FLUX PINNING AND FLUX FLOW NOISE IN Pb$_{80}$In$_{20}$ SAMPLES EXHIBITING A DOUBLE PEAK IN THE VOLUME PINNING FORCE†

F. Habbal and W.C.H. Joiner

Physics Department, University of Cincinnati, Cincinnati, Ohio, USA

Résumé.— Des alliages de Pb$_{80}$In$_{20}$ correctement préparés avec une haute densité de dislocations montrent que la force d'ancre de volume possède deux pics en fonction du champ magnétique, et que la puissance de bruit du mouvement de flux possède un pic aigu. Le recuit à la température ambiante provoque une importante réduction du bruit, la disparition du pic de la puissance de bruit et un seul pic dans la force d'ancre en volume. Nous pouvons expliquer ces caractéristiques, en tenant compte de la structure métallurgique de nos échantillons.

Abstract.— Pb$_{80}$In$_{20}$ alloys, when properly prepared with a high dislocation density, show two volume pinning force peaks as a function of magnetic field, and also a sharp peak in the flux flow noise power. Room temperature annealing produces a significant reduction in the noise, a disappearance of the peak in the noise power, and a single peak in the volume pinning force. These features can be explained in terms of the metallurgical structure of the samples.

The volume pinning force, $F_p$, of the flux line lattice (FLL) in a type II superconductor generally exhibits a peak as a function of magnetic field /1/, /2/, /3/. The shape and location of this peak depends upon the metallurgical state of the sample /4/. This behavior is understood in terms of the elastic properties of the FLL /5/. At low fields the FLL is rigid and flux flow can take place only if a force depins the entire lattice simultaneously. As the field increases, and the shear constant decreases, elastic deformation permits fluxoids to move from weaker to stronger pinning sites, thus increasing $F_p$ /3/. This process, known as synchronization, breaks down when the deformation becomes so large that plastic shear takes place /6/.

The attribution of the peak in $F_p$ to the transition from pin breaking to plastic shear is also supported by recent flux flow noise data, where we have found that the noise amplitude decreases rapidly as the field is increased into the shear regime /7/.

Pb$_{80}$In$_{20}$ foil samples, prepared by quenching the molten ingot to liquid nitrogen temperature, and then immediately compressing the metal to a foil, show two peaks in $F_p$ as a function of magnetic field. We have examined the field and temperature dependence of $F_p$ in these samples, as well as the field dependence of the amplitude of the flux flow noise power at zero frequency, $\delta V^2$. We have also observed changes in $F_p$ and $\delta V^2$ with room temperature annealing.

A curve of $F_p$ vs. field is displayed in figure 1 (solid curve). The sample is prepared as described, and mounted and cooled to liquid nitrogen temperature within 10 minutes after preparation.

![Graph](https://via.placeholder.com/150)

**Fig. 1:** Volume pinning force (solid curve), $F_p$, and flux flow noise power at zero frequency (dashed curve), $\delta V^2$, vs. magnetic field, for Pb$_{80}$In$_{20}$ foil sample annealed at room temperature 10 minutes after preparation. $T = 2.14$ K. $\delta V^2$ obtained with a dc flux flow voltage of 1500 $uV$ and 3 cycle bandwidth. $F_p$ obtained at 0.5 $uV$.

†Work supported by US Department of Energy
According to Kramer's theory of the line pinning \cite{6}, the high field peak can be associated with strong pinning. Also shown in Figure 1 as a dashed line is the curve representing \( \delta V^2 \). The interesting feature of this curve is the decrease in \( \delta V^2 \) with field until one reaches the field region where \( F_p \) begins to increase. \( \delta V^2 \) then shows a sharp rise with field, followed by a sharp decrease, as one approaches the field of the second peak in \( F_p \).

In Figure 2 we show the effects of room temperature annealing on \( F_p \). Initially the high field force peak decreases in height, and both peaks shift to higher fields. After 2 days at room temperature, only a single broad peak remains.

![Figure 2: Volume pinning force, \( F_p \), vs. reduced field \( h = H/H_{c2} \), after various annealing times at room temperature. \( T = 2.14 \) K.](image)

When \( F_p \) curves are taken at different temperatures and data are plotted as \( F_p/F_{p, \text{max}} \) vs. reduced field, \( h = H/H_{c2} \), a scaling law exists, indicating that the force peaks are irregular, and the mechanism for pinning is not temperature dependent \cite{12}. Also, although the metallurgical structure changes on annealing, the high field portion of the various pinning force curves superimpose, confirming that in this region flux flow is controlled by shear, and is not structure sensitive. Near \( H_{c2} \), \( F_p \) fits the functional form \( k(1-h)^2 \), as predicted by Kramer \cite{6}.

In Figure 3 we show the effect of room temperature annealing on \( \delta V^2 \). The noise power decreases rapidly with annealing (by about 2 orders of magnitude), and the peak in \( \delta V^2 \) has completely disappeared after 9 hours at room temperature.

![Figure 3: Flux flow noise power, \( \delta V^2 \), vs. reduced field, \( h = H/H_{c2} \), after various annealing times at room temperature. \( T = 2.14 \) K. \( \delta V^2 \) obtained with a dc flux flow voltage of 1500 \( \mu \text{V} \), and for 3 cycle bandwidth at \( f = 0 \).](image)

Initially the sample consists of very small grains (2\( \mu \text{m} \) diameter after 1 hour at room temperature) of high dislocation density. On annealing, the dislocation density is greatly reduced, and the grains grow (60\( \mu \text{m} \) diameter after 6 hours). After 1-2 days at room temperature, inner-grain dislocation densities are low and pinning is principally at grain boundaries \cite{8}. 
We suggest that the metallurgy is consistent with the data for both \( F_p \) and \( \delta V^2 \). Initially pinning can be attributed to two sources, inner-grain dislocations and grain boundaries. The inner-grain dislocations represent the weaker pinning interaction and give rise to the high field force peak, while the grain boundaries are responsible for the stronger pinning, lower field force peak. As the field is increased to the field region where flux flow is initiated by plastic shear with respect to grain boundary pinning, \( \delta V^2 \), which depends upon fluxoid-pinning interactions /9/, decreases. At still higher fields elastic shear of the FLL within the grains produces synchronization with respect to inner-grain dislocation pinning, enhancing the flux bundle size, and increasing \( \delta V^2 \). Finally, in the plastic shear region for inner-grain dislocation pinning, the bundle size and \( \delta V^2 \) once again decrease rapidly.

Annealing reduces the dislocation density both within the grains and in the grain boundaries. This causes the high field peak in \( F_p \) and the peak in \( \delta V^2 \) to disappear. The resulting weaker grain boundary pinning shifts the low field peak in \( \delta V^2 \) to higher fields. The overall reduction in pinning produces decreased noise at all fields.

References