Hagen and Griessen reply

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Hagen and Griessen Reply: Although Chaddah and Bhagwat[1] point out rightly in their Comment that the relaxation rate of the magnetization M of a superconductor depends on the field profile inside the sample at time $t=0$, we show here that their argument is based on a wrong expression for $M=M(t)$.

In several publications[2-4] we have shown, on the basis of Monte Carlo simulations as well as of an exact solution of a four-pinning-region model, that over approximately 90% of the relaxation

$$M(t)=M(t=0)\left[1-\frac{kT}{E(T)}\ln\left(1+\frac{t}{\tau}\right)\right], \qquad (1)$$

if (i) the sample is homogeneous, in the sense that all pinning centers are described by the same activation energy $E(T)$, and (ii) the field has initially completely penetrated the sample so as to establish a critical state. These two conditions guarantee that everywhere the current density j is equal to the critical current j_c at $t=0$. For $t \gg \tau$ (as is the case in all experiments carried out so far) Eq. (1) reduces to Eq. (1) in the Comment.

In Eq. (3), Chaddah and Bhagwat[1] assume without derivation that the same logarithmic time dependence is valid for the case where the field has not penetrated the sample completely at $t=0$, i.e., when $H<H^*$. We show here that this assumption which has also been made by many other authors (see, e.g., Refs. 5-9) is, in fact, not justified.

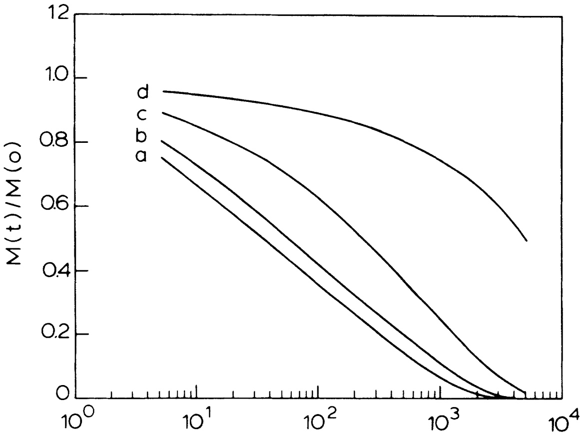

FIG. 1. Magnetization relaxation normalized to its value at $t=0$ for a sample containing twenty pinning centers as obtained from Monte Carlo simulations. For the fully field-penetrated sample a, the density of flux lines at $t=0$ decreases from 1300 at the surfaces of the slab to 400 at the center of the sample. For sample b, the density of flux lines decreases from 900 at the surfaces to zero at the center. This corresponds to $H=H^*$. For the partially penetrated samples c and d, the density is 500 and 100, respectively, at the surface. The density gradient (i.e., the critical current) and $E/kT=7.5$ is the same for all samples. The time is indicated in units of Monte Carlo (MC) steps.

For this we consider a slab of thickness $2a$ and infinite dimensions in the y and z directions in a magnetic field H applied along the z axis. At $t=0$, $|j|=j_c$ in a surface sheet $x_0<|x|<a$, and $j=0$ in the central part, $|x|\leq x_0$, of the sample. Using the same Monte Carlo simulation as in Refs. 3 and 10 we obtain the relaxation curves shown in Fig. 1 for various cases of fully and partially field-penetrated samples. For the partially penetrated samples, $M(t)$ does not obviously vary linearly with $\ln t$ and the relaxation rate $dM/d\ln t$ is not uniquely defined; i.e., $A(H)$ in Eq. (3) of Chaddah and Bhagwat is, in fact, strongly *time dependent*. An analytic expression for $A(H,T,t)$ will be published elsewhere.[10] It is important to point out that convex M vs $\ln t$ curves in partially penetrated $Bi_2Sr_2CaCu_2O_x$ single crystals have been observed by Shi, Xu, and Umezawa[8] (e.g., at 8 K in a field of 0.1 T).

In conclusion, we do not believe that a maximum in $d\ln M/d\ln t$ can satisfactorily be explained with the arguments put forward by the authors. It is, however, obvious that relaxation processes in partially field-penetrated samples have to be taken into account for a correct description of flux creep at low fields and temperatures.

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