. Results of the magnetic field map measurements using a NMR-magnetometer are given. The MPT set-up is installed in the beam line of polarized neutrons produced by break-up of polarized deuterons extracted from the Synchrophasotron of LHE, JINR, Dubna.

The investigation has been performed at the Laboratory of High Energies, JINR.

Сверхпроводящий магнит с высокой однородностью магнитного поля для подвижной поляризованной мишени

Н.Г.Анищенко и др.

Создан сверхпроводящий поляризующий магнит для подвижной поляризованной мишени (ППМ) с рабочим объемом 200 мм длиной и 30 мм в диаметре [1]. Магнит обеспечивает поляризующее магнитное поле до 6 Тл при однородности $4{,}5 \times 10^{-4}$ в рабочем объеме мишени. Все обмотки выполнены из NbTi провода, пропитаны эпоксидным компаундом и помещены в горизонтальный криостат, диаметр «тёплой» апертуры которого равен 96 мм. Описаны конструкция и технология намотки магнита. Приведены результаты измерений карты магнитного поля с использованием ЯМР-магнитометра. Установка с ППМ смонтирована на пучке поляризованных нейтронов, образующихся при развале поляризованных дейтронов, выведенных из синхрофазотрона ЛВЭ ОИЯИ (Дубна).

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

1. Introduction

MPT in Dubna was reconstructed from the previous proton polarized target (PPT) built in 1985–1988 at Saclay by ANL and Saclay experts for purposes of the E-704 Femilab experiment. This PPT has been used at FNAL during 1988–1990 [2,3]. It has been

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transported to JINR (Dubna) in 1994 and reconstructed before the end of the year as the movable target, easily transportable from one beam line to another [4]. The international experimental program with MPT on the polarized neutron beam at the Dubna Synchrophasotron was accepted in early 1994. The first experiment in physics was carried out in February–March 1995 [5]. Just after the measurements, the original polarizing magnet was dispatched to Mainz (Germany). Therefore, a new magnet was needed to be manufactured.

2. Design, Technology of the Winding and Basic Parameters of the Magnet

The superconducting polarizing magnet (Fig.1 and the Table) contains a main solenoidal winding 1 (558 mm long, 206 and 144 mm in outside and inside diameters, respectively) as well as compensating 6 and correcting 7 windings at its ends. Multifilament NbTi wires are wound on welded frame 2 of steel 1X18H10T consisting of a pipe and flanges, insulating with demountable half-disks 3. Frame 2 with an outside vessel and other parts forms welded helium vessel 4, which is fixed into vacuum casing 5 with the help of glasstextolite support cone 8. The thermal insulation of the helium vessel is provided with

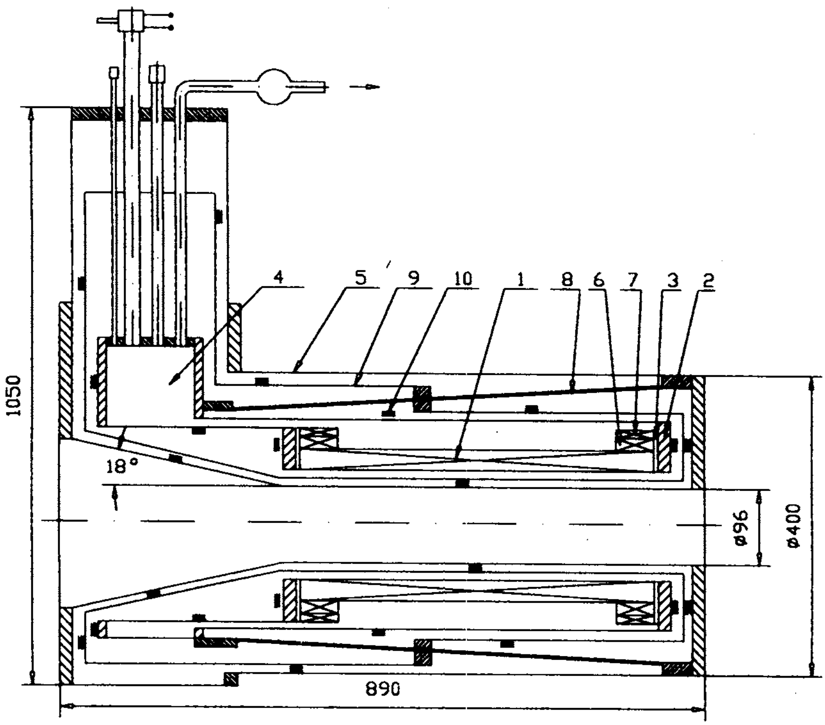

Fig.1. Polarizing magnet MPT: 1 — basic winding; 2 — frame of stainless steel; 3 — insulating half-disks; 4 — hehum vessel; 5 — vacuum vessel; 6 — compensating windings; 7 — correcting windings; 8 — glasstextolite support cone; 9 — copper radiation screen; 10 — multilayer superinsulation

cooled helium vapours by copper screens 9 and multilayer screens 10 made of metal-coated mylar.

Table. Basic parameters of the polarizing magnet

Item	Unit	Value
Cryostat (vacuum casing):		
— length	mm	890
— diameter: inside«warm»	mm	96
outside	mm	400
Solenoid		
— inductance (basic and two compensating windings)	H	13
— winding length	mm	558
— diameter: inside	mm	144
outside (basic winding)	mm	206
outside (frame flanges)	mm	268
— number of sections of the basic winding		6
— calculated maximum working current, Io	A	186
— maximum reached working current	A	160
— current density in wire (with Io)	A/cm^2	2.4×10^4
— critical current density with 4.2 K in a field of 7 T, no less	A/cm^2	4.5×10^4
— field in the centre of the aperture (with Io)	T	6.7
— maximum field (with Io; $z = \pm 230$ mm)	T	6.9
— reached field in the aperture centre (with 160 A)	T	~ 5.8
— current of the correcting windings	A	$0 \div 10$
— mass cooled to 4.2 K	kg	120
— number of wire solderings		6
Compensating winding (in two sections):		
— winding length of each section (40 coils)	mm	43
— winding thickness (30 layers)	mm	27
— outside diameter of the winding	mm	254
— number of coils in the winding of each section		1200
Correcting winding (in two sections):		
— winding thickness (10 layers)	mm	7.0
— outside diameter of the winding	mm	268
— number of coils in winding of each section		768
Wire (NbTi in a copper matrix):		
Basic and compensating windings:		
— diameter (in insulation)	mm	$1.06 \div 1.09$
— number of filaments in a wire of sections 3 and 4		2970
— number of filaments in a wire of sections 1,2,5 and 6		60
— factor of filling with superconductor		$0.405 \div 0.51$
Correcting windings:		
— diameter (in insulation)	mm	0.75

Among the basic technical requirements on the magnet, note the following: the induction of a magnetic field in the centre of the magnet with a maximum working current of 186 A should be 6.7 T, the uniformity of the field in a «warm» working volume no worse than 10^{-4}. The windings are mounted on frame 2 (pipe ∅ 143.5 mm) with case electric glasstextolite insulation. The main winding consists of 6 concentric sections. When winding, glasstextolite spacers 0.2 mm thick are used to keep layer cylindricity. Two sections of compensating winding 6 are wound up (also by wire ∅ 1 mm) sequentially with the basic section and over it. There are two correcting NbTi windings 7 of a wire ∅ 0.75 mm over the compensating windings.

The wire strain with winding the magnet was $10 \div 12$ kg. During the winding layer-by-layer cylindricity was periodically controlled by measuring the winding diameter in six cross sections along the magnet axis by a micrometric device with an accuracy of no worse than 0.01 mm.

The temperature of the adiabatic heating of the hottest point in case of the transition of the winding to a normal state and the evacuation of stored energy for an external damping resistance of 2 Ω was calculated. The most dangerous regime was considered: the origin of a normal zone at the point of wire soldering; the conditions of heating are adiabatic; the current at the moment of transition is 200 A. The calculation has shown that the heating does not exceed 100 K. When calculating we have used the method suggested in [6].

3. Current Leads and Magnetic Measurement System

Combined current leads cooled by return helium for the main (200 A) and two correcting windings (2×10 A) were placed in the stainless steel pipe ∅ 40 mm, whereas the current-carrying elements are copper foils. The heat leaks to liquid helium via the current leads, were no more than 0.8 W for a current-carrying pair to the main winding of the magnet at 200 A and a flow rate of cooling gaseous helium of ~ 0.8 nm^3/h.

The system for measurements of the magnetic field map in the warm working solenoid volume contains the magnetometer using the nuclear magnetic resonance (NMR). The errors of the magnetic field induction measurement turned out to be below 10^{-5}. The volume of an active part containing polarizable protons was approximately 3.5 mm^3 [7,8].

4. Results of Tests

Repeated long time-frame tests of the polarizing magnet at currents of 80 and 120 A were successfully undertaken [9]. The current of 160 A was applied for a short time period only. The emergency protection of the magnet winding was tested as the superconductor passed to a normal state.

The magnetic field map inside the warm working magnet volume was repeatedly measured (Fig 2). The measurements were carried out over the length L from the middle of the magnet, along its axis ($R = 0$ curves). Other measurements were performed at $R = 15$ mm in horizontal steps of 10 mm and in an angle step of 45°. The field uniformity of 4.6×10^{-4} within the right (the first along the beam path) half of working volume was achieved. This uniformity in the second half was better — 7.8×10^{-5}.

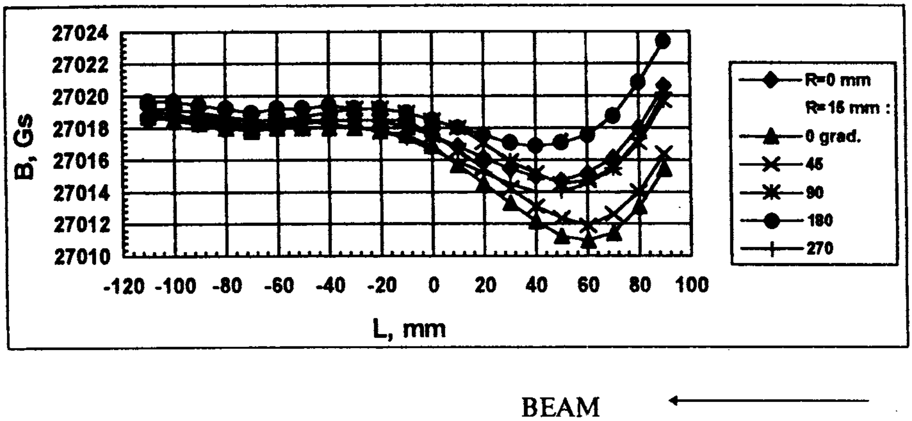

Fig.2. Results of measurements of the magnetic field in the working volume of the target ($I_{main.} = 74.42\,A$; $I_{cor.1} = 2.60\,A$; $I_{cor.2} = 4.64\,A$)

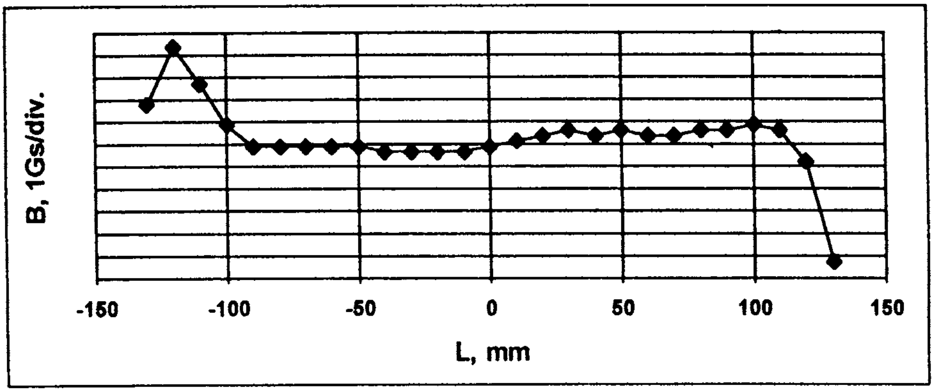

Fig.3. Results of measurements of the magnetic field in the working volume of the target using an additional «warm» correction ($I_{basic} = 74.4\,A$; $I_{cor.1} = 2.60\,A$; $I_{cor.2} = 4.65\,A$). $R = 0$; $L = -100$ mm + + 100 mm; $[B_{max} - B_{min}]/B_0 = 4.4 \times 10^{-5}$

The magnet operated reliably in the July 1997 physics experiment in which polarized neutron beam together with MPT was again used. The longitudinal MPT polarization, averaged over the target volume was 73%. During the whole run, the magnet field uniformity along the working volume axis was better than 5.7×10^{-4}.

Using an additional «warm» correction we could really increase the field uniformity by a factor of 1.7 over the warm working volume (Fig. 3). «Warm» correction was applied by a small steel ring ($\varnothing_{mid.}$ 95 mm at a cross section of (0.35×3) mm^2) and by a three-layer coil (102 coils; (1×8) mm^2; $\varnothing_{mid.}$ 95 mm; current of 0.211 A).

5. Conclusion

The constructed polarizing magnet for MPT allows one to continue the programme in physics and to plan future experiments at the LHE Synchrophasotron. Different magnet parameters may be improved as experimentally shown above. This will increase the MPT polarization and spare the machine time.

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References

1. Bazhanov N.A. et al. — Nucl. Instrum. Methods, 1996, v.A372, p.349—351.
2. Chaumette P., Derégel J., Desportes H. et al. — Proceedings of International Workshop on Polarized Sources and Targets. Editors: S.Jaccard and S.Mango. Montana (Switzerland), January 13—17, 1986, p.767—771 and Helvetica Physica Acta, 1986, v.59, p.786—787.
3. Chaumette P., Derégel J., Desportes H. et al. — First Use of the Polarized Target Facility at Fermilab, 9th International Symposium on High Energy Spin Physics, Bonn (Germany), September 6—15, 1990, Proceedings edited by W.Meyer, E.Staffens and W.Thiel, Springer Verlag, 1991, v.2, p.320—324.
4. Anishchenko N., Bazhanov N., Benda B. et al. — A New Movable Polarized Target at Dubna. 11th Intern. Symposium on High Energy Spin Physics, Bloomington, Indiana, USA, September 1994, AIP Conference Proceedings, 343. Editors: K.Heller and S.Smith, AIP Press, Woodbury, N.Y., p.572—575.
5. Adiasevich B.P., Antonenko V.G., Averichev S.A. et al. — Measurement of the Total Cross Section Difference DsL in np Transmission at 1.19, 2.49 and 3.65 GeV. Zeitschrift für Physik; 1996, v.C71, p.65—74.
6. McAshak M.S. — MIITS Integrals for Copper and for Nb-46.5 Wt of % Ti. Preprint SSC, No.468, 1988.
7. Ivashkevich S.A., Lagish Ja. — Automatic Nuclear Magnetometer with a Resonance on Protons up to 6 T. JINR Communication P13-90- 400, Dubna, 1990.
8. Ivashkevich S.A. — The Circuit for Fast Automatic Search of a Resonance and Set-Up with It in Nuclear Magnetometer. JINR Communication D13-93-222, Dubna, 1993.
9. Anishchenko N.G. et al. — Superconducting Polarizing Magnet for a Movable Polarized Target, JINR, 13-98-197, Dubna, 1998.

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