Remote Magnetic Sensing of Plastically Deformed Steel

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Outline

- Motivation
- Introduction
- Materials and Methodology
- Results and Discussion
- Conclusion
- Acknowledgements

Motivation

https://www.google.ca/search?q=pipe+digging+for+testing&rlz

Collection of above-ground survey data.

Pipes– Residual Magnetization

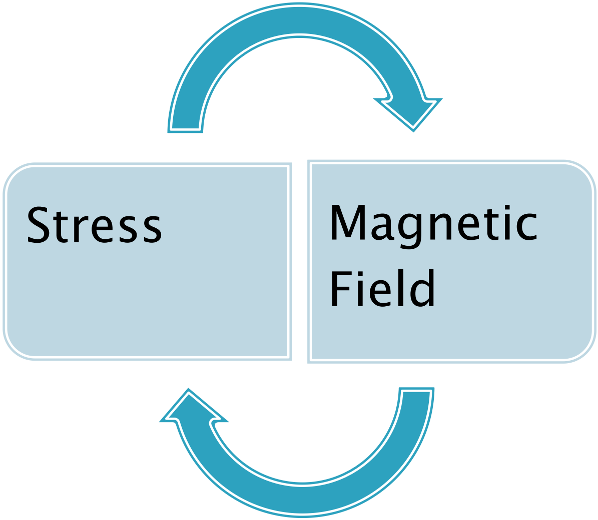
- Underground steel pipes – carrying high pressure fluid or gas – Stress from internal pressure, placement and ground settling produces residual magnetization
- Orientation of pipes with respect to Earth's magnetic field
- Pipe manufacturing process may also cause residual magnetization
- Stress concentration zones and anomalies cause a local change in magnetic permeability – Self Magnetic Flux Leakage (SMFL)
- Metal Magnetic Memory (MMM) – Contact and Non-Contact methods

Advantages of MMM

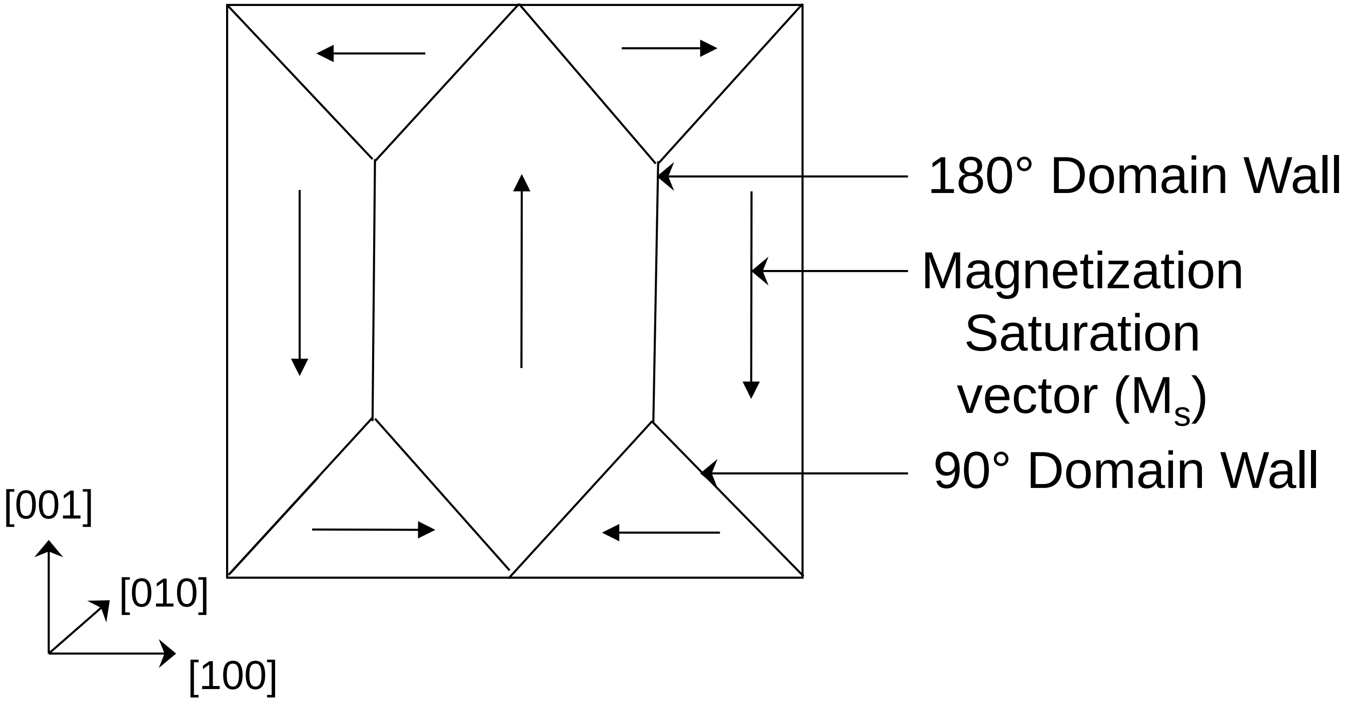
- No external applied magnetic field is required
- Larger detection distance compared to other currently used methods
- Easy to use and time saving process
- Effective in detection of stress induced magnetization in steel pipeline material

Magnetization due to Stress

Metal Magnetic Memory (MMM): Based on the principle of Inverse Magnetostriction (Piezomagnetic effect or Villari effect)

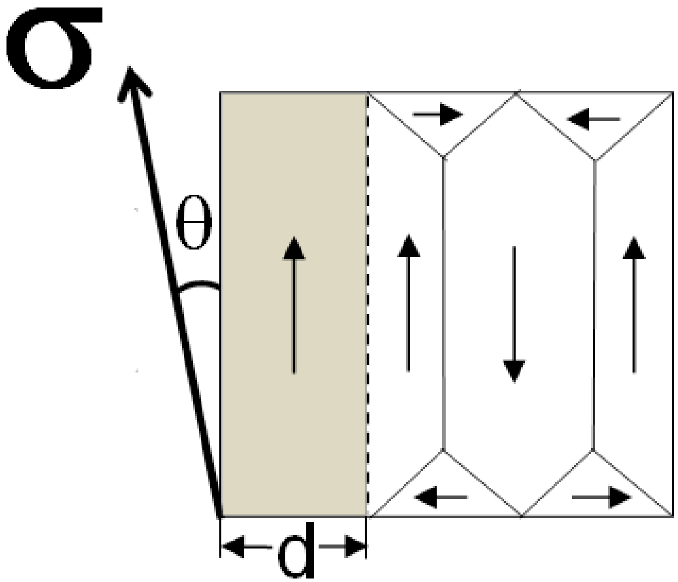


Magnetic Domains



T.W. Krause and A. Samimi, "Micromagnetic Techniques", in ASM HandbookVolume17: Nondestructive Evaluation and Quality Control, 515-530, 2018.

Magnetic Domains under Stress



$$E_\sigma = \frac{3}{2}\lambda_s \sigma cos^2\theta$$

E_σ – magnetoelastic energy
θ – angle between saturation magnetization of the domain and applied stress (σ)
λ_s – saturation magnetostrictive constant

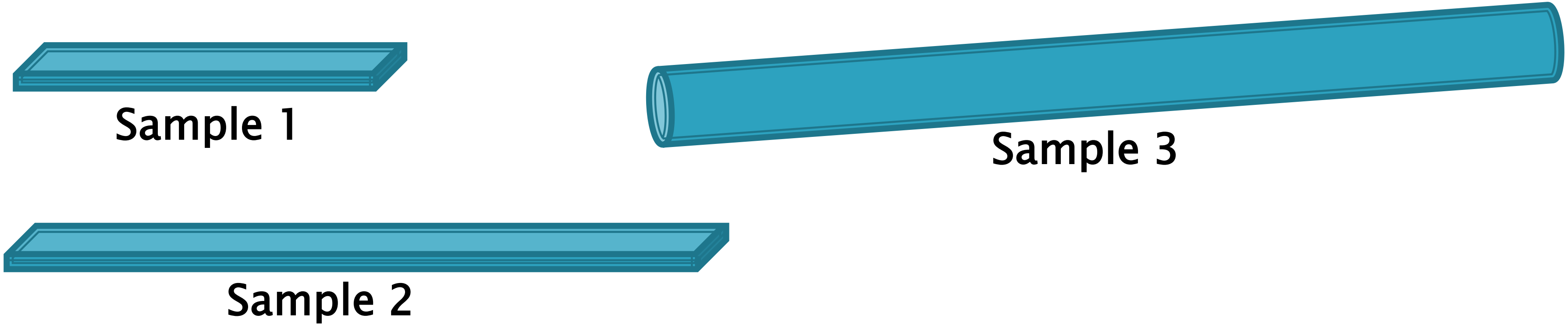
M. Kashefi, T. W. Krause, L. Clapham, P. R. Underhill and A. K. Krause, "Stress Induced Self Magnetic Flux Leakage at Stress Concentration Zone".

Materials and Methodology

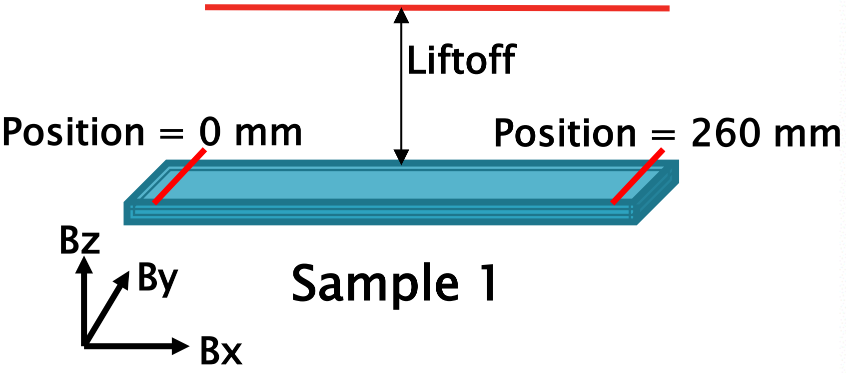
Sample	Shape	Length(mm)	Width/Outer diameter (mm)	Thickness (mm)
Sample 1	Bar	275	19	3
Sample 2	Bar	560	19	3
Sample 3	Tube	1170	32	1.8

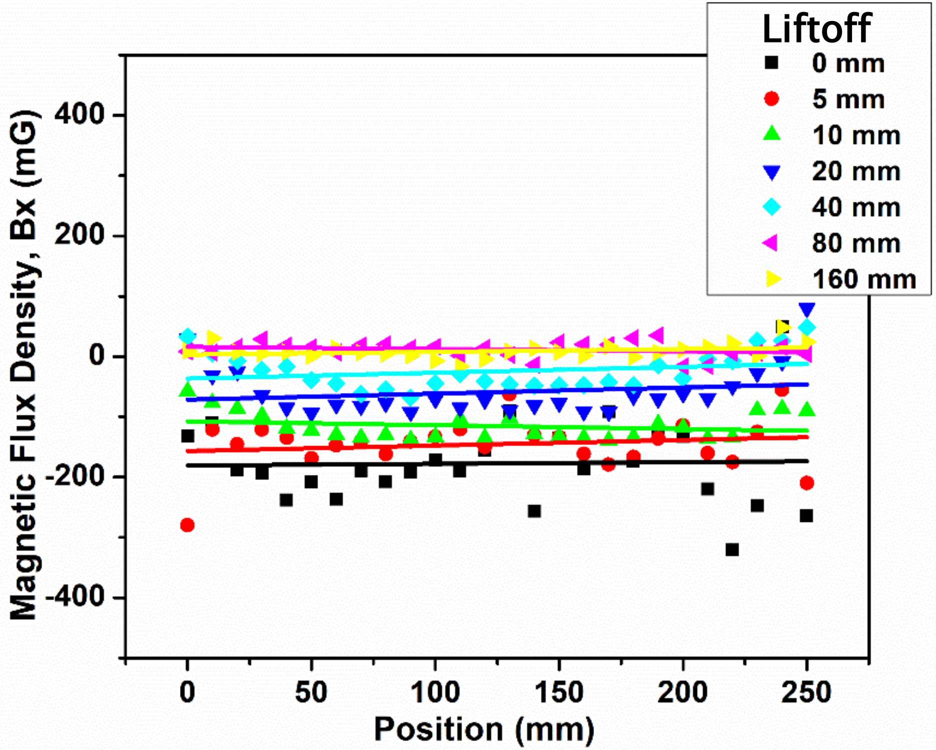
<u>Sensor used</u>

- Honeywell 3-Axis (HMC 5883L) anisotropic magnetoresistive (AMR) sensor
- 4.5 milliGauss (mG) resolution
- ±8 Gauss maximum field range



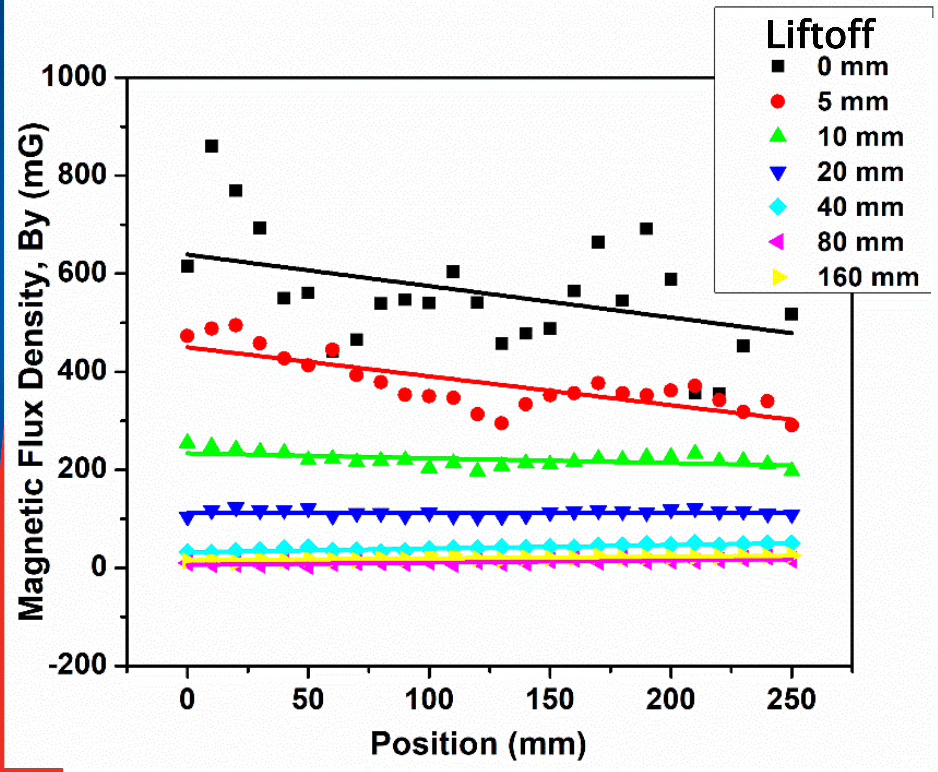
Sample 1 – Short Bar

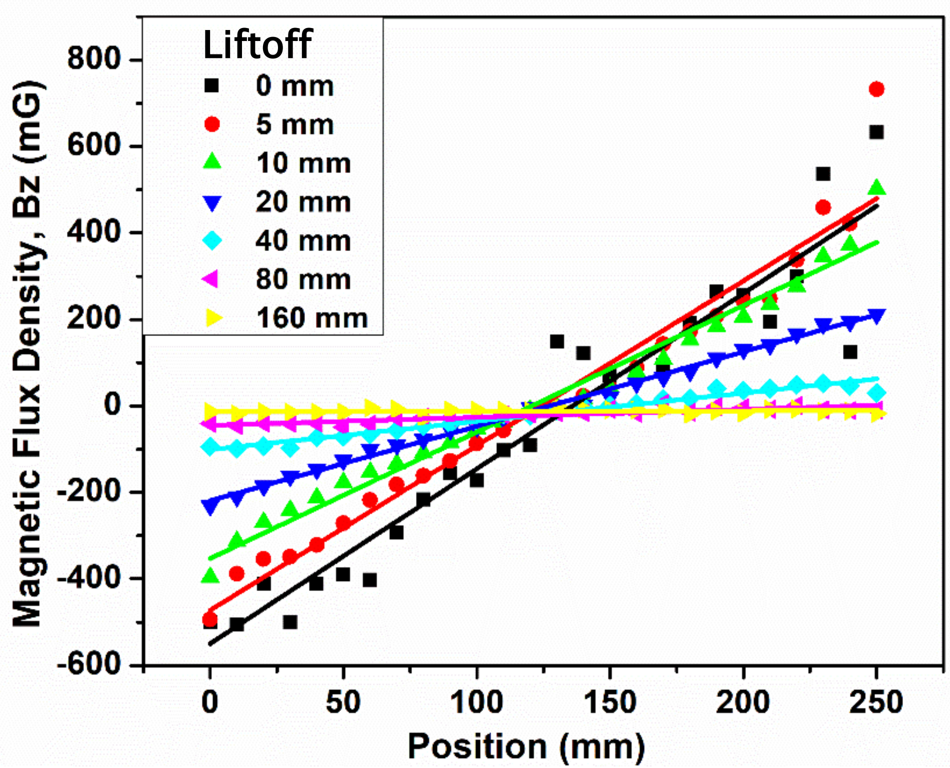




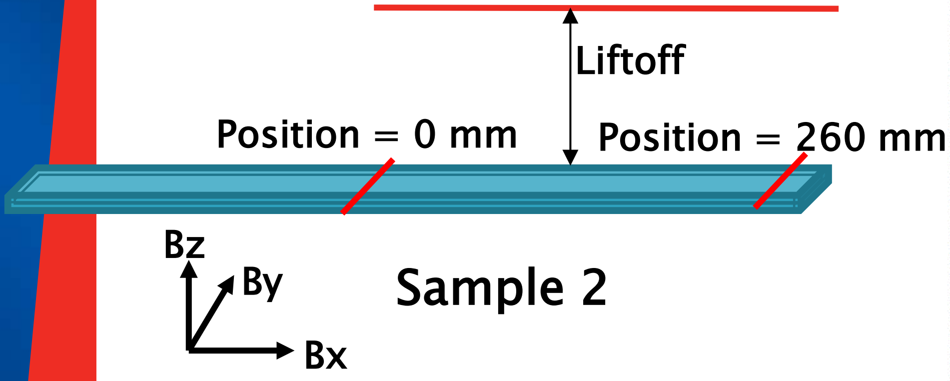
Sensor
X – along the long edge of the sample
Y – perpendicular to the paper
Z – normal to the sample surface

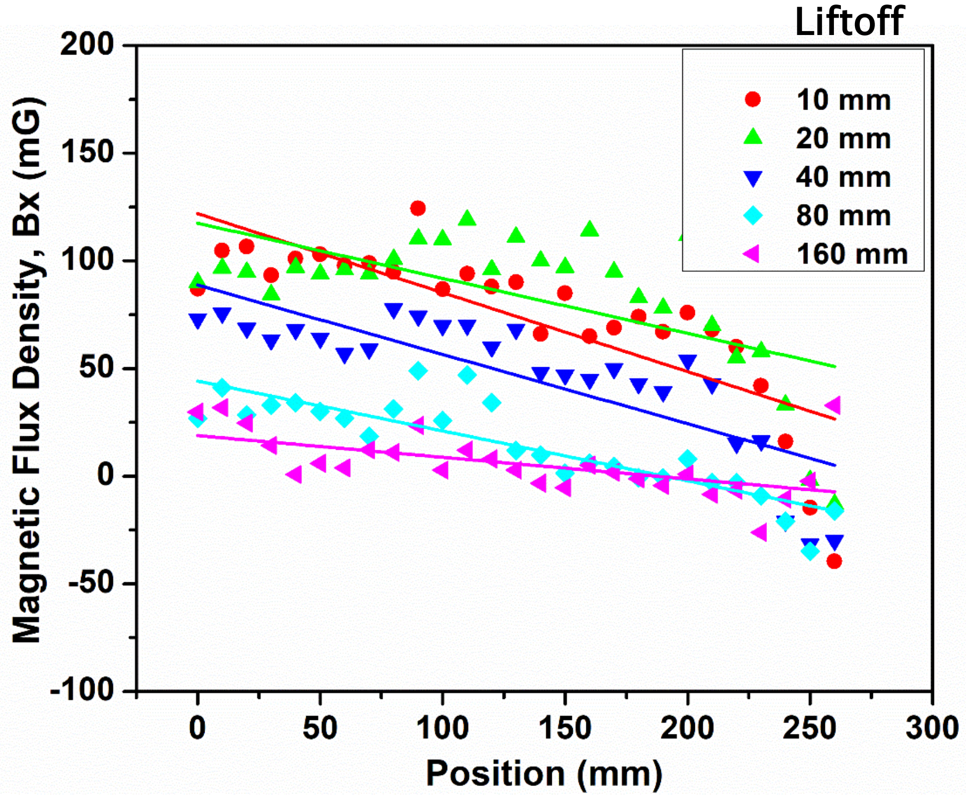
Sample 1 – Short Bar



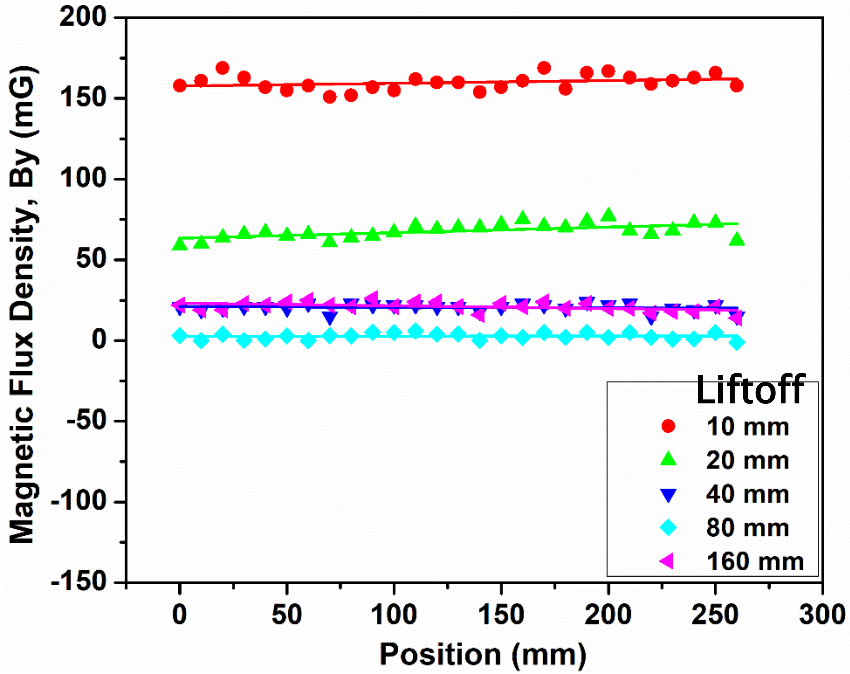


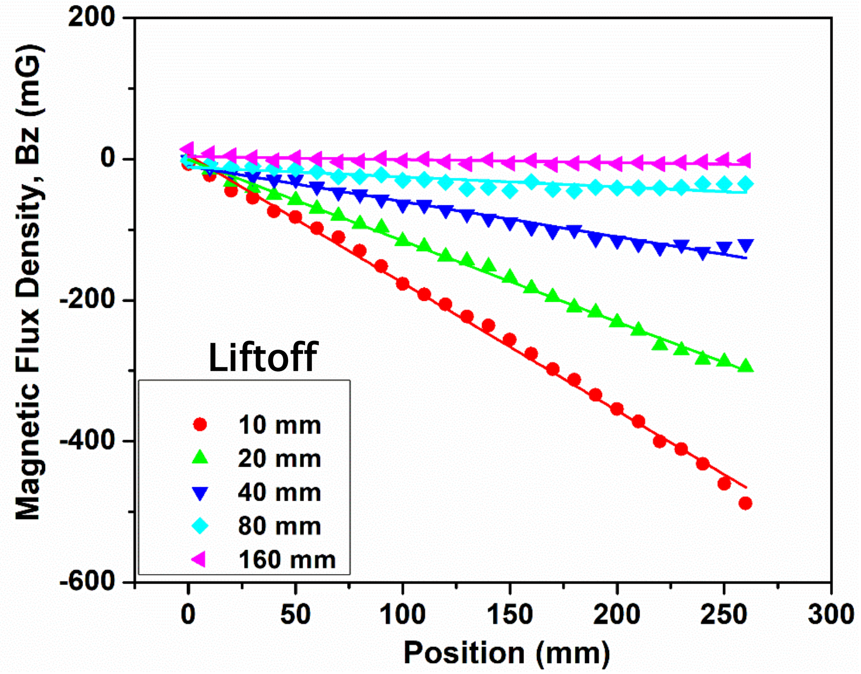
Sample 2 – Long Bar



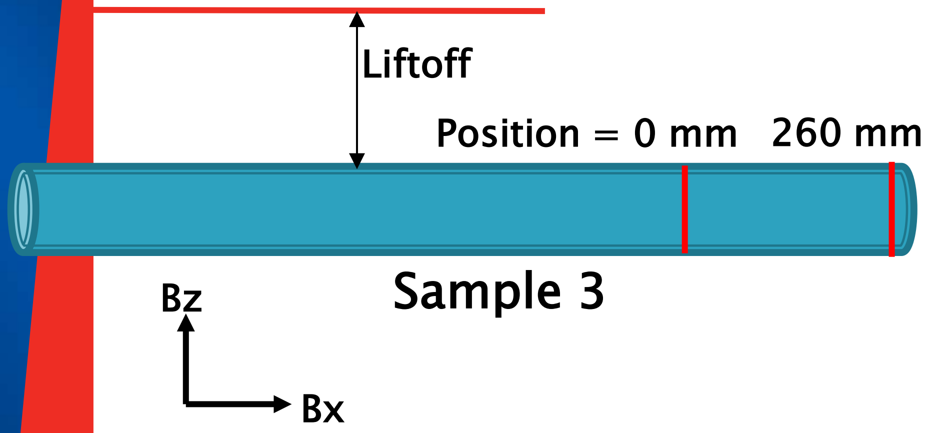


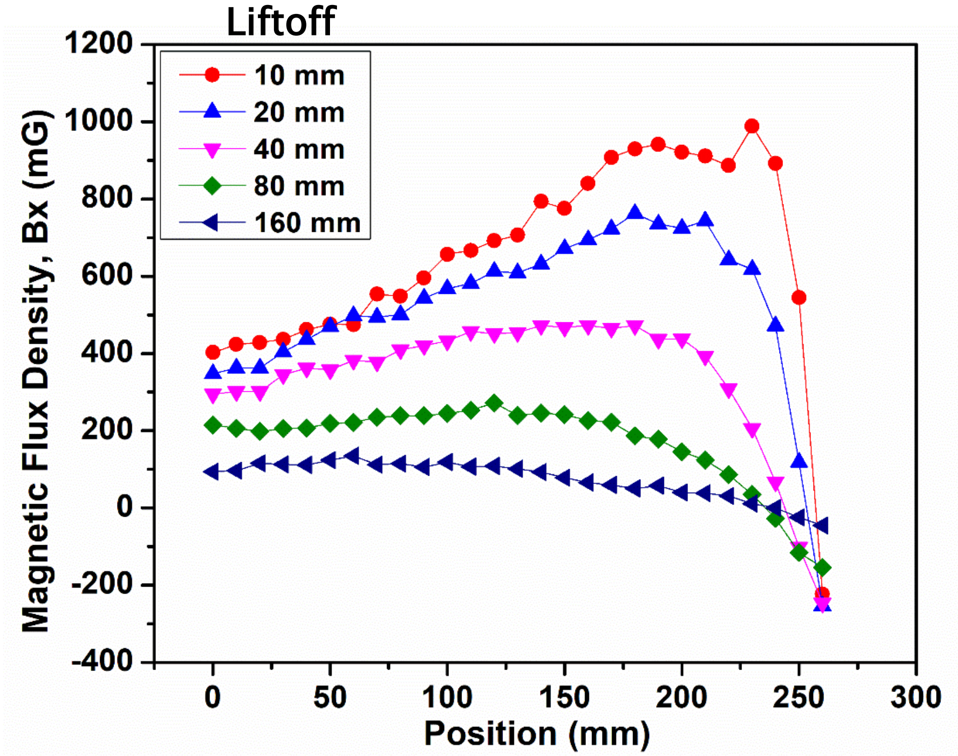
Sample 2 – Long Bar





Sample 3 – Tube





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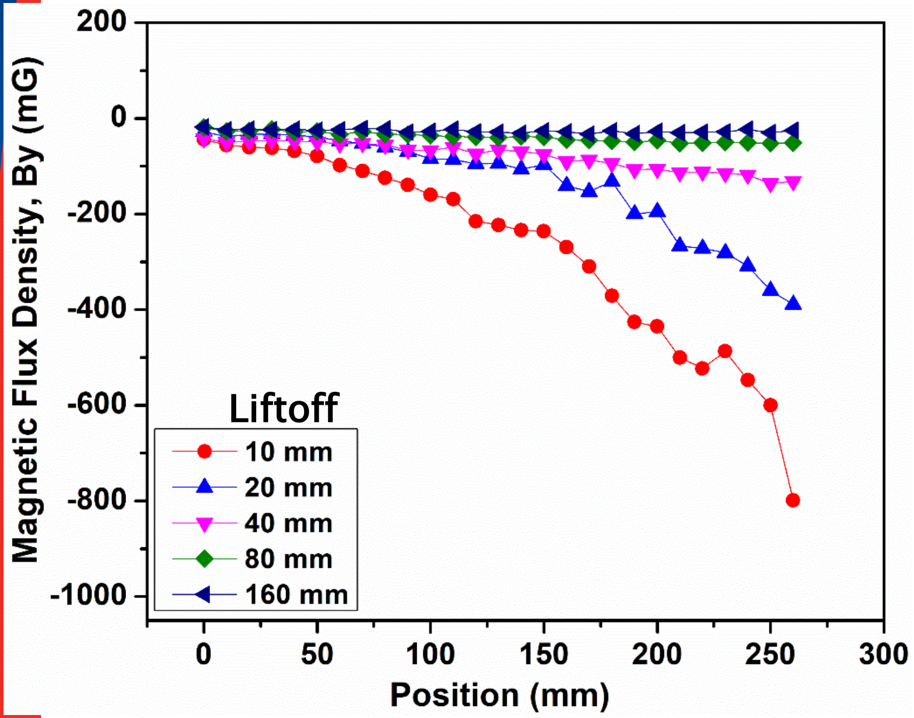
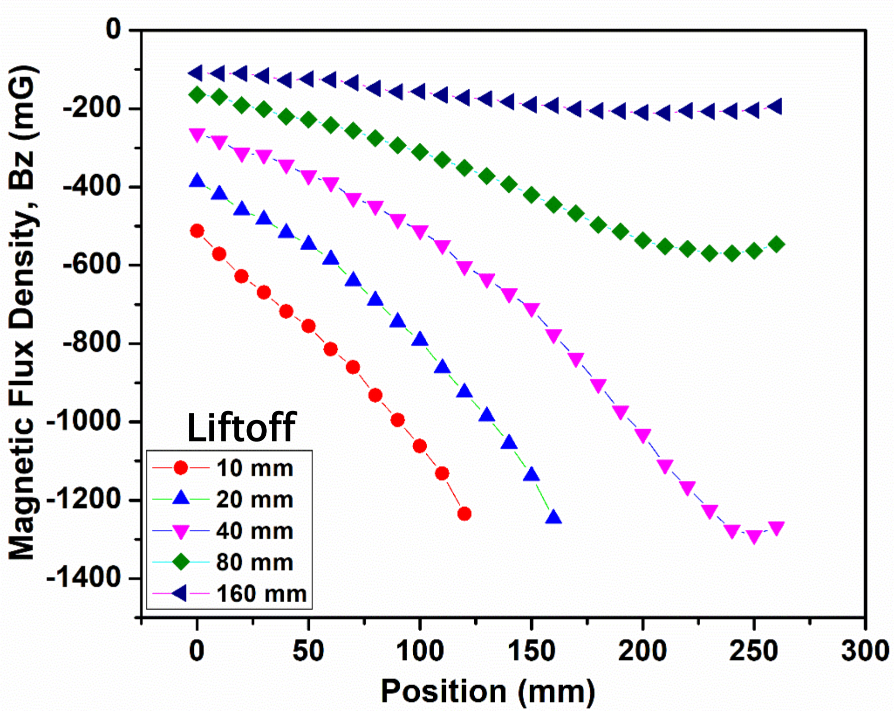
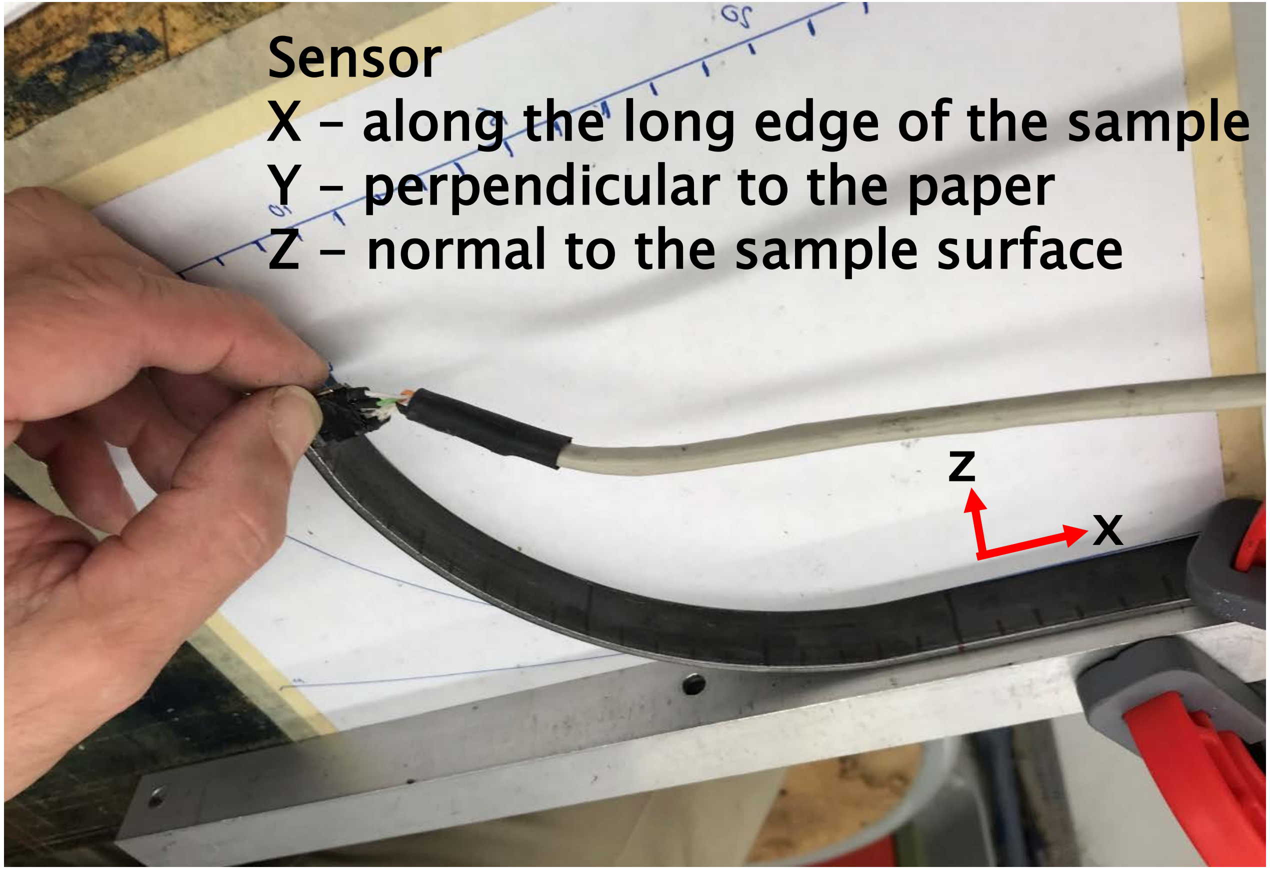
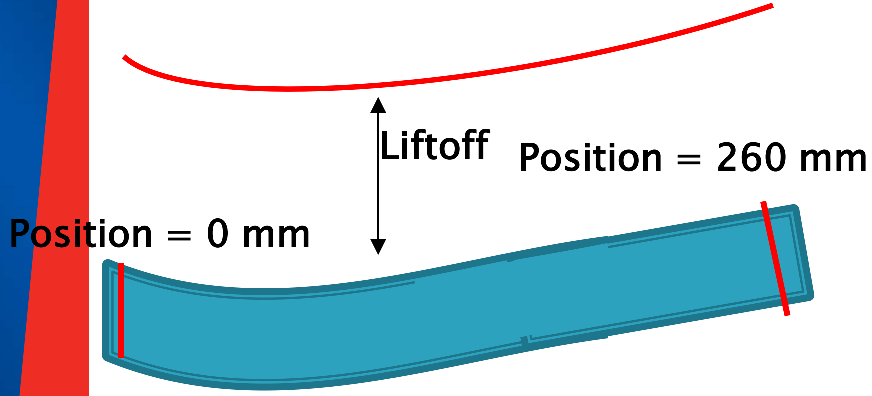


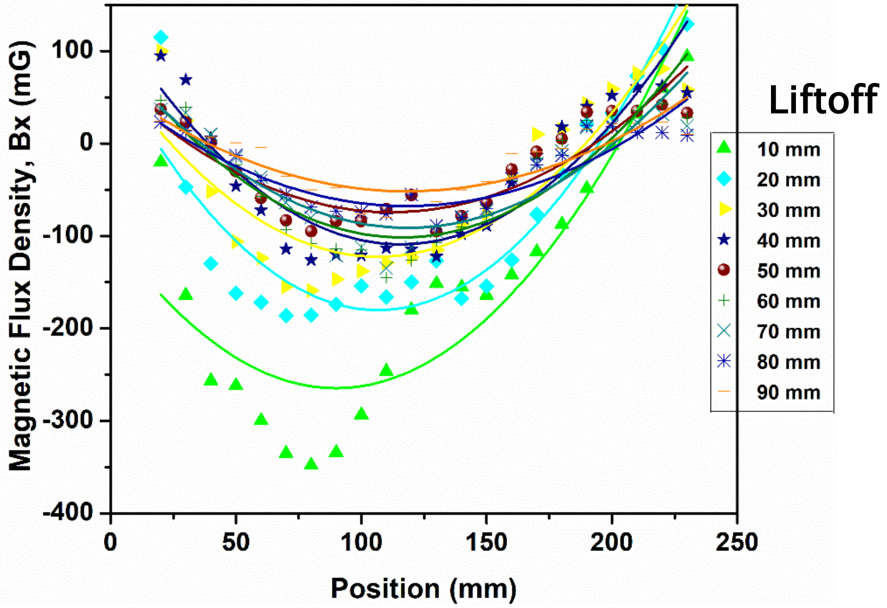


Bending Stress – Short Bar Sample



Bent Short Bar Sample 1





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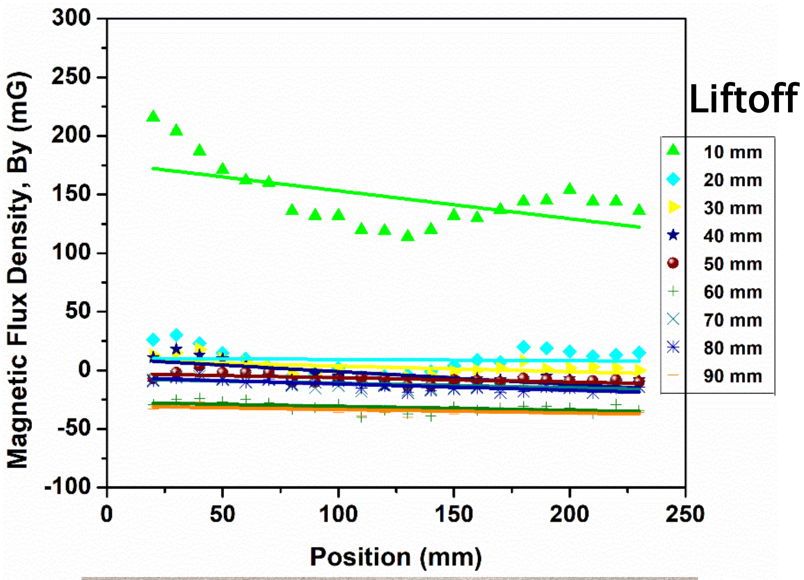
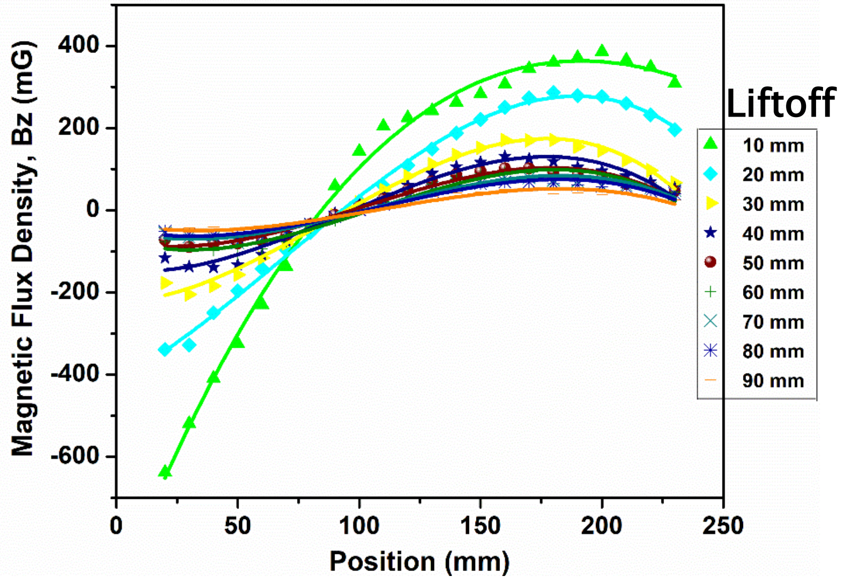
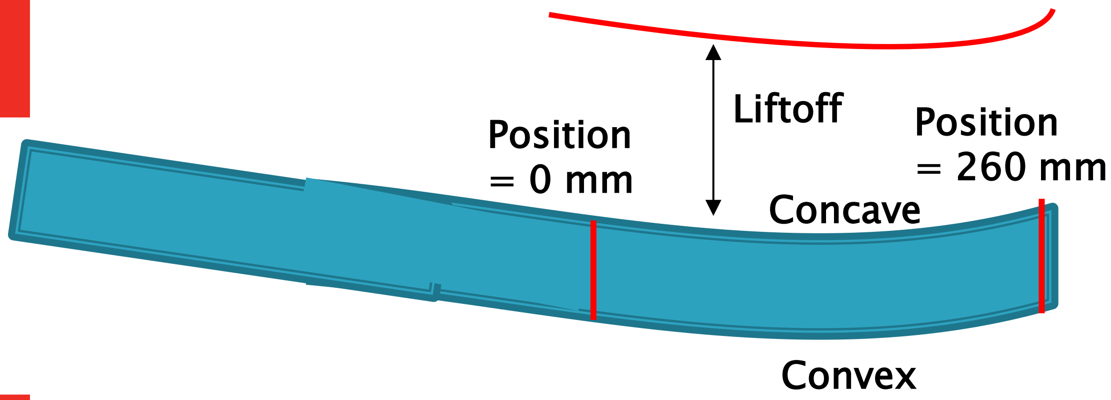
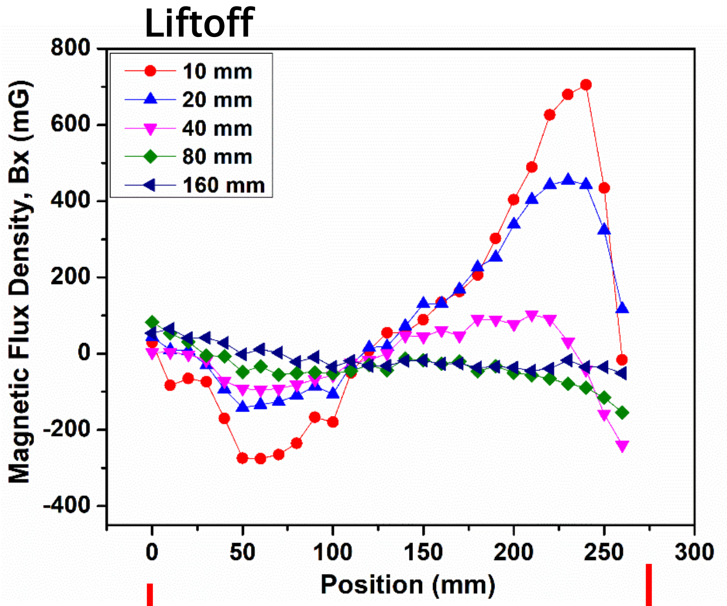




Bent Tube Sample 3





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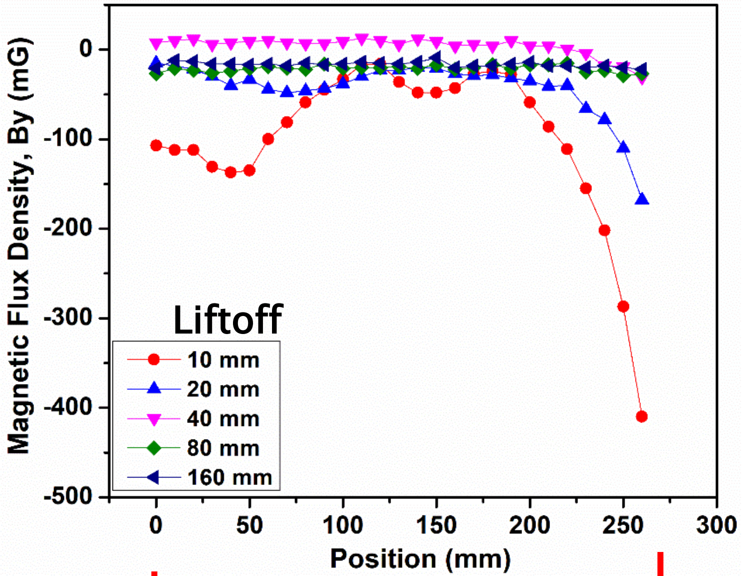
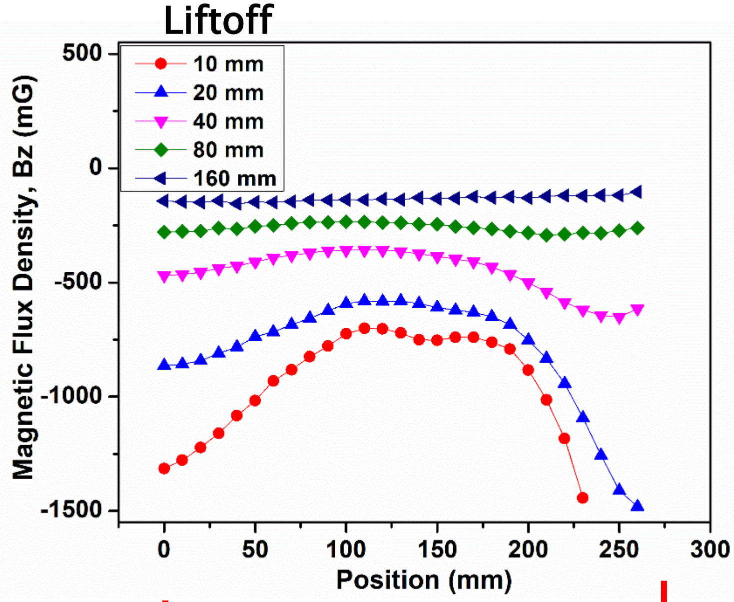
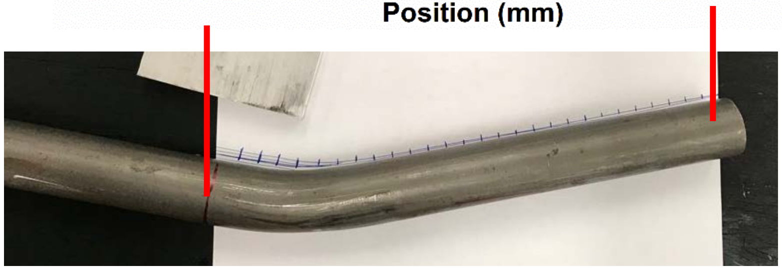
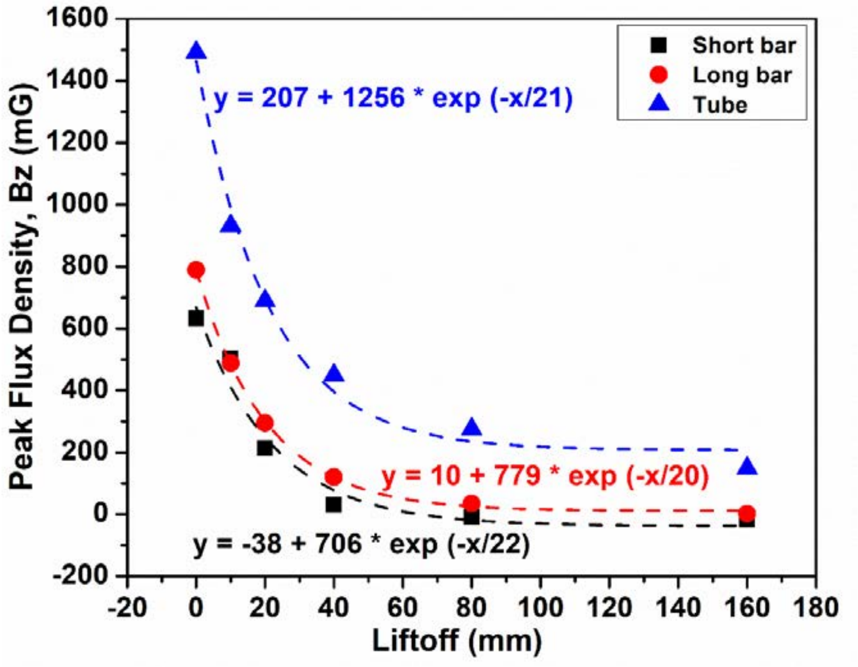




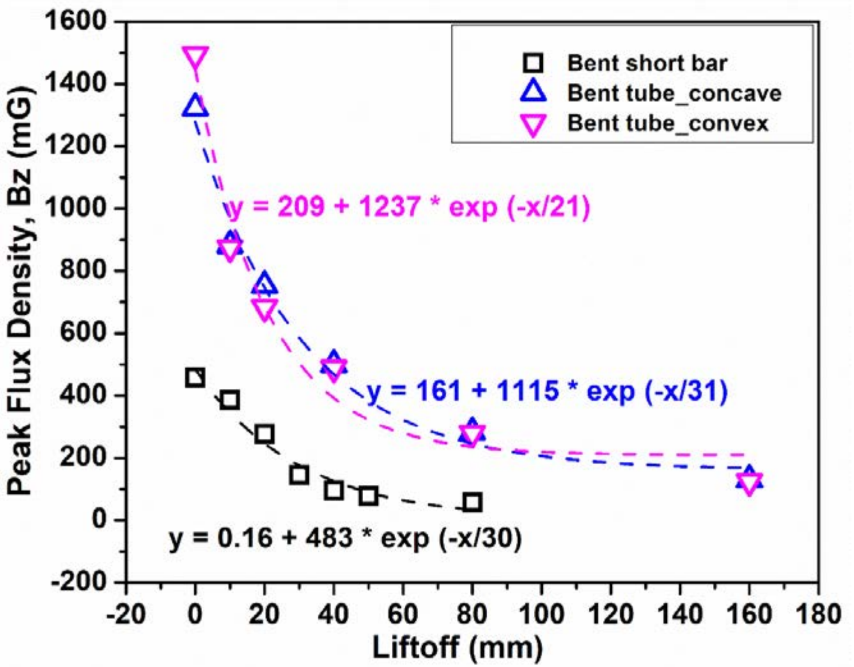


Effect of Bending

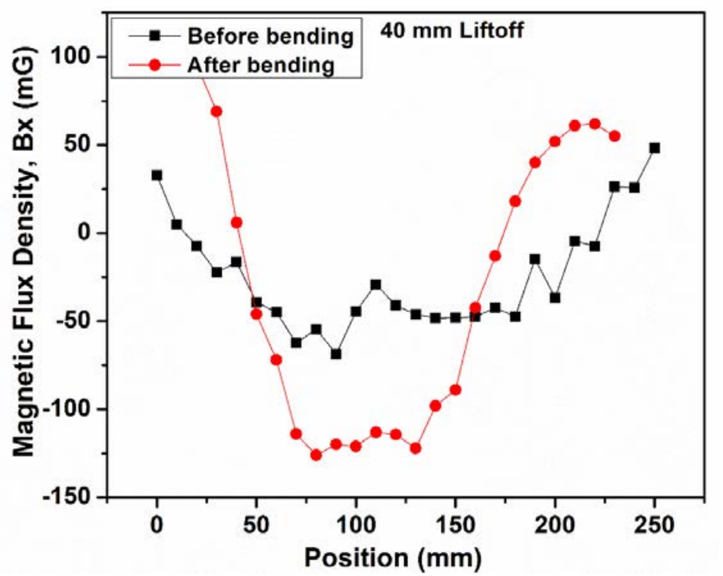
Before bending

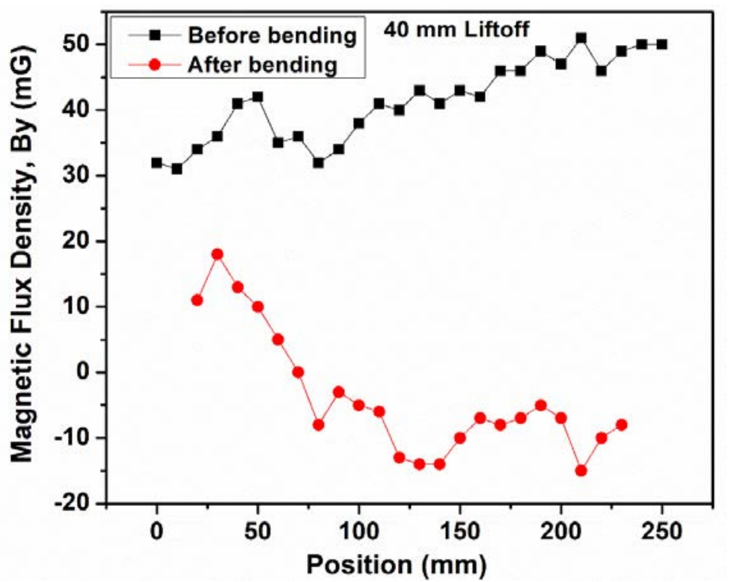


After bending



Effect of Bending_Short Bar Sample 1





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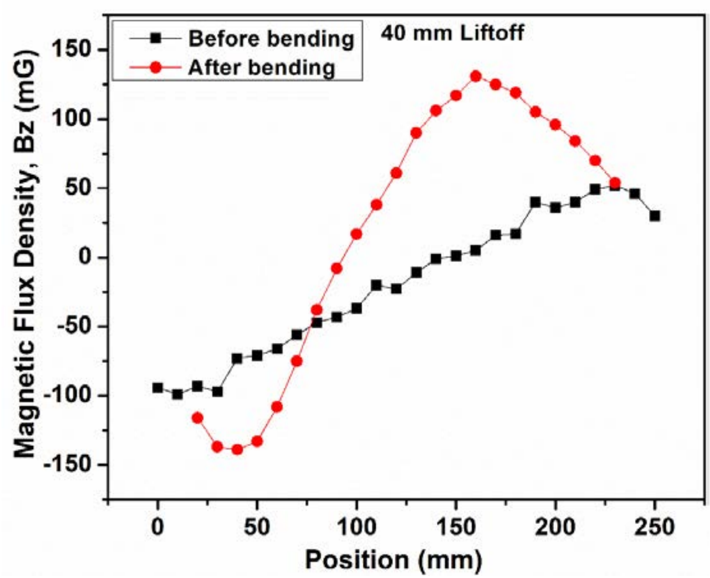
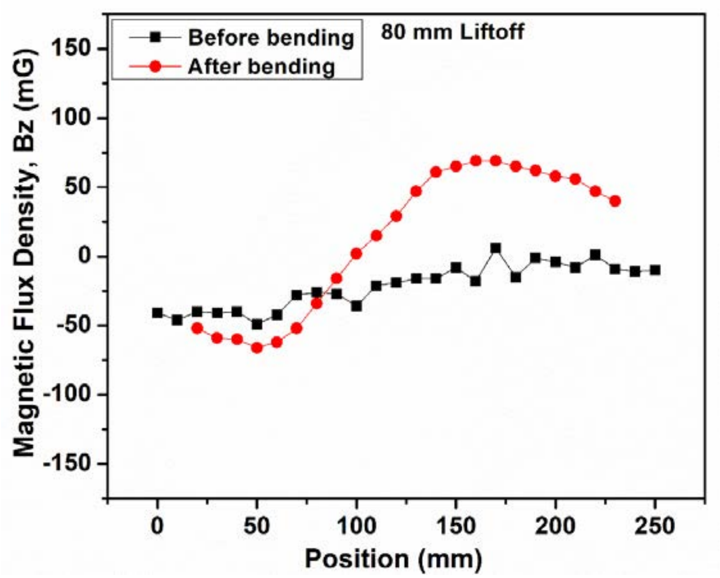
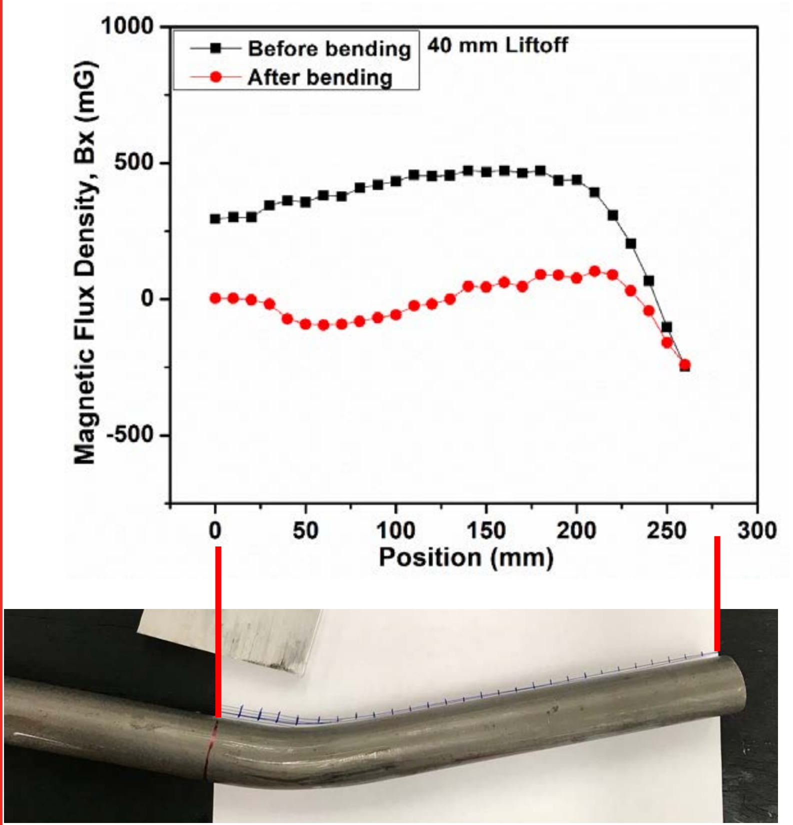
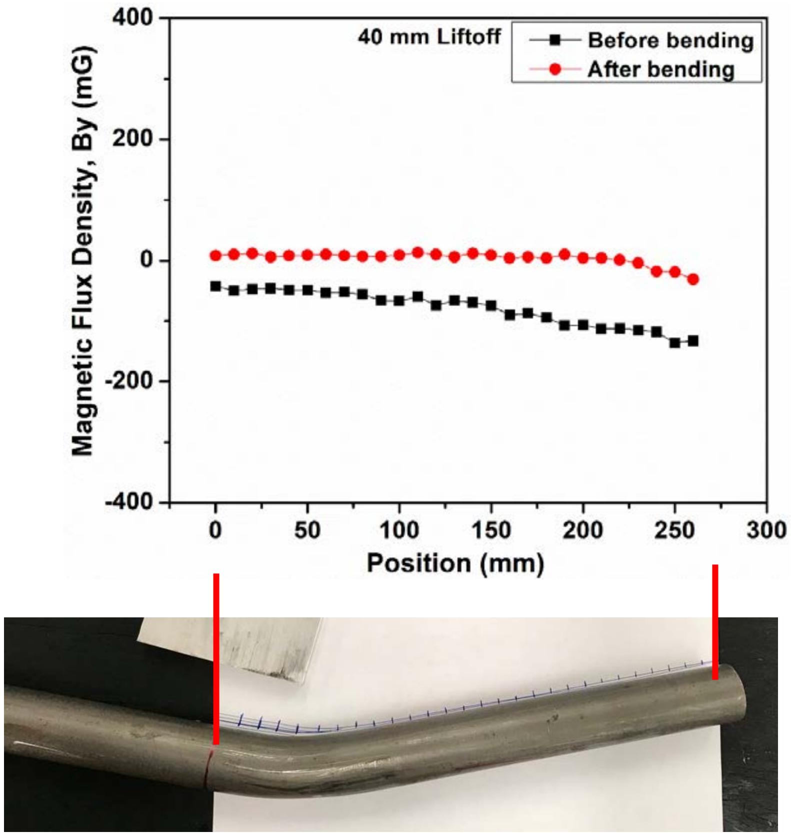


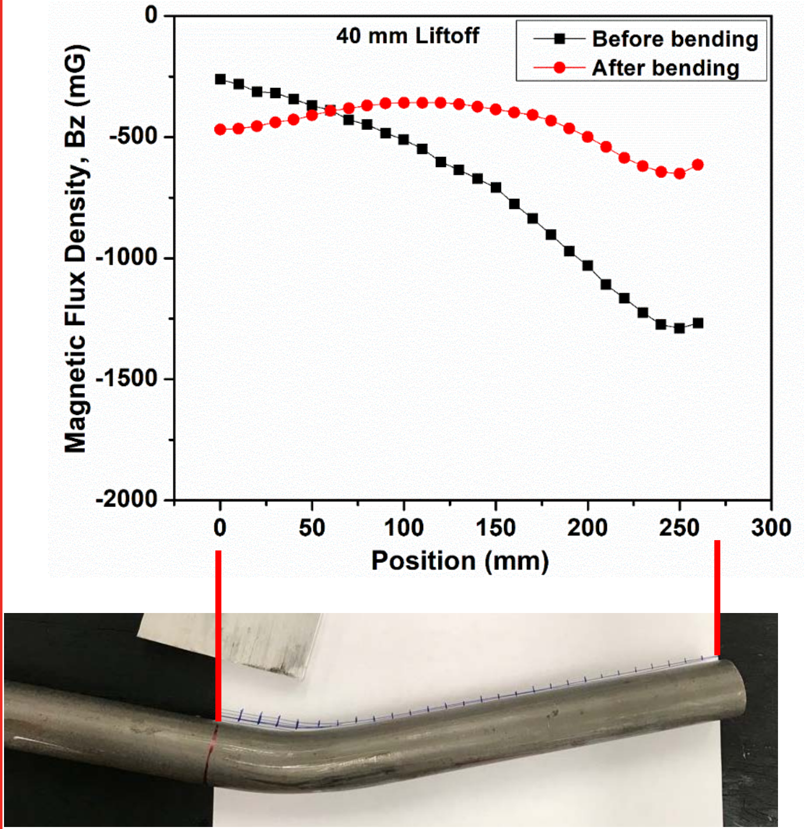


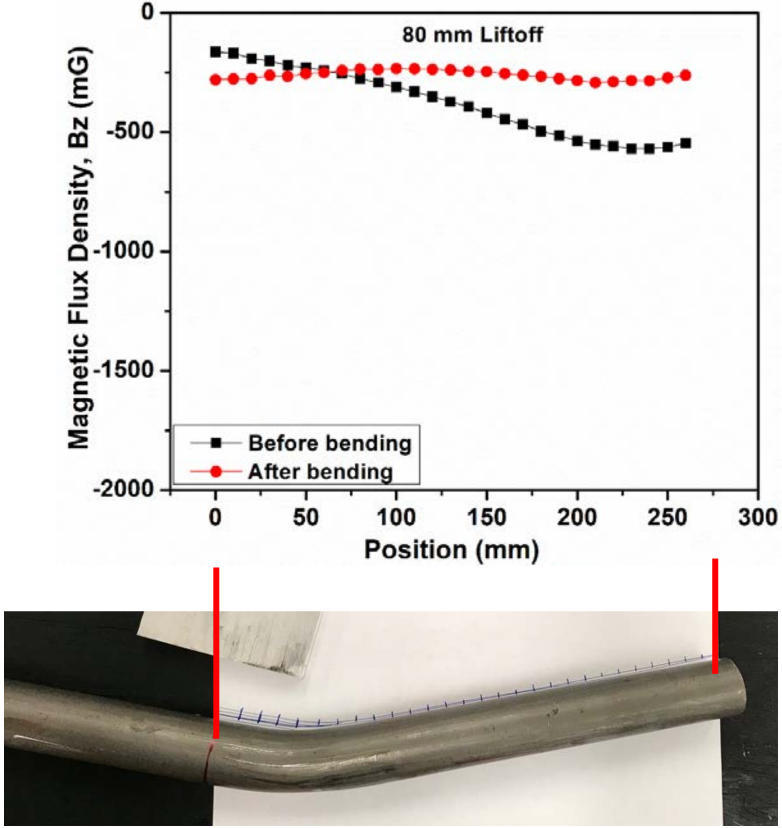
Effect of Bending_Tube Sample 3





Effect of Bending_Tube Sample 3





Discussion

- Larger signal from long bar associated with larger dipole
- More material appears to generate larger residual magnetization before and after bending
- Residual stress components in tube are more complex and generate a larger remnant signal
- Results have implications for underground oil and gas pipeline, which is continuous (no end effects), and larger and deeper (scaling effects may be assumed).

Conclusions

- MMM technology has the potential to be used to characterize pipeline magnetic signature
- Magnetic flux density is affected by residual stress in all three directions
- Bending changes the residual magnetization of the sample, which is most prominent in z-component (normal to the surface) of the field
- The decay constant for unbent bar and tube samples was about 22 mm, whereas it was 30 mm for bent samples.

Acknowledgements

- Peter Snell for assistance with sample preparation
- Ontario Centres of Excellence
- Natural Sciences and Engineering Research Council of Canada

Thank you