A multi-feature fusion method for quantitative evaluation of plastic deformation via magnetic Barkhausen noise signals

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This paper presents a novel methodology for quantitative evaluation of plastic deformation in low-carbon steel through multi-feature fusion analysis of magnetic Barkhausen noise (MBN) signals. The method comprises three key components: 1) Comprehensive feature extraction from time and frequency domains of raw MBN signals, e.g., envelope profiles, energy hysteresis loops etc., to generate 140 feature parameters; 2) A hybrid feature selection strategy combining coefficient of variation-Fisher score filtering with principal component and correlation analysis ranking to identify deformation-sensitive features; 3) Establishment of a Lasso regression model using the optimized features, to achieve a small relative error in quantitative evaluation of plastic deformation. The proposed method demonstrates exceptional transferability for MBN-based approach for evaluation of other types of material degradation.

Keywords: Magnetic Barkhausen noise; Plastic deformation; Multi-feature fusion; Quantitative non-destructive evaluation

1. Introduction

In ferromagnetic materials, discontinuous domain wall motion under varying magnetic fields generates microsecond-scale magnetic pulses, termed magnetic Barkhausen noise (MBN)[1]. The interplay between domain wall and dislocation configurations leads to two distinct MBN energy trends with plastic deformation: monotonic decrease or initial increase followed by reduction, which complicates their quantitative evaluation[2]. To address this challenge, we propose a multi-feature fusion method to achieve high-precision quantitative non-destructive evaluation (NDE) of plastic deformation.

2. Methodology and Results

The quantitative NDE of plastic deformation using the MBN signals usually consists of three steps as show in Fig. 1, i.e., Feature extraction: extracting diverse MBN features to retain critical information; Feature filtering & sorting: identifying stable, discriminative features and ranking them by relevance; Quantitative evaluation: building and validating a predictive model using the selected features.

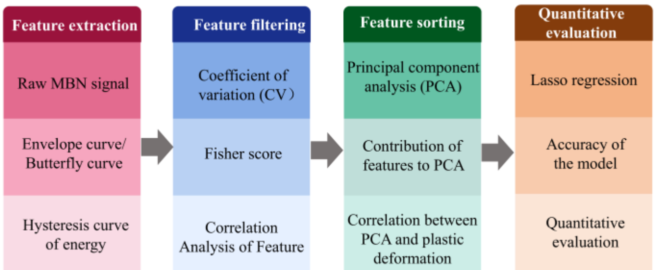
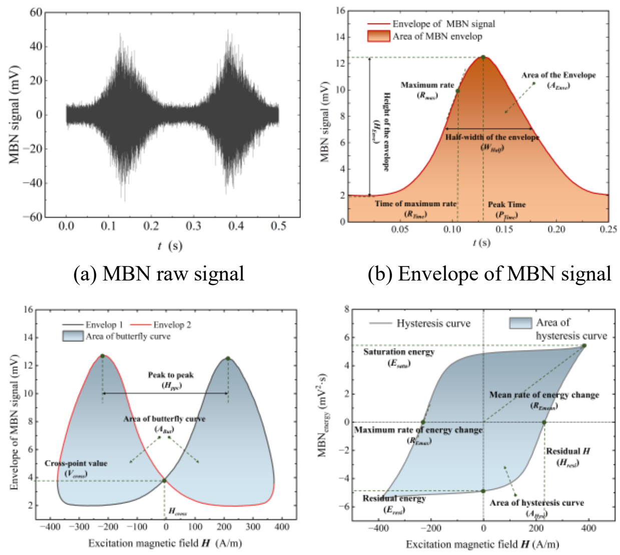


Fig.1 Flowchart of quantitative evaluation of plastic deformation

The raw MBN signals are typically recorded as discrete-time series, representing sampled voltage values. These time-domain datasets serve as the fundamental information for subsequent analyses, which can be expressed as:

$$V_{\text{MBN}} = (x_{1j}, x_{2j}, x_{3j}, \cdots, x_{N-1,j}) \tag{1}$$

where, x_{ij} is the i-th voltage pulse of the MBN signal of the j-th measurement. By appropriately processing of V_{MBN}, the MBN envelope/butterfly curve and energy hysteresis loop can be obtained. Feature extraction is then performed in both the time and frequency domains. As shown in Fig. 2, various methods are employed for MBN feature extraction.



(a) MBN raw signal (b) Envelope of MBN signal

(c) Butterfly curve (d) Energy hysteresis curve

Fig. 2 Feature extraction approach for MBN signals

Optimized signal features were utilized to establish a Lasso regression model, with parameters tuned via 10-fold cross-validation. The maximum relative error of 5.26% on independent test specimens demonstrates the effectiveness of this multi-feature fusion evaluation methodology.

Fig. 2 Feature extraction approach for MBN signals

Real value (%)	Predicted value (%)	Absolute error	Relative error (%)
8	7.58	0.42	5.26
13	12.71	0.29	2.22

References

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[2] Z. Wang, et al. *J. Appl. Phys*. 134, 065103 (2023).

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