Theoretical Problem 2

SUPERCONDUCTING MAGNET

Super conducting magnets are widely used in laboratories. The most common form of super conducting magnets is a solenoid made of super conducting wire. The wonderful thing about a superconducting magnet is that it produces high magnetic fields without any energy dissipation due to Joule heating, since the electrical resistance of the superconducting wire becomes zero when the magnet is immersed in liquid helium at a temperature of 4.2 K. Usually, the magnet is provided with a specially designed superconducting switch, as shown in Fig. 1. The resistance r of the switch can be controlled: either r=0 in the superconducting state, or $r = r_n$ in the normal state. When the persistent mode, with a current circulating through the magnet and superconducting switch indefinitely. The persistent mode allows a steady magnetic field to be maintained for long periods with the external source cut off.

The details of the superconducting switch are not given in Fig. 1. It is usually a small length of superconducting wire wrapped with a heater wire and suitably thermally insulated from the liquid helium bath. On being heated, the temperature of the superconducting wire increases and it reverts to the resistive normal state. The typical value of r_n is a few ohms. Here we assume it to be $5\,\Omega$. The inductance of a superconducting magnet depends on its size; assume it be 10 H for the magnet in Fig. 1. The total current I can be changed by adjusting the resistance R.

This problem will be graded by the plots only!

The arrows denote the positive direction of I, I_1 and I_2.

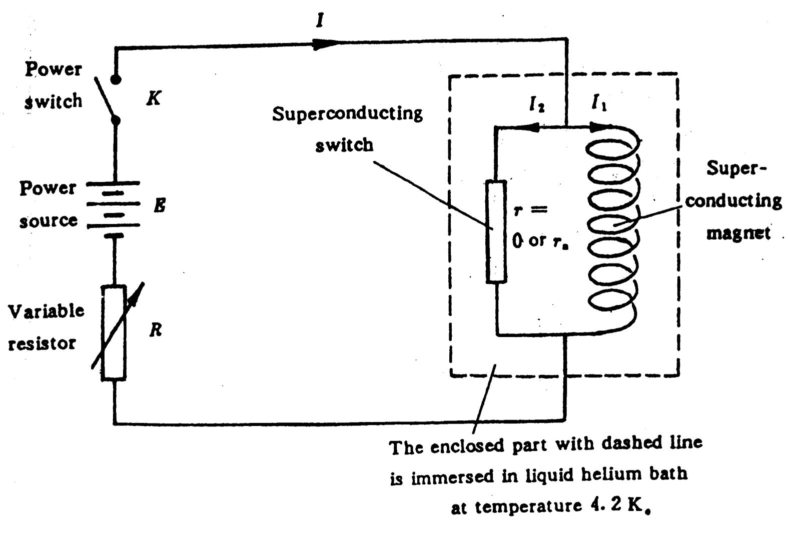


Fig. 1

1) If the total current I and the resistance r of the superconducting switch are controlled

to vary with time in the way shown in Figs, 2a and 2b respectively, and assuming the currents I_1 and I_2 flowing through the magnet and the switch respectively are equal at the beginning (Fig. 2c and Fig. 2d), how do they vary with time from t_1 to t_4? Plot your answer in Fig. 2c and Fig. 2d

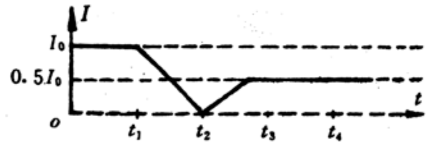
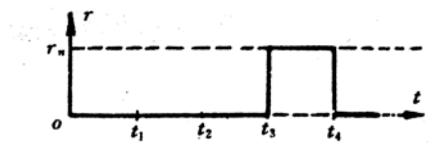
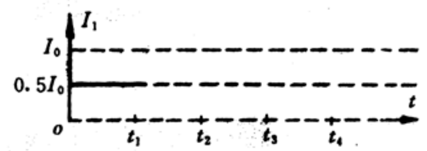


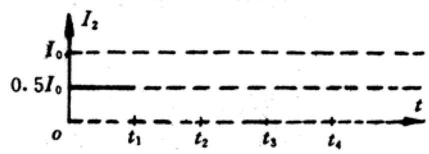
Fig.2a



2b



2c



2d

2) Suppose the power switch K is turned on at time t=0 when r=0, I_1=0 and R=7.5 Ω, and the total current I is 0.5A. With K kept closed, the resistance r of the superconducting switch is varied in he way shown in Fig. 3b. Plot the corresponding time dependences of I, I_1 and I_2 in Figs. 3a, 3c and 3d respectively.

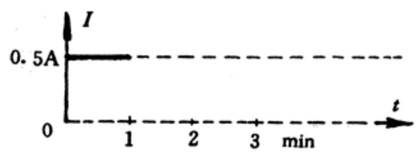
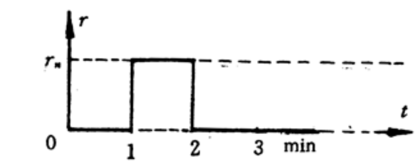
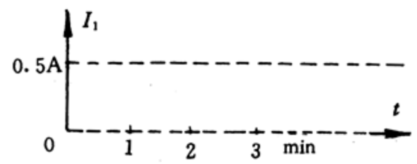


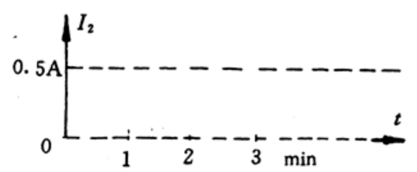
Fig. 3a



3b



3c



3d

3) Only small currents, less than 0.5A, are allowed to flow through the

superconducting switch when it is in the normal state, with larger currents the switch will be burnt out. Suppose the superconducting magnet is operated in a persistent mode, i. e. I=0, and I_1=i_1(e. g. 20A), I_2=-i_1, as shown in Fig. 4, from t=0 to t=3min. If the experiment is to be stopped by reducting the current through the magnet to zero, how would you do it? This has to be done in several operation steps. Plot the corresponding changes of I, r, I_1 and I_2 in Fig. 4

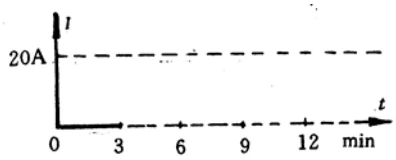
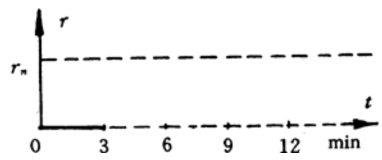
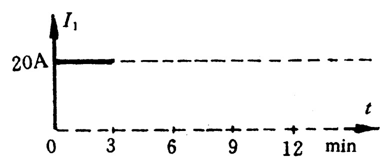


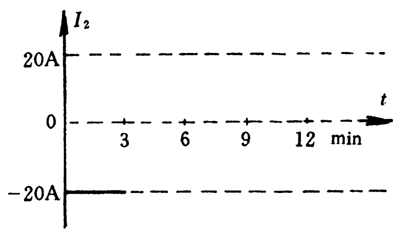
Fig. 4a



4b



4c



4d

4) Suppose the magnet is operated in a persistent mode with a persistent current of 20A (t=0 to t=3min. See Fig. 5). How would you change it to a persistent mode with a current of 30a? plot your answer in Fig. 5.

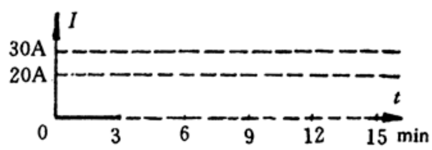
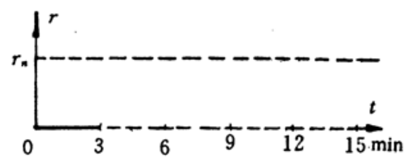
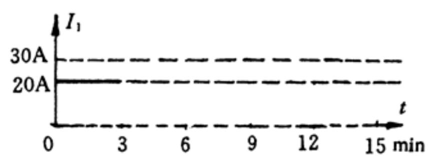


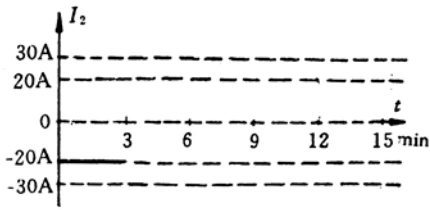
Fig. 5a



5b



5c



5d