Experimental report

26/01/2018

Proposal: **5-42-456** **Council:** 10/2016

Title: Metastable states of flux line ensembles and the Bragg glass

Research area: Physics

This proposal is a new proposal

Main proposer: **Camilla BUHL LARSEN**

Experimental team: Mark LAVER
Camilla BUHL LARSEN

Local contacts: Robert CUBITT

Samples: Vanadium

Instrument	Requested days	Allocated days	From	To
D11	5	0		
D33	5	3	13/02/2017	16/02/2017
D22	4	0		

Abstract:

The behaviour of flux line lattices (FLL) in type-II superconductors are heavily affected by the presence of impurities in the sample. Impurities or crystalline defects reduce the order parameter and thereby act as pinning sites for the vortices. At low fields and temperatures the flux line lattice exists in the so-called Bragg glass (BrG) phase, a phase characterized by an algebraically decaying translational order, where the vortices are only weakly distorted by the pinning sites. As the field or temperature is increased dislocations in the flux line lattice cause the quasi-long range order to be replaced by short-range correlations, signifying the transition to a disordered vortex glass phase.

ILL Experimental Report, Experiment 5-42-456

Metastable states of flux line ensembles and the Bragg glass

Experimental team

C. B. Larsen[1], R. Cubitt[2], and M. Laver[1]

[1]*School of Metallurgy and Materials, University of Birmingham, United Kingdom*
[2]*Institut Laue–Langevin, 71 Avenue des Martyrs, 38042 Grenoble, France*

1 Background

The behaviour of the flux line lattice (FLL) depends on a number of different parameters of the superconducting sample, such as temperature, applied field, density and type of impurities. In the weak pinning regime, where vortices are only weakly affected by impurities or crystal defects, the vortices retain an algebraically decaying translational order[1, 2, 3]. The resulting ordered phase, known as the Bragg glass phase, is of interest because it can be used as a general model for the behaviour of a crystalline material with added weak disorder. Upon increasing the applied field or temperature, the quasi-long range order breaks down, and the vortex ensemble is expected to undergo a transition to a disordered vortex glass phase[4].

Preceding measurements on the behaviour of the vortex lattice close to the order-to-disorder transition were carried out at the FRM-II with a cylindrical vanadium sample. Close to the transition, it was observed that translational order can be restored in the vortex glass phase by applying a perpendicular oscillatory field, thereby "wiggling" back the transition line. In general, it was recognized that larger oscillatory fields resulted in higher Bragg peak intensities. In the current study at the ILL, we have continued the exploration of the effect of oscillatory fields on the metastable states in vanadium. Furthermore, we have utilized the high flux at D33 to make detailed measurements of the decay of positional order in the Bragg glass phase.

2 Experimental details

SANS measurements were carried out on a vanadium single crystal disc. The main static field was applied along the ⟨111⟩ direction of the sample and perpendicular to the beam direction. The vanadium sample was mounted within a Helmholtz coil stage which allows a small oscillating field to be applied perpendicular to the static field direction of

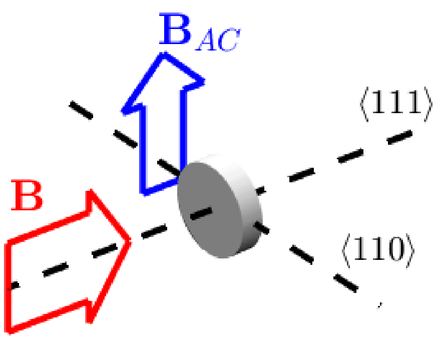

Figure 1: Illustration of the experimental setup. The vanadium sample had a diameter of 5 mm and a thickness of two diameter. The static field was applied along the face of the sample (red arrow), corresponding to the ⟨111⟩ direction. The oscillating field (red arrow) was applied perpendicular to this direction, along the ⟨110⟩ direction.

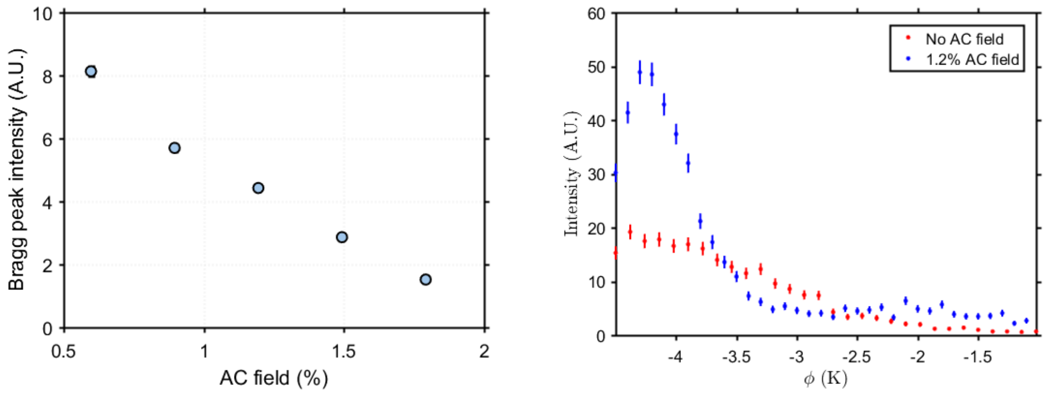

Figure 2: Left: Neutron intensity summed over the Bragg spot on the detector at the peak of the rocking curve as a function of the AC field amplitude. The AC field had a frequency of 50 Hz and its amplitude is given as a percentage of the main field (310 mT). **Right**: Rocking scans concentrated on the tail of the Bragg peak carried out at 250 mT, with and without an 1.2% 50 Hz AC field.

the cryomagnet. An illustration of the sample orientation is shown in Fig. 1. With the intent of making measurements of the peak tails with good statistics, the first part of the experiment was dedicated to optimizing the configuration of the instrument. A neutron wavelength of 10 Å and a collimation of 10.3 m was used. As part of the investigation, parameters of the oscillating field were also studied. The Helmholtz coil stage used here permitted larger oscillating fields than those we have previously measured. Results of the investigations are shown in Fig. 2, where the left plot depicts an amplitude scan carried out at 1.5 K. It is apparent that the Bragg peak intensity decreases at high AC field values, indicating an detrimental effect on the translational order of the vortex lattice. A similar scan carried out at base temperature with a 250 mT static field and a 1.2% AC field showed no discernible frequency dependence. The right plot in Fig. 2 depicts two full rocking scan test measurements of the tail of the peak. While the amplitude scan showed that the order of the vortex lattice can be weakened if the AC field amplitude is too high, we still see a clear improvement in peak intensity and width compared to the completely unshaken case.

A field scan was carried out at base temperature and showed that the Bragg peak intensities become negligible around 340 mT. Accordingly, it was decided to take a high statistic measurement at base temperature and with a main field of 250 mT, seeing as this should be firmly in the Bragg glass phase. Additionally, a high statistic measurement was taken at base temperature and with a 310 mT field, as this allows us to probe how the peak shape changes as the order to disorder phase transition line is approached.

3 Preliminary results

Due to time constraints, we were limited to two high-statistic measurements of the Bragg peak tail at static fields of 250 mT and 310 mT. Both measurements were performed with an applied AC field in order to get as close to the equilibrium ground state as possible. High-statistics background measurements were also performed at both field strengths. After ensuring that there was no field dependence, the two background measurements were added together in order to optimize the statistics. The background-subtracted tail measurements are shown in Fig. 3. At 250 mT, where the vortices are only weakly affected by pinning, intensity decays as a power-law determined to be 2.6(1), which is well in line with the Bragg glass theory[2, 3]. As the vortex glass phase is approached, the Bragg peak intensity and also the apparent power-law exponent decrease. A full reverse Monte Carlo analysis of the full real-space correlation functions[2] have been inhibited by the mosaicity in this particular sample, as discerned from the bumps appearing far out in the peak tails.

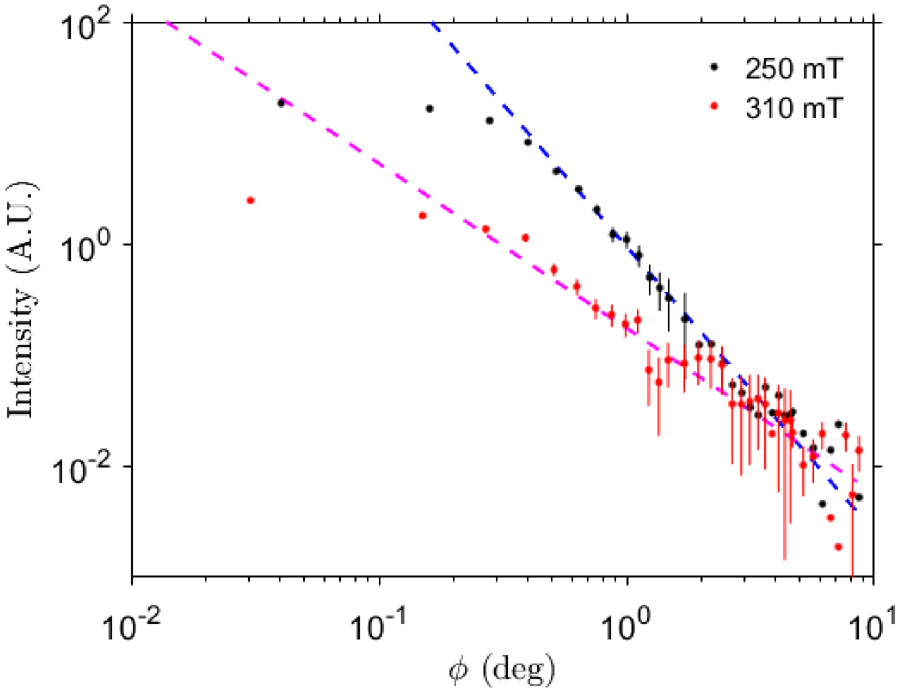

Figure 3: High-statistics tail measurements of the Bragg peak at 250 mT and 310 mT. The x-axis has been offset such that the peak-centre is located at 0°. Both measurements have been performed with an applied 50 Hz AC field of 1.2% of the static field strength. Counting times for data points close to the centres of the peaks are up to 1 minute, while counting times for data points far out in the tails are up to 16 minutes per point. The straight lines are power law fits with exponents 2.6(1) (blue) and 1.5(1) (pink).

In conclusion, detailed measurements have been made of the Bragg peak tails in the Bragg glass phase, which can be used for further analysis of the decaying order. In addition, we have performed a systematic investigation of the effect of an applied oscillatory field. Conjointly with other experimental data from samples with different geometries, this can help illuminate the pinning in the vortex glass phase.

References

[1] T. Klein *et al.*, Nature **413**, 404 (2001)

[2] M. Laver *et al.*, Phys. Rev. Lett. **100**, 107001 (2008)

[3] T. Giamarchi and P. Le Doussal, Phys. Rev. B **52**, 1242 (1995)

[4] J. Kierfeld *et al*, Phys. Rev. B **55**, 626 (1997)