A facility to measure the critical current of superconducting wires

M.R. Singh, D. G. Kulkarni, G. Ravikumar, K. L. Patel, P. K. Mishra,
T. V. Chandrasekhar Rao, H. N. Karandikar, K. V. Bhagwat and V. C. Sahni
Technical Physics & Prototype Engineering Division

For the upcoming Superconducting Cyclotron programme at VECC, Calcutta, one requires multi-filamentary Nb-Ti/Cu composite superconducting wires capable of carrying 1030 amperes at 4.2 K under a field of 5.5 Tesla. The fabrication of these conductors requires a careful fine-tuning of the metallurgical processing conditions of the superconducting wires. For this purpose, a careful Voltage (V) vs Current (I) characterization of the developed conductors by the way of identifying resistive transition is essential.

A facility to measure the V vs I characteristics on short samples (approximately 1 metre) of the developed wires, with the field perpendicular to the current direction, was set up. The set-up (Fig. 1) uses the usual four probe method. The facility is equipped with a 30 litre liquid helium dewar and a home-made superconducting magnet (of length 200 mm and a bore diameter of 55 mm) capable of providing a magnetic field of 7.4 Tesla. This bore is adequate to accommodate a sample insert, which carries a 45 mm diameter tube for mounting the short sample of the superconducting wire. The current in the superconducting magnet is controlled with the help of a PC to achieve a steady field, covering the range from 0 to 7.4 Tesla.

To generate accurate V vs I data, two pairs of voltage leads are soldered on a helically wound superconducting wire immersed in liquid helium. A nano-voltmeter is used to monitor the voltage drop across the sample. Sample current is transported by suitably designed vapour-cooled leads to take maximum advantage of the evaporated helium gas.

An indigenously built constant current power supply, capable of delivering a maximum current of 1200 amperes, is used to pass a variable current through the sample. To obtain the sample current accurately, a 1Ω water-cooled standard resistor is kept in series with the superconducting sample and the voltage V_i (proportional to I) across the standard resistor (proportional to the sample current I) is measured. The voltage drop V across the sample and V_i are fed to a PC using a GPIB interface to obtain V vs I curves.

Fig. 1 Experimental set-up to measure critical current of superconducting wires

Fig. 2 V-I curves of the 0.5 mm diameter Vacuumschneize wire at different magnetic fields.
In Fig. 2, the V-I transition curves are shown which were obtained on a Vacuumschmelze (Germany) wire of 0.5 mm diameter and copper to superconductor ratio of 1.9:1 (45 filaments of Nb-Ti), whose critical current vs field values are known from earlier measurements. The critical current ($I_c$) obtained using a voltage criterion of 0.2 µV/cm matches very accurately with the available data on this sample.

In Fig. 3, V-I curves obtained at different magnetic fields on a 1 mm diameter Nb-Ti/Cu wire with a copper to superconductor ratio 1.937:1 (45 filaments of Nb-Ti), fabricated earlier by AFD, BARC, are shown. The field dependent critical current density for these two (Vacuumschmelze and AFD) superconductors is plotted in Fig. 4 for comparison.

A further quality requirement of these superconductors is the filament uniformity. It is usually characterized by fitting the V-I curve to the form $V \propto I^n$. Typically $n$ should be larger than 30 for a filament non-uniformity below 5-10%. From the data in Figures 2 and 3, it was found that $n$ values are in the range of 40 to 50 for both the samples studied, indicating a good filament quality.

Figure 5 displays the V-I curve recorded on a twisted composite superconducting wire sample (1.37 mm diameter, 402 filaments of Nb-Ti/Cu, twist pitch 12.4 mm) recently developed in AFD, BARC for VECC Superconducting Cyclotron program. The figure clearly shows the resistive transition under a field of 5.5 T. In the inset of this figure, the $V$ vs $I$ characteristic in a log-linear scale is also shown. The continuous line in the inset indicates the voltage criterion of 0.1 µV/cm used for determining the critical current $I_c$. The noise level in the data (indicated by a dotted line) is an order of magnitude below the voltage criterion used in obtaining the $I_c$ value. The resistive transition index 'n' obtained is 63, which translates into a highly uniform Nb-Ti filament cross-section. It should be mentioned here that, to be able to see the resistive transition without quenching the sample, special care has to be taken when designing the sample mounting arrangement. It is important to provide adequate thermal stabilization to prevent thermal runaway leading to sample quench. In some earlier runs on these wires conducted abroad, the resistive transition index 'n' could not be estimated due to thermal runaway.
To summarize, a facility to characterize Nb-Ti/Cu multi-filamentary composite superconducting wires with current carrying capacity up to 1500 amperes in a variable magnetic field up to ~ 7.4 Tesla has been developed. This is a unique facility in the country, which not only can measure the critical current density but also can assess the quality of the superconducting filaments.

Fig. 5 Voltage-current characteristic measured at 5.5 Tesla on the 1.37 mm diameter twisted AFD Nb-Ti/Cu superconducting composite. In the inset, the voltage axis on a log scale is shown with the dotted line indicating the noise level and the continuous line indicating the voltage criterion used in obtaining the critical current Ic.