# Measurement and Modelling of 2D Magnetostriction of Non-oriented Electrical Steel


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**Abstract — Magnetostriction of a non-oriented electrical steel was measured under magnetisation conditions present in an AC machine stator core, and compared with the modelled magnetostriction based on an analogy of mechanical elasticity. This model can cope with shear magnetostriction and magnetostriction perpendicular to the magnetisation direction, which shows possibilities of improving the accuracy of stator core deformation and vibration calculations.**


## I. Introduction

Magnetostriction in non-oriented (NO) electrical steel sheet is a source of deformation and vibration of rotating machine cores. Previously, orthogonal normal magnetostriction components along the rolling (RD) and transverse (TD) directions were used in calculation of core deformation and vibration [1], [2]. However, at the tooth roots and back iron of an AC machine stator core two-dimensional (2D) flux occurs. Therefore, the shear component of the in-plane magnetostriction under such 2D magnetisation is also of importance as it defines the principal magnetostriction axis [3]. This paper presents measurement and modelling of 2D magnetostriction of a NO steel under magnetisation conditions present in induction motor stator core.

## II. 2D Magnetostriction Measurement System

An 80 mm disc sample of an M400-50A NO steel was magnetised in a two-phase stator core shown in Fig. 1 (a). Flux density components along the RD and TD ($b_x$ and $b_y$) were calculated from voltages induced in orthogonal single turn b coils wound at the centre of the disc depicted in Fig. 1 (b). Arbitrary in-plane magnetostriction, $\lambda(\varphi,t)$ comprising two orthogonal components ($\lambda_x(t)$ and $\lambda_y(t)$) and a shear component ($\gamma_{xy}(t)$), is given by

$$\lambda(\varphi,t)=\lambda_x(t)\cos^2\varphi+\lambda_y(t)\sin^2\varphi+\gamma_{xy}(t)\sin\varphi\cos\varphi \qquad (1)$$

where $\varphi$ is the angle with respect to the $x$ axis. Therefore, rosette resistance strain gauges attached at the centre of the disc were used to measure magnetostrictive strains ($\lambda_a$, $\lambda_b$ and $\lambda_c$) at $\theta_a$=0°, $\theta_b$=-45° and $\theta_c$=-90° to the RD then they were transformed into $\lambda_x$, $\lambda_y$ and $\gamma_{xy}$ using

$$\begin{bmatrix}\lambda_x\\ \lambda_y\\ \gamma_{xy}\end{bmatrix}=\begin{bmatrix}\cos^2\theta_a & \sin^2\theta_a & \sin\theta_a\cos\theta_a\\ \cos^2\theta_b & \sin^2\theta_b & \sin\theta_b\cos\theta_b\\ \cos^2\theta_c & \sin^2\theta_c & \sin\theta_c\cos\theta_c\end{bmatrix}^{-1}\cdot\begin{bmatrix}\lambda_a\\ \lambda_b\\ \lambda_c\end{bmatrix}. \qquad (2)$$

Flux densities $b_x$ and $b_y$ were controlled independently in a LabVIEW program. Details of this experimental setup are described in [4].

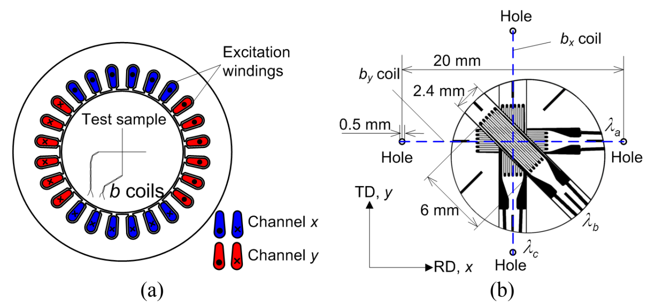


Fig. 1. (a) An 80 mm disc sample magnetised in a two-phase stator core, (b) Locations of orthogonal b coils and rosette resistance strain gauges at the centre of the disc sample.

## III. 2D Magnetostriction Model

2D magnetostriction of electrical steel sheet can be described by analogy with plane mechanical elasticity [5], which is given by

$$\tau\frac{d}{dt}\begin{bmatrix}\lambda_x\\ \lambda_y\\ \gamma_{xy}\end{bmatrix}+\begin{bmatrix}\lambda_x\\ \lambda_y\\ \gamma_{xy}\end{bmatrix}=\begin{bmatrix}1/P_x & -\xi_x/P_y & 0\\ -\xi_y/P_x & 1/P_y & 0\\ 0 & 0 & 1/G_{xy}\end{bmatrix}\cdot\frac{1}{2\mu_0}\begin{bmatrix}b_x^2\\ b_y^2\\ b_xb_y\end{bmatrix} \qquad (3)$$

where $\mu_0$ is the permeability of free space, $P_x$, $P_y$ and $\xi_x$, $\xi_y$ are the magnetic moduli and Poisson's ratios along the RD and TD respectively, and $G_{xy}$ is the shear modulus between the RD and TD. The first order differential equation with time constant $\tau$ is used for adjusting hysteresis in the magnetostriction waveforms. It was verified that this model is capable of representing 2D magnetostriction of anisotropic NO steel under sinusoidal 2D magnetisation [2]. The parameters $P_x$, $P_y$, $\xi_x$, $\xi_y$, $G_{xy}$ and $\tau$ can be identified experimentally using the 2D magnetostriction system [3]. Firstly, circular flux magnetisation at 50 Hz was applied to the disc sample to obtain $G_{xy}$ and $\tau$. Unidirectional magnetisation was then applied along the RD to identify $P_x$ and $\xi_y$, and along the

TD to determine $P_y$ and $\xi_x$ respectively. Table I lists the identified parameters, which were carried out at 0.80 to 1.30 T, 50 Hz and repeated five times.

TABLE I
PARAMETER USED IN 2D MAGNETOSTRICTION MODEL OF AN M400-50A NO STEEL

| $P_x$ [GPa] | $\xi_x$ | $P_y$ [GPa] | $\xi_y$ | $G_{xy}$ [GPa] | $\tau$ [ms] |
|---|---|---|---|---|---|
| 2,145 | 1.0 | 81 | 1.0 | 42 | 0.17 |

## IV. Results and Discussion

A flux density locus measured at a back iron of an induction motor model core shown in Fig. (2) [6] was used as the reference waveforms of the 2D magnetostriction measurement system. Peak and total harmonic distortion values of $b_x$ and $b_y$ were maintained within ± 2 % of the reference waveforms. The locus in Fig. 2 was also fed into the 2D magnetostriction model in (3). Fig. 3 shows and waveforms, and corresponding measured and modelled magnetostriction $\lambda_x$, $\lambda_y$ and $\gamma_{xy}$.

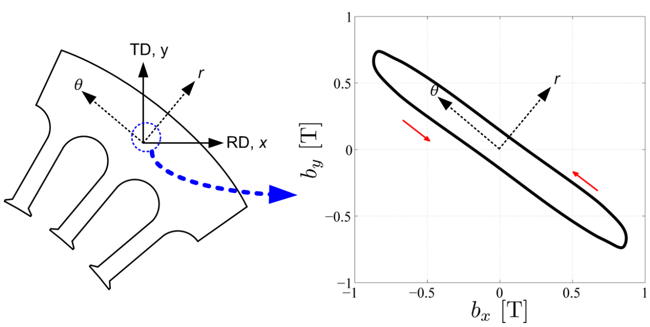


Fig. 2. Flux density locus at the back iron of an induction motor stator core.

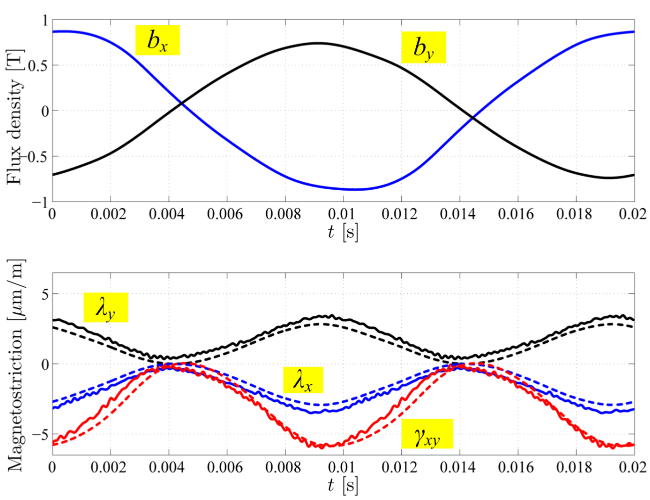


Fig. 3. Flux density waveforms $b_x$ and $b_y$, and corresponding magnetostriction waveforms $\lambda_x$, $\lambda_y$ and $\gamma_{xy}$ (solid lines – measurements, dashed lines – modelling).

$\gamma_{xy}$ changes corresponding to $b_y$ because this material is anisotropic, which can be also observed from $P_x >> P_y$ in Table I. Magnetostriction reaches it minima when $b_y = 0$. This indicates that $b_y$ plays an important role in the mechanism of 2D magnetostriction. The modelled magnetostriction agrees closely with the measurement even under distorted magnetisation waveforms, which occur locally in typical AC machine cores. In addition, high values in $\xi_x$ and $\xi_y$ indicate magnetostriction perpendicular to the magnetisation is as large as that along the magnetisation direction. This is expected to cause large deformation, which was previously neglected [1].

## V. Conclusion

This paper illustrates that 2D magnetostriction model has the potential to represent magnetostriction of anisotropic NO steel under practical magnetisation conditions. It is also highlighted that shear magnetostriction and magnetic Poisson's ratios are not negligible and should be included in calculations of core vibration.

## VI. Acknowledgements


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## VII. References


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