Damping in Magnetostriction Measurements Performed on Samples under Stress

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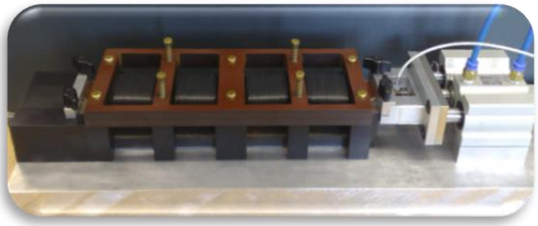
Abstract: Two measurement systems developed for characterising the magnetostriction of Epstein strips were compared using high permeability grain oriented silicon steel. The systems were of similar design, where magnetostriction is measured by double integration of acceleration, but having different sizes of pneumatic cylinders. It was observed that the characteristic trends of magnetostriction under stress of the two systems were very similar, however the system with the larger cylinder exhibited a lower magnitude over the whole range of applied stress indicating that there was significant damping of the measured acceleration due to magnetostrictive forces. The results of the measurements show that a damping coefficient can be obtained for the pneumatic cylinder. A theoretical model for the damping coefficient was developed which gave a reasonable approximation of the observed damping and demonstrated that the moving mass of the stressing apparatus was the largest contribution to the damping force.

I. Magnetostriction Measurement Systems

A. Cardiff Measurement System

A magnetostriction measurement system based in Cardiff University (UK) is used as a reference system in this comparison. The system was designed to test Epstein strips (305 x 30 mm) of electrical steel of various thicknesses from 0.23 mm to 0.50 mm with an uncertainty less than ± 5 % under ± 10 MPa stress. A single strip is inserted into the support, which is enwrapped by secondary and primary windings, where the flux during magnetisation is closed through the steel yoke. A tensile or compressive stress is applied to the sample by a light-weight clamp, which is connected to a pneumatic cylinder. The other end of the strip is fixed to the base of the system. To control the applied stress a load cell is place between the clamp and the cylinder. The acceleration of the strip, measured by the two piezoelectric accelerometers (one at the free end of the strip and the other at the fixed end which acts as a reference), is double integrated to obtain a displacement and then magnetostriction. The accelerometers are supplied and their outputs amplified by a suitable coupler. Magnetisation, stress and measurements are controlled and analysed by a LabView Virtual Instrument (VI). The magnetostriction measurements of the system have been validated via detailed measurements of static domain structures over the whole stress range and comparison between measured and modelled magnetostriction which showed close correlation.



B. Nottingham Measurement System

A high stressing magnetostriction measurement system, based at Nottingham University (UK), for testing of Epstein strips was built and developed by Brockhaus Messtechnik to apply stress in the range of 500 MPa tensile and up to -250 MPa compressive stress. The system was designed to test high strength electrical steel laminations with optimised mechanical properties. The measurement principle of the system is similar to that described in section A. However a much larger pneumatic cylinder capable to applying forces up to 5 kN, connected with a guiding system in order to avoid twisting of the sample (especially under high loads) was used.

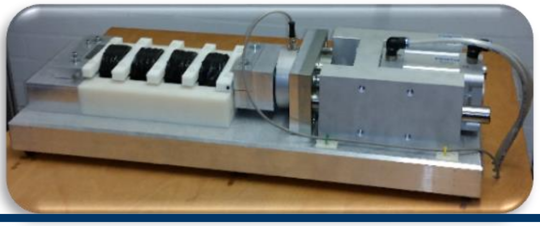


Table 1. Moving mass (kg) of each component connected with the cylinder

	Rod	Guides	Clamp	Sensors	Total moving mass
Cardiff	0.005	0.025	0.081	0.02	0.13
Nottingham	1.25	5.50	2.4	0.35	9.5

Table 2. Peak displacement, velocity and acceleration for a peak magnetostriction (ε) of 25x10[-6]

	l_m (mm)	$\hat{x}$ (μm)	$\hat{\dot{x}}$ (m/s)	$\hat{\ddot{x}}$ (m/s²)
Cardiff	270	6.78	2.13 x10⁻³	1.34
Nottingham	241	6.03	1.89 x10⁻³	1.19

II. Model of Damping Factor

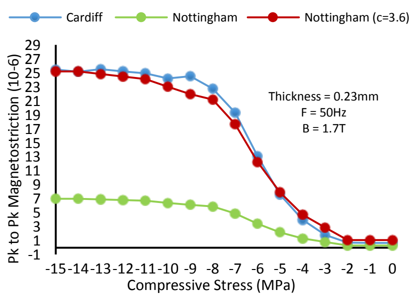
$$Magnetostriction\ force \Rightarrow F_m = E \cdot A \cdot \varepsilon = \mathbf{16.88N}$$

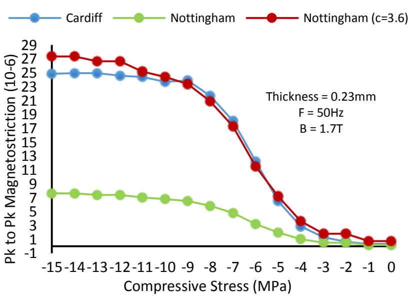
$$\text{Cardiff System} \Rightarrow F_d = M_{moving} \cdot \hat{\ddot{x}} = 0.13 \cdot 1.34 = \mathbf{0.17N}$$

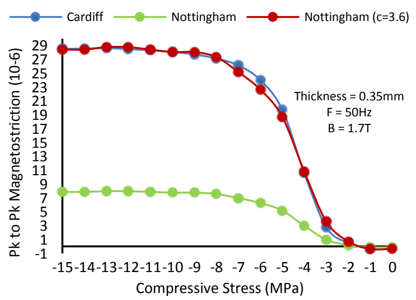
$$\text{Nottingham System} \Rightarrow F_d = M_{moving} \cdot \hat{\ddot{x}} = 9.50 \cdot 1.19 = \mathbf{11.30N}$$

$$\text{Calculated Damping Coefficient} \Rightarrow c = \frac{\varepsilon_{measured}}{\left(\frac{F_m - F_d}{E * A}\right)} = \mathbf{3.0}$$

III. Results







IV. Conclusions

Two magnetostriction measurement systems were compared and a simple model of the damping coefficient was presented. The larger size of loading cylinder designed for higher range of applied compressive stress in a single Epstein strip causes significant damping of magnetostriction of fitted magnitude of 3.6. Estimation of moving mass of the cylinder and also maximum displacement enables to estimate the damping coefficient of the used cylinder. The analysis validates the use of a constant damping coefficient to compensate for the mass loading of large stressing apparatus.

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