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Short-circuit current limiter utilizing a high-T_c superconductor

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Experimental data are given on a prototype short-circuit current limiter utilizing a polycrystalline high-T_c superconductor of composition $Y_1Ba_2Cu_3O_{7-\delta}$. The limiter comprises a series-connected dc circuit element immersed in liquid nitrogen. To improve the efficiency, a polycrystalline high-T_c superconductor having an S-shaped current–voltage characteristic is used as the current limiter. © *1998 American Institute of Physics.* [S1063-7842(98)02410-6]

The protection of electrical circuits against catastrophic extremes in short-circuit regimes poses a timely problem in view of the nonexistence of 100% reliable protection elements. The conceptual possibility of employing superconducting in shutdown devices (cryotrons) has been known for some time.[1] The advent of high-temperature (high-T_c) superconductors has led to reports of the design feasibility of current limiters operating at liquid-nitrogen temperature.[2,3] It has been proposed[4] that a single-crystal high-T_c superconductor be used as the active element of a cryotron, thereby affording the possibility of exploiting anisotropy to separate the control current and the working current. The development of a 2.2-kA cryotron with a control winding made from a bismuth high-T_c superconductor has been reported.[5]

Here we give the results of measurements of the parameters of a polycrystalline (ceramic) high-T_c superconducting device, which is not connected into a cryotron configuration, but functions as a series circuit component. In the ideal scenario this type of ballast resistance is equal to zero for a below-critical (J_c) transport current, but in the event of an emergency excess with the current exceeding J_c, it connects into the circuit and limits the current at a safe level. In the practical implementation of the limiter it is necessary to solve a number of technical problems, foremost of which, in our opinion, are the problem of contacts in the high-T_c superconductor, the removal of heat from the high-T_c superconducting protective element in the short-circuit-protection regime (when the high-T_c superconductor remains the sole user), and the corollary problem of matching the voltage drop across the high-T_c superconducting element in the resistive state with the voltage of the protected circuit; the matching problem dictates the geometry of the element and its power release per unit volume.

The samples used for the measurements were made by

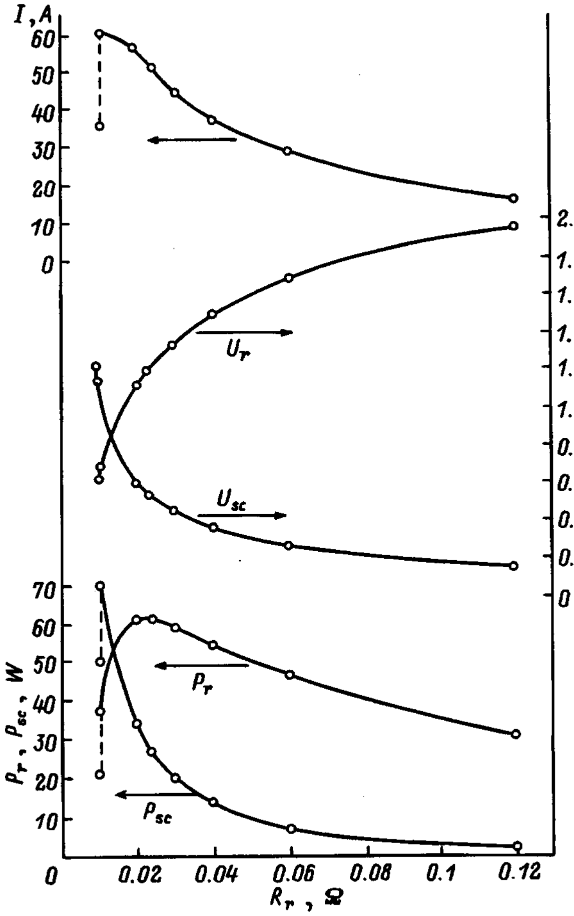

FIG. 1. Circuit variables (the current I in the circuit formed by the series-connected battery, superconductor, and load resistance R_r; the voltage drop U_r across R_r; the voltage drop U_{sc} across the superconductor; the power P_r released in R_r, and the power P_{sc} released in the superconductor) versus load resistance R_r.

pressing from previously prepared high-T_c superconducting $Y_1Ba_2Cu_3O_{7-\delta}$ powder. Silver contact patches for the current leads were formed on the end faces of the sample. The samples had typical dimensions of $2\times7\times44$ mm. To maximize the contact area, the current contacts were coated with an In–Ga eutectic. The assembled device was placed in a liquid-nitrogen tank. Owing to the smallness of the contact resistance, the difference in the voltage drops measured by two-contact and four-contact techniques was significant; two-probe data are given here. The current source was a 6 ST-132 battery with its six elements connected in parallel. In Fig. 1 all the curves for one series of measured samples are plotted as functions of the load resistance R_r, in this case a step rheostat.

It is evident from the figure that as R_r is decreased, the current in the circuit for $I>20$ A begins to deviate from the hyperbolic law $I=U/R_r$; at $R_r=0.01\,\Omega$ the current attains its maximum value ~60 A and then spontaneously decreases to ~35 A. We attribute this behavior to the transition of the current–voltage (I–V) curve into a branch having a higher differential resistance, a phenomenon that we have observed previously.[6] The figure shows how the voltage drops across the superconductor U_{sc} and across the load U_r are redistributed.

Clearly, a protection effect is observed at the minimum attained load resistance, where specifically the voltage drop across the load is lower than that across the superconductor. The variations of the power releases in the load P_r and in the superconductor P_{sc} are also shown in the figure. It is evident that when the load is a minimum, the power released in it is only ~20 W, as opposed to ~400 W without the high-T_c superconductor (in the first approximation $P_r=U_2/R_r$, and the indicated value is obtained for $U=2$ V and $R_r=0.01\,\Omega$). The power in the superconductor does not exceed 70 W in this case and is effectively removed by the liquid nitrogen.

Consequently, a high-T_c superconducting sample having an *S*-shaped I–V curve can be used to achieve a switching effect and to construct an alternative to the cryotron current limiter.

Although these results imply that the parameters of the current limiter utilizing a high-T_c superconductor are far from perfect, we are hopeful that a detailed study of the hysteresis feature of the I–V curves of polycrystalline high-T_c superconductors with a view toward the practical exploitation of this hysteresis will set the stage for the design of a protection element with parameters closely approaching practical requirements.

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