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MAGNETIC AFTER EFFECTS IN A TYP-II SUPERCONDUCTOR

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Résumé.- Les effets de "bascule et reptation", phénomène connu du comportement des matériaux ferromagnétiques /1/ soumis à un champ alternatif et un champ magnétique constant, existent également dans les supraconducteurs de type II.

Abstract.- Periodically swept minor hysteresis loops of type-II superconductors show a creep effect, that consists of a) a displacement and b) a tilting of the minor loop. The initial dependence of the creep on the number of swept minor hysteresis cycle can be described by a logarithmic law, deviations occur at high cycle numbers. The effect appears not to be due to simple thermal relaxation: for not too fast sweep rates no dependence of creep rate on the total measuring time was found within accuracy of measurement. Moreover the flux density gradient appears to increase with increasing cycle number in the region of the sample which is subject to periodic magnetization change indicating a more effective pinning of flux lines.

Hysteretic ferromagnetic or ferroelectric materials often exhibit after effects, in which domain walls move to energetically more favorable positions /2/. These effects can be observed under various experimental conditions, a special one being creep and tilting of periodically swept minor hysteresis loops under the presence of a constant magnetic dc-bias field. In the case of type-II superconductors such a field program is used in methods to determine the flux density profile in the material /3,4,5/, and the question arises whether the swept hysteresis loops are stationary or undergo an after effect similar to that observed in ferromagnetic materials /6/.

As a prerequisite for studying such an effect, one needs a system to measure the magnetization of the superconducting specimen under test with sufficient resolution over comparatively long time periods. Due to thermal emf's, the necessary low drift hardly can be realized using conventional electronic integration techniques. We therefore developed a measuring system based upon the use of a microwave biased rf-SQUID with fast response \((2 \times 10^7 \text{ flux quanta/s}) /7/, the schematic diagram of which is shown in figure 1.

The magnetic field is generated with an accuracy of \(2 \times 10^{-5}\) by a superconducting solenoid fed from a precision current supply. Well defined programs for the field sweep can be run by means of a microprocessor, which via a 16 bit DAC provides the input signal of the current generator and also controls the operation of the whole system. An adjustable differential flux transformer system, consisting of three separate loops a, b and c, is used to measure the magnetization of the specimen under test. The input loop of transformer c can be adjusted such that either a differential flux proportional to the induction B or to the magnetization M of the specimen is coupled to the SQUID. The resolution of the present system is ca. 1\(\mu\)T and the drift less than 3\(\mu\)T/h, allowing magnetization measurements with negligible drift over a period of time of the order of 10 h, that is presently limited only by helium boil-off.

Magnetization curves of a vanadium sample obtained with this system are shown in figure 2. The behaviour of a small minor loop starting at point A of the virgin branch 1 for linear periodic field...
sweeps between fixed values $H_1$ and $H_2$ can be seen from the inset, where the 1., 10., and 100. cycle is depicted in a $B(H)$-plot. Flux creep is clearly visible in the displacement of the loops, and is observed also for other dc-bias fields along branches 1 and 2 of the magnetization curve. The creep rate is found to vary along the minor hysteresis loop, an effect that becomes more pronounced for larger amplitudes of the ac-field $|B|$. This leads to a tilting of the minor loop which was always observed to be connected to a decrease of the total flux density variation in the sample during the field sweep. Pinning of flux lines obviously becomes more effective in this process.

Figure 3 shows the displacement

$$\Delta B = B(H_1, n) - B(H_1, 1)$$

of the inner loop end point $A$ for the first 100 cycles. Deviations from this relationship leading to a slower variation of $\Delta B$ can be observed at higher $n$-values. Apart from a deviation at the highest sweep rate $|dH/dt| = 139 \ A/cm \ s$ which may be due to sample heating no systematic dependence of the creep rate $d\Delta B/d\ln(n)$ on $|dH/dt|$ is observed. The measuring time therefore does not appear to play a role in the observed after effect. This and the above mentioned fact, that the overall flux density gradient becomes steeper in the volume fraction of the sample, in which the periodic magnetization change takes place, is contrary to results obtained for purely thermal activated relaxation processes as for instance in the flux creep experiments using cylindrical tubes /9,10/. The periodic flux shuttling obviously aids to the rearrangement of the flux lines in the sample. The dependence of this process on material parameters and to what extent thermal motion comes into play is subject of further investigations.

References

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Fig. 3: Loop displacement $\Delta B(n)$ for different sweep rates as function of cycle number $n$. To good approximation $\Delta B \propto \ln(n)$ for the first 100 cycles.