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Measurement of pinning frequency in superconductors

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Abstract

It is well known phenomena that in type – II superconductors there exists two critical fields H_{c1} and $H_{c2.}$ In between these critical fields Meissner effect is incomplete, superconductor contains both transport current and the magnetic flux threading to it. Due to there co-existence magnetic flux exerts Lorentz force on the current carriers. Therefore to this force there is an equal and opposite reacting force acts on the magnetic flux lines known as Lorentz driving force. Because of this force flux lines are driven into motion which gives rise to resistivity of the sample. So to carry high current through the superconductor vortex lines must be pinned. This can be done by introducing various types of impurities in the material. In this article the equation of motion of vortex has been solved considering viscous damping force. It is found that the real part of resistivity depends upon the frequency which may lead to the determination of pinning frequency.

Keywords: fluxoid, pinning frequency, resistivity, viscosity.

Introduction:

For high – T_c superconductors the upper critical field H_{c2} can be as high as 10^6 Oe or higher. The basic criteria for making superconducting magnet is that superconducting material must not only have a critical field substantially higher than the field to be produced but it must be able to carry high current in that field without resistance. The resistance less current in a homogeneous type –II superconductor is limited to the value which just produces the field $H_{c1.}$ For a wire of radius 'a' this condition is given by Silsbee's rule, $\frac{2I}{a} = H_{c1}$. At H_{c1} the superconductor enters into the mixed state and sample contains both the transport current and the magnetic flux threading through the bulk superconductor. Due to their coexistence magnetic flux exerts Lorentz force on the current carriers. This force per unit volume is given by

$$F = J \times \frac{B}{c}$$

where J is the current density and B is the average magnetic induction. To this force there is an equal and opposite reacting force which acts on magnetic flux lines referred to as Lorentz driving force. This driving force which acts on a single vortex can be written as

$$f_L = J \times \frac{\Phi_0}{c}$$

Where Φ_0 is the flux quantum. Because of this force, flux lines tend to move transverse to the current. In a homogeneous medium there is no counteracting force which results that vortex lines are driven into motion. This vortex motion gives rise to resistance which is not of practical interest.

Clearly to carry high current without resistance, the vortex lines must be pinned so that their motion is inhibited. This can be done by introducing in the material various types of in-homogeneities, which may include lattice defects such as dislocations, precipitates grain boundaries etc. In hard superconductors in-homogeneities offer pinning force counteracting the driving force and a static non-uniform vortex distribution becomes permissible, provided $f_L < f_p$, where f_p is the maximum pinning force acting on each vortex.

Stephen and Bardeen [1,2] shown that the viscous flow of vortices can give rise to a normal resistivity ρ_n . The pinning frequency ω_p is determined by the force constant of oscillation of a vortex and by the viscosity $\omega_p = \frac{k}{\eta}$ where k is the force constant and η is the viscosity.

Some times ago Volovik [3] has found the mass of the vortex as

$$M = m_e k_F^3 \xi^2 L \left(\frac{B_{c2}}{B}\right)^{1/2}$$

Where m_e is the mass of electron, k_F is the Fermi wave vector, ξ the coherence length, L is the length of the current loop, B_{c2} upper critical field inside the superconductor and B the magnetic field. The mass of the vortex calculated and it reflect that it is several hundred times than that of electronic mass m_e. Suhl [4] calculated the inertial mass per unit length of a flux line is about $4000 m_e$.

Theory:

We assumed [5] that moving fluxiods are subjected to harmonic force with force constant k, viscous force ηv proportional to velocity v and mass of the fluxiod is M, so the equation of motion is

$$M\frac{dv}{dt} + \eta v + kx = \frac{1}{c} J\Phi_0$$

We take the time dependence of fluxiod velocity as $v = v_0 e^{-i\omega t}$. After substitution this in the above equation we get the expression of velocity as

$$v = \frac{J\Phi_0 B}{c\left\{\eta - i\omega M + \frac{ik}{\omega}\right\}}$$

Moving fluxiod produces an electric field $E_\varphi = -\left(\frac{1}{c}\right) vB$, that opposes the current so that

$$E_\varphi = -\frac{J\Phi_0 B}{c^2\left(\eta - i\omega M + \frac{ik}{\omega}\right)}$$

Now the London equation in terms of vector potential is

$$J = -\frac{c}{4\pi\lambda_L^2}A$$

Differentiating this with respect to time and replacing the time derivative of vector potential, $-\frac{\partial A}{\partial t} = E + E_\varphi$ we write

$$\frac{dJ}{dt} = \frac{c^2}{4\pi\lambda_L^2}(E + E_\varphi)$$

Substituting the value of E_φ from the earlier equation to this equation and taking the time dependence of current as $J = J_0\, e^{-i\omega t}$ we find

$$J = E\left[\frac{\Phi_0 B}{c^2\left(\eta - i\omega M + \frac{ik}{\omega}\right)} - \frac{4\pi i\omega\lambda_L^2}{c^2}\right]^{-1}$$

Now the resistivity $\rho = \frac{E}{J}$ so that

$$\rho = \frac{\Phi_0 B(\eta - im)}{c^2(\eta^2 + m^2)} - \frac{4\pi i\omega\lambda_L^2}{c^2}$$

Where, $m = \frac{k}{\omega} - \omega M$. The complex resistivity now can be written as

$$\rho = \frac{\Phi_0 B\eta}{c^2(\eta^2 + m^2)} - i\left[\frac{m\Phi_0 B}{c^2(\eta^2 + m^2)} + \frac{4\pi\omega\lambda_L^2}{c^2}\right]$$

The real part of resistivity is

$$\rho_{real} = \frac{\Phi_0 B\eta}{c^2(\eta^2 + m^2)}$$

Substituting the value of m we get,

$$\rho_{real} = \frac{\Phi_0 B\eta\omega^2}{c^2(\omega^2\eta^2 + k^2 + \omega^4 M^2 - 2k\omega^2 M)}$$

For small vortex mass M can be neglected, so

$$\rho_{real} = \frac{\Phi_0 B\eta\omega^2}{c^2(\omega^2\eta^2 + k^2)}$$

Now substituting pinning frequency $\omega_p = \frac{k}{\eta}$ this equation becomes

$$\rho_{real} = \frac{\Phi_0 B\omega^2}{c^2\eta(\omega^2 + \omega_p^2)}$$

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Therefore, we see that measurement of resistivity as a function of frequency leads to the determination of pinning frequency. In dimensionless form this equation can be written as

$$\frac{\rho(\omega)}{\rho(\omega = const)} = \frac{\omega^2}{\omega^2 + \omega_p^2}$$

Comparison with Experiment:

The frequency dependence of the real part of resistivity of 2H-$NbSe_2$ at a field of 0.5 T and at a temperature 3K is measured by Henderson et al. [6]. They have plotted the resistivity relative to the value at 2.8 GHz in dimensionless units as a function of logarithm of frequency from 10MHz to 1000MHz. In Fig.1 the dimensionless resistivity is plotted as function of frequency according to the above equation which does not have any logarithmic term. The calculated values for ω_p = 145.7 MHz, 212.7 MHz and 327 MHz are shown. At low frequencies, the calculated curve with ω_p = 145.7 MHz fits the experimental data very well. It may be noted that only the frequency is varied to measure the pinning frequency but the temperature is kept constant. The symmetry of the system may change from s-wave to d-wave in varying the temperature and the flux lattice may melt [7,8]. Frequency dependence of rf power dissipation due to vortex oscillation using nanoparticle pinning centres reported by some researchers [9,10].

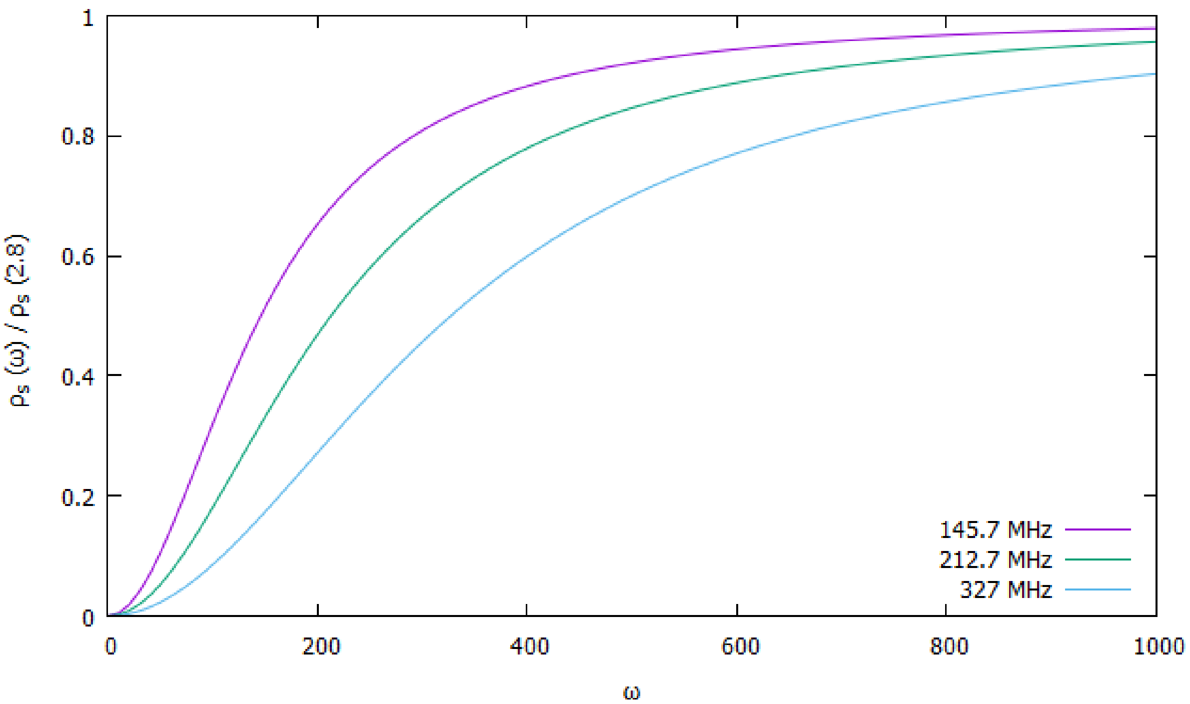

Fig.1 The relative surface resistivity as a function of frequency. Curves are shown for three different values of pinning frequency ω_p.

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Conclusion:

The vortex oscillation, viscosity and their kinetic energy all contribute to the resistivity of the sample. When the contribution of kinetic energy is small the measurement of resistivity leads to the evaluation of pinning frequency. Theoretical expression of resistivity given above is compared with the experimental measurement of resistivity of 2H-$NbSe_2$ as a function of frequency. The comparison shows that at high frequency the mass of the vortex may take part in resistivity.

References:

1. Stephen M.J. and Bardeen J., Phys. Rev. Lett. **14**, 112 (1965)
2. Bardeen J. And Stephen M.J., Phys. Rev. **140**, A1197 (1965)
3. Volovik G.E., JETP Lett. **65**, 217 (1997)
4. Suhl H., Phys. Rev. Lett. **14**, 226 (1965)
5. Ghosh P.K., Krishna N.M. and Shrivastava K.N., J. Phys. Condens. Matter **9**, L663 (1997)
6. Henderson W., Andrei E.Y.,Higgins M.J. and Bhattacharya S., Phys. Rev. Lett. **80**, 381 (1998)
7. Shrivastava K.N., Phys. Rev. B **41**, 11168 (1990)
8. Krishna N.M. and Shrivastava K.N., Physica B**230**, 939 (1997)
9. Haugan T., Barnes P.N., Wheeler R., Meisenkothen F. And Sumption M., Nature **430**, 867 (2004).
10. Gurevich A. and Ciovati G., Phys. Rev. B **87**, 54502 (2013).