# Force spectroscopy across a flux line

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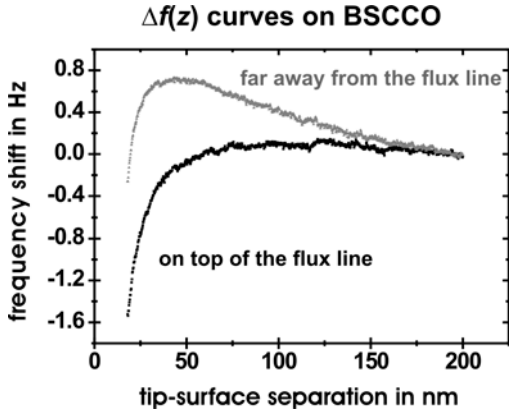
Using force spectroscopy in the dynamic frequency modulation mode at low temperature, we measured the interaction between a magnetic tip and an individual flux line trapped by an artificial columnar defect in a $Bi_2Sr_2CaCu_2O_{8+\delta}$ single crystal [1]. Frequency shift versus distance data were recorded on top and far away from a flux line (see Fig. below) and converted into force-distance curves. In the undisturbed superconducting region the repulsive Meissner force amounts to about 4 pN for a tip-surface separation of about 40 nm. Since the core of a flux line is normal conducting, the Meissner force vanishes directly above it. For a tip-magnetization aligned parallel with the flux line polarity, we determined a magnetostatic attraction of about 5 pN. Evaluating spectroscopy data obtained across a flux line, we could reconstruct the tip-sample interaction energy landscape around the flux line. This allowed us to further estimate the lateral magnetostatic dragging force exerted by the tip on the flux line to about 1.5 pN. Both, the lateral as well as the vertical interaction force are in good quantitative agreement with theoretical calculations, where the tip is modelled as a point magnetic charge.




[1] U. H. Pi *et al*., Appl. Phys. Lett. **85**, 5307 (2004)