Nb$_3$Sn single crystals, polycrystals and multifilamentary wires: common and different features in the magnetic response

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Abstract. The magnetic response of different Nb$_3$Sn samples has been investigated studying the temperature dependence of both the 1st and 3rd harmonics of the AC magnetic susceptibility, in presence of a DC field up to 19 T. In single crystal and in polycrystalline samples, the occurrence of a Peak Effect was observed within DC magnetic fields ranging from 3 T to about 13 T. It corresponds to a transition in the vortex lattice between the Bragg Glass phase and a disordered phase. This transition has been also detected at higher magnetic fields in both the samples, thanks to the 3rd harmonics measurements. In contrast to single crystals and polycrystals, no Peak Effect and no indications about the Bragg/disordered phase transition have been detected in the analysed multifilamentary wires.

1. Introduction

An universal field/temperature (H-T) phase diagram has been supposed for all the type-II superconductors with point defects [1]. It includes a transition in the vortex lattice between a disordered phase and the Bragg glass phase. This last one is characterized by a quasi long range order and a perfect topological order, where the vortex lattice stills survives, although the presence of the pinning [1]. In this work we analyzed the H-T phase diagram of the Nb$_3$Sn [2], by measurements of both the 1st and 3rd harmonics of the AC magnetic susceptibility. This experimental technique is very useful to investigate flux quanta properties, both vortex dynamics [3] and equilibrium properties [4]. We analyzed different types of samples, with different critical current densities $J_c$, pinning properties, geometrical shapes, compositional and structural characteristics, in order to investigate main parameters that influence the magnetic behavior.

2. Experimental results

We measured the 1st and 3rd harmonics of the AC magnetic susceptibility as a function of the temperature, at various DC magnetic fields up to 19 T, at a fixed frequency ($\nu = 107$ Hz) and amplitude ($h_{AC} = 128$ Oe) of the AC magnetic field. Measurements have been performed on three different Nb$_3$Sn samples: a single crystal [5], an homogeneous polycrystal [6] and a bronze route multifilamentary wire [7].
2.1. Single Crystal and Polycrystal

In Figures 1 and 2, the temperature dependence of the real part of both the 1st ($\chi_1'$) and the 3rd ($\chi_3'$) harmonics of the AC magnetic susceptibility are reported, as measured on the single crystal and the polycrystal, respectively. A dip in $\chi_1'$, corresponding to a peak in $J_c(T)$, can be observed in both the samples, for $H > 3$ T. It disappears at higher fields (at $H = 13$ T in the single crystal and at $H = 11$ T in the polycrystalline sample). The corresponding 3rd harmonics are characterized by a positive peak at low fields ($H < 3$ T) near $T_c$. A negative peak can be also detected in the polycrystal at lower temperatures, in the same DC field range. For increasing fields, two positive peaks can be only detected in both the samples: the first one, near $T_c$, is almost field independent, whereas the second one, at lower temperatures, decreases for increasing fields. The only peak near $T_c$ has been detected at high fields, where the Peak Effect cannot be observed anymore in the first harmonics. It is remarkable that, although the relative heights of the peaks are different in the two samples, the general behavior of the 3rd harmonics is the same.

![Figure 1](image1.png)  ![Figure 2](image2.png)

**Figure 1.** $\chi_1'(T)$ and $\chi_3'(T)$ as measured on a Nb$_3$Sn single crystal at various DC magnetic fields.

**Figure 2.** $\chi_1'(T)$ and $\chi_3'(T)$ measured on an homogeneous polycrystalline Nb$_3$Sn sample, at various DC magnetic fields.

In Figure 3, the reduced H-T phase diagram is shown, both for the single crystal and the polycrystalline sample. It has been obtained by plotting $T_c$ and the dip-temperature, $T_p$, extracted from the 1st harmonics measurements, and the onset temperature of the positive peak near $T_c$, from the 3rd harmonics curves, $T^+\big(\chi_3'\big)$, at various DC fields. The irreversibility temperature, measured as the onset of the 3rd harmonics, corresponds to $T_c$ for both the samples, so it has not been reported.
Figure 3. Reduced H-T phase diagram of the Nb₃Sn single crystal and polycrystalline sample.

From Figure 3, we can observe that the two analyzed samples have the same reduced phase diagram. In particular, a disordered phase can be individuated in the region between $T_c$ and $T_p$. The $T^* (\chi'_3)$ line coincides in both the samples with $T_p$ and it corresponds to the transition temperature between a disorder and the Bragg Glass phase. As we already showed [4], the 3rd harmonics is a very powerful tool to detect the Disordered/Bragg phase transition, in particular in the high field/low temperature region, where the 1st harmonics fails. It is remarkable to observe that the two samples have different superconducting characteristics, geometrical shapes, pinning and structural properties [5-7]. Nevertheless, our experimental results imply that all of these features do not significantly influence the H-T phase diagram.

2.2. Bronze Route Multifilamentary wire

In Figure 4, the temperature dependence of $\chi'_1$ and $\chi'_3$ performed on a bronze route multifilamentary wire is shown. A different magnetic behaviour has been observed in this sample. In particular, no dip (so No Peak Effect) has been detected in the 1st harmonics of the AC magnetic susceptibility. Moreover, no indications about the transition between a disordered and the Bragg Glass phase can be detected in the 3rd harmonics measurements, too. In particular, 3rd harmonics curves show a negative minimum in the low temperature region, growing for increasing fields, which was absent in the single crystal (see Figure 1) and present in the polycrystals for low fields ($H < 3$ T) only (Figure 2). This negative minimum is also in disagreement with what predicted by the static Bean model and we suppose it is due to vortex dynamical phenomena (similar to what observed for HTS) [3]. The corresponding H-T phase diagram, shown in Figure 5, is only characterised by the disordered phase, with an irreversibility line ($T_m$) clearly distinct from the $T_c$ ones, in agreement with the H-T phase diagram reported in literature for other similar wires [8]. Further investigations are necessary to individuate main causes of the observed differences between mono and polycrystalline samples on a side and the analysed wire on the other side.
3. Conclusions

Measurements of the 1\textsuperscript{st} and the 3\textsuperscript{rd} harmonics of the AC magnetic susceptibility have been used to investigate the H-T phase diagram of three different Nb\textsubscript{3}Sn samples: a single crystal, a polycrystal and a bronze route multifilamentary wire. We observed that the single crystal and the polycrystal have the same reduced phase diagram, characterized by a transition phase between a disordered and the Bragg Glass phase. On the contrary, the wire has a different magnetic behavior, in which only the disordered phase can be distinguished and, inside of it, the Irreversibility Line can be detected (not observed in the previous samples). Further analysis are necessary to investigate these magnetic differences between the wire and the single crystal and polycrystalline samples.

References

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