THE HYDROGEN-HELIUM SUPERCONDUCTING MAGNET BUBBLE CHAMBER *

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1. INTRODUCTION

A 25 cm diameter 35 cm deep liquid helium bubble chamber has been operated at Argonne National Laboratory [1]. The chamber system, which has also operated with liquid hydrogen, is shown schematically in Fig. 1. The magnetic field is provided by a Nb-Zr superconducting magnet [2]. The maximum field obtained on the first test of this magnet was 32.8 kG. One window of the chamber is a plexiglas lens which is attached to the chamber body by an omega bellows.

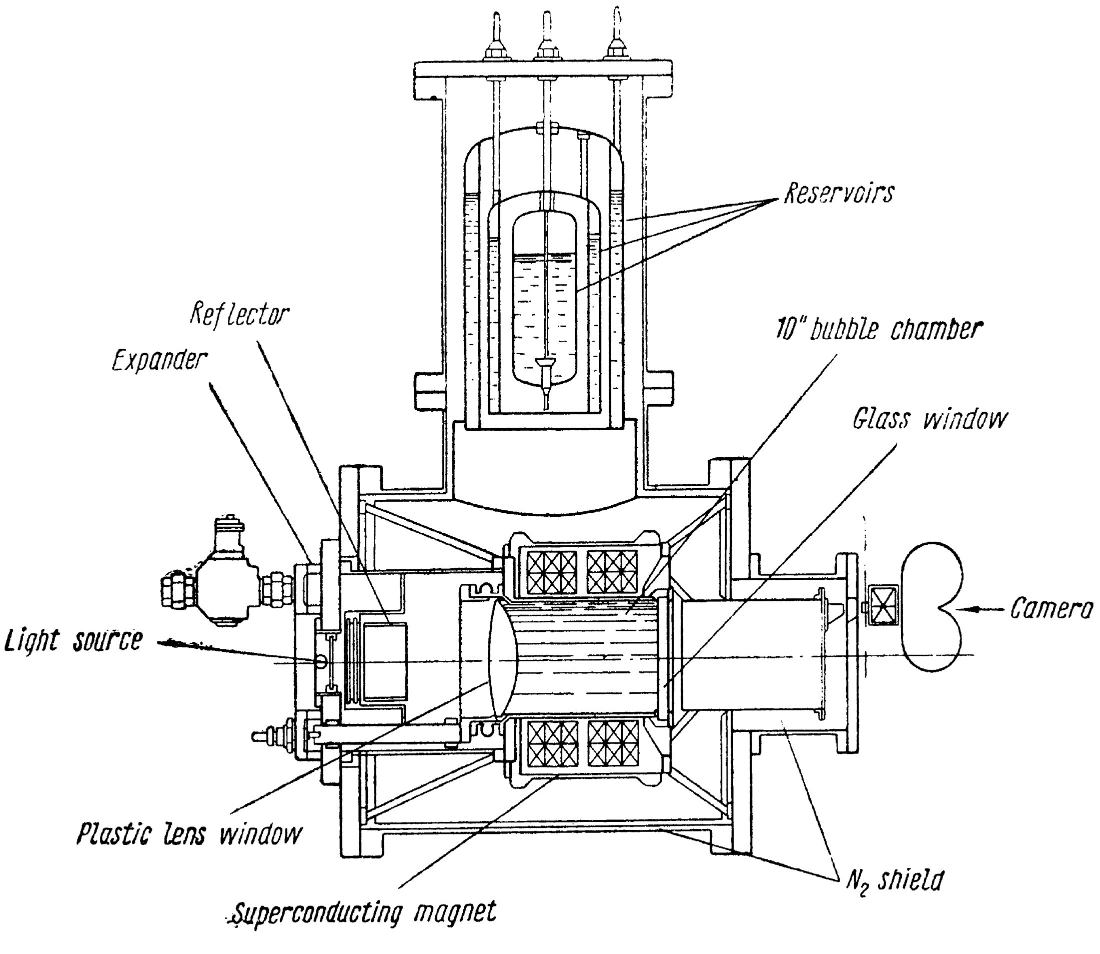

Fig. 1. Superconducting magnet bubble chamber assembly.

Expansions are made by a 3 mm movement of this lens. The illumination system enables tracks to be photographed over the whole chamber volume (19 liters).

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This chamber system has been designed for low energy experiments requiring large magnetic fields and high spatial resolution, as well as for investigating the feasibility of large superconducting magnets.

2. OPTICS

As seen from Fig. 1, the chamber has a rather unconventional aspect ratio. This configuration was necessary to obtain reasonable field uniformity from the iron-free solenoid producing the magnetic field, and is quite well suited for the study of low energy interactions. The illumination of such a long cylinder for dark field photography presented a special problem. It is desirable to have the light from the source focus at the camera plane so that the scattered intensity to each camera from bubbles anywhere in the chamber be roughly constant. Fig. 2 shows the illumination system. There are two cylindrical reflectors (one of which is the wall of the chamber) which produce an intermediate virtual ring source or image. The following parameters were varied in the design of the optical system in order to get an equal intensity of the direct and reflected light: position of small reflector, radius of curvature of the spherical surface of the plastic aspheric condensing lens, and thickness of the condensing lens. The light source is a 2 cm diameter flat spiral, xenon flash tube.

The chamber is photographed on 35 mm film with three lenses located on a 25 cm diameter circle, yielding a stereo half angle and mean scattering angle of the light of about 10°. The cameras are modified (non-magnetic) Model 201 Flight Research cameras with remote electric motors. The three cameras are located on a common plate which is mounted on the vacuum chamber by means of a ball joint on the optical axis of the illumination system, allowing convenient alignment of the camera plane.

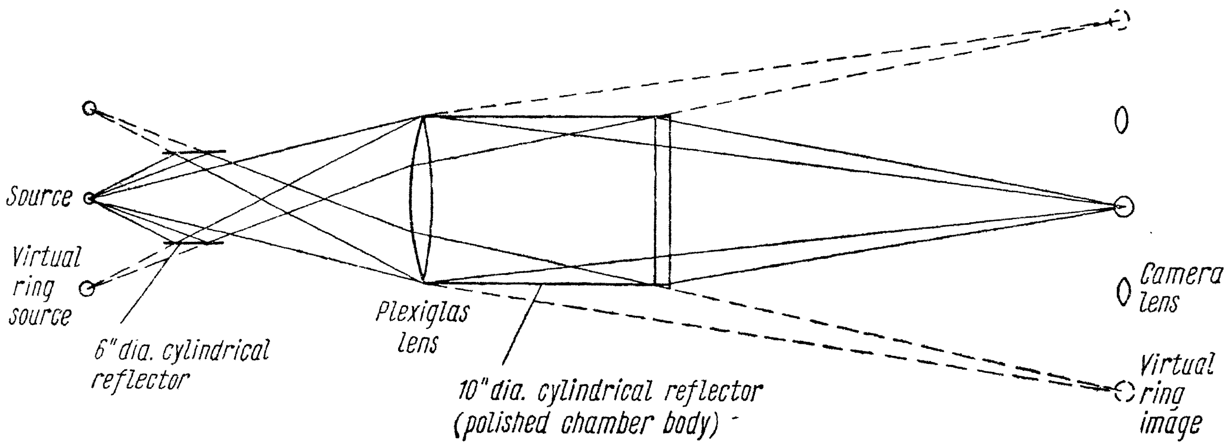

Fig. 2. Ray diagram of illumination optics.

3. EXPANDER

The salient features of the expander mechanism are shown in Fig. 3. A principal objective in the design was to achieve a highly uniform expansion, free from turbulence. To this end, liquid-phase expansion is utilized with movement initiated over the largest practicable area, so that fluid velocities are kept to a minimum. A further improvement in precision is achieved by having the direction of expansion coincide with the direction of the magnetic field, so that turbulence distortion causes a minimal error in sagitta measurement.

This type of expansion is effected by using the condensing lens as a moving wall of the chamber. The lens is sealed [3] to the chamber with a stainless steel omega bellows [4], and is made of plexiglas to help minimize the mass of moving parts. The energy for an expansion comes solely from the stored energy of the liquid in the case of hydrogen, but when using helium, which operates at only 400 mm Hg, the expansion force is obtained from a set of springs installed under the room temperature annular piston. Recompression is obtained by compressed air acting on the piston, with the force transmitted to the lens by three pushrods. A complete expansion-recompression cycle can be made in 15 msec; this high speed of expansion and recompression makes for good thermo-dynamic efficiency.

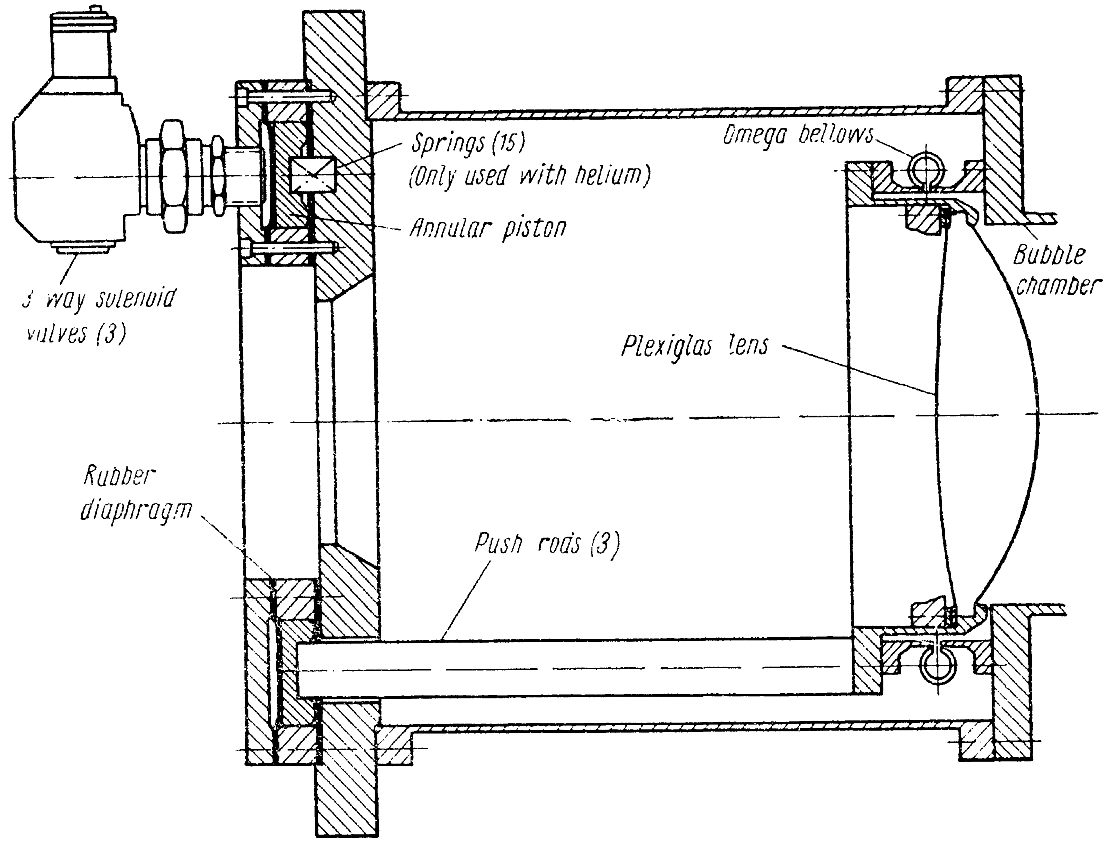

Fig. 3. Detail of expansion mechanism.

4. REFRIGERATION

Temperature regulation of the bubble chamber is accomplished by circulation of liquid through a copper heat exchanger which forms the top of the bubble chamber body. The heat exchanger is connected either directly to the reservoir, or through a second heat exchanger for hydrogen operation. A temperature difference of 0.3° K between the reservoir and chamber is observed for helium operation.

Two cooling fins are located in the bubble chamber to remove part of the heat load from pulsing the chamber. One fin is located between the inside of the re-entrant flange and the bellows of the chamber. The second fin is located in the top of the bellows to condense gas which could otherwid be thermally trapped in that space.

The loss rates have been determined for the bubble chamber in preliminary runs without the magnet. The static loss rates for operation with liquid hydrogen in the chamber is $\sim$11 liters/hour of liquid nitrogen and $\sim$6 liters/hour of liquid hydrogen. With liquid helium in the bubble chamber, the static losses for liquid nitrogen and liquid hydrogen remain about the same or decrease slightly. No detectable difference was observed in the liquid helium consumption of 2-1/2 liters/hour between static and dynamic operation, indicating efficient operation of the expansion system.

5. MAGNET

The magnet, shown in Fig. 4, consists of an assembly of 12 separate coils arranged as a split solenoid system with a central gap of approximately 2 cm. The length of the system is 25 cm, the inner diameter 27 cm, and the outer diameter 54 cm. Copper-coated, insulated superconducting wire of diameter 0.25 mm is used in the coils, with Nb 25% Zr wire in the region of low field and Nb 33% Zr wire in the high field region. A nominal radial thickness of 0.02 mm of electrodeposited copper is used around the superconductor but there are wide variations in the radial thickness of the coating.

Each coil unit has a winding length of 3.3 cm and is wound on a copper bobbin with detachable stainless steel flanges. Each coil contains approximately 10,000 turns of superconducting wire, and alternate layers are shunted together by nichrome shunts having an aggregate resistance of approximately 15 ohms per coil. Four layers of 0.025 mm copper ribbon are wound into the coil between every other layer of superconducting winding, and a quartz-filled epoxy potting compound was applied during the winding operation. The shunts and joints are mounted on the outer periphery of each pancake of one inner and one outer coil.

Protection during the transition to the normal state is obtained in several ways. The copper coating around the superconductor acts as a shunt during the transition and so decreases the propagation velocity of the normal front. A further increase in the time constant for the transition to the normal state occurs due to the induced eddy currents and resultant energy dissipation in the interwound copper secondaries and in the copper bobbin about which each coil is wound. Interlayer voltages are limited by the resistive shunts between alternate layers. The shunts also absorb energy in those regions where the transition occurs and lengthens the time constant of each coil by providing a low resistance current path across layers which have been driven normal. The design [5] of the protective system is due to Z. J. J. Stekly of the AVCO-Everett Research Laboratories.

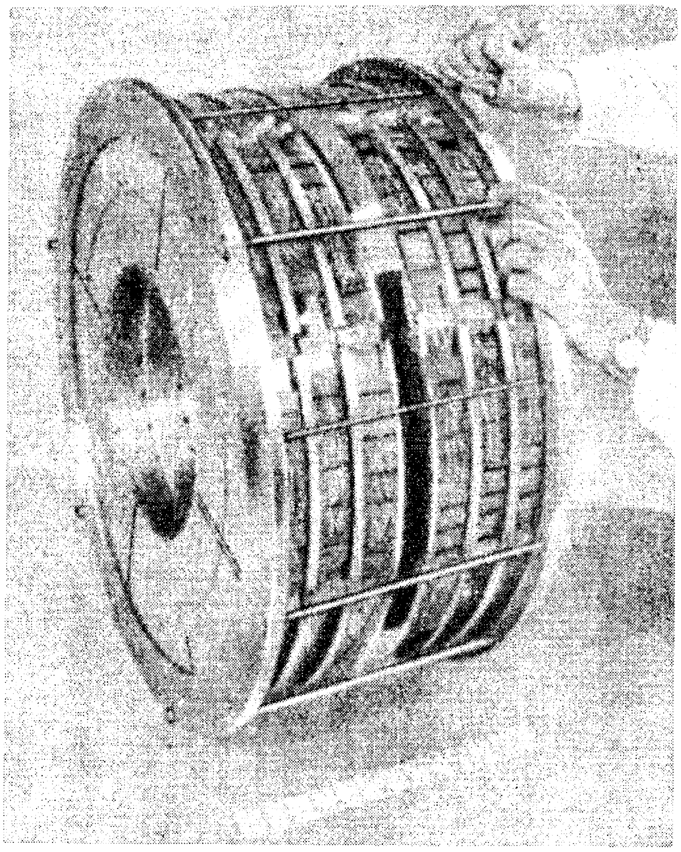

Fig. 4. Magnet segment assembly.

The wire lengths available when the project began were typically about 8 kilometers. Each wire end is brought out of the coil and led along a radial slot in the stainless steel flanges to the periphery of the appropriate outer coil. The superconducting joints are aligned parallel to the field, which maximizes their current-carrying capacity. Each joint uses two independent sub-joints, a crimped copper tube and a clamping block of Nb Zr. Joint resistance of 1 μ Ω or less at thirty kilogauss were obtained in this way, and each joint was instrumented so that the voltage across the joint could be measured when the coil was energized.

The system was assembled for test in early April 1964 as a continuous solenoid and generated a central field of 32.8 kilogauss at an average coil current of approximately 11 amperes. The measured inductance of the coil system was approximately 7000 henries and the stored energy was in excess of 300,000 joules. The time constant for the transition to the normal state was a few seconds, and for a high field quench, approximately 130 liters of liquid helium was boiled off over a period of about five minutes. The static helium loss rate of the magnet will be about two liters/hour, when mounted in place around the bubble chamber.

6. CONCLUDING REMARKS

This chamber system will be used within the next few months for a run at the ZGS in order to study hyperfragment binding energies and decay modes. The feasibility of this size of superconducting magnet seems established; we are now evaluating several means for increasing the field strength and making other substantial improvements in the magnet.

REFERENCES

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DISCUSSION

Dr. S. Nikitin

What is the weight of the magnet?

M. Derrick

The total weight of the magnet assembly is 1100 lbs but only 160 lbs of this is superconductor. The difference between these two represents the weight of the stainless steel coil forms and the copper necessary to entire safety during a magnet quench.