Calculation of Magnetic Hysteresis Minor Loop and New Features Extraction based on Magnetic Barkhausen Noise

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Abstract: Magnetic Barkhausen Noise (MBN) is an effective non-destructive testing approach for ferromagnetic material residual stress measurement and evaluation. However, the common MBN signal features such as the time to peak value and frequency spectrum are not accurate enough for stress evaluation due to the randomness of MBN signal. This paper proposed a new method to calculate a curve which looks like magnetic hysteresis loop (B-H curve) based on the line integral from envelope curve of MBN signal. And some new features are extracted from the above integrated B-H curve. These new signal features show a good linear relationship with applied stress. By comparing these new features with previous common features, we find that the envelope area and center height difference of new features can effectively reduce the adverse impact on stress evaluation due to the randomness of MBN signal.

1 Introduction

The ferromagnetic materials, which is composed by many small magnetic domains with different orientations, can be magnetized by the external magnetic field as the orientations of magnetic domains turn to the direction of the external magnetic field. In the process of magnetization, a series of magnetic pulses (Magnetic Barkhausen Noise, MBN) and mechanical vibrations (Magnetic Acoustic emission, MAE) occurs with the movement of the boundaries and the changing of the directions of the magnetic domains. The movement of the magnetic domains is influenced by the micro-structure features as well as by the stress of the materials, so the information about these features and stress can be detected by the observation of the MBN and MAE[1][2].

When the dependence of MBN on stress is analyzed, frequently used feature values are: power spectrum[3], root mean square(RMS)[4], mean and ring numbers(Nr)[5]. And the envelope of MBN signal is also extracted to obtain peak(Vp), peak time(Tp), full width at half maximum (FWHM)[6] and other information.Because of the randomness of MBN signal, difference between two measurements is obvious, when peak time or FWHM is used as feature value. And the ring numbers can be affected by threshold and intercept time.

2 MBN signal and B-H curve

There will be magnetization in the ferromagnetic material under the effect of external magnetic field. When the saturation occurs in the ferromagnetic materials, the magnetic state is not restored to its original state after removing the magnetic field. When the magnetic field changes back and forth in the positive and negative directions, the magnetization of the media is in a cycle, thus forming a hysteresis loop[7](see Fig. 1) . By observing the hysteresis loop of the ferromagnetic materials we find that the curve displays a step-jitter state in the irreversible magnetization phase, rather than a smooth and continuous curve. The coil placed on the surface of the specimen produces a noise pulse in the form of voltage indicating that the magnetization process of the ferromagnetic materials is not continuous[8].

Some researchers found that the shapes of hysteresis loops, coercivity and remanence changed in some regularity with the difference applied stress. With the increase of tensile stress which is parallel to the direction of the external magnetic field, both of the coercivity and the remanence increase. While with the increase of compressive stress, both of the coercivity and the remanence decrease[9].

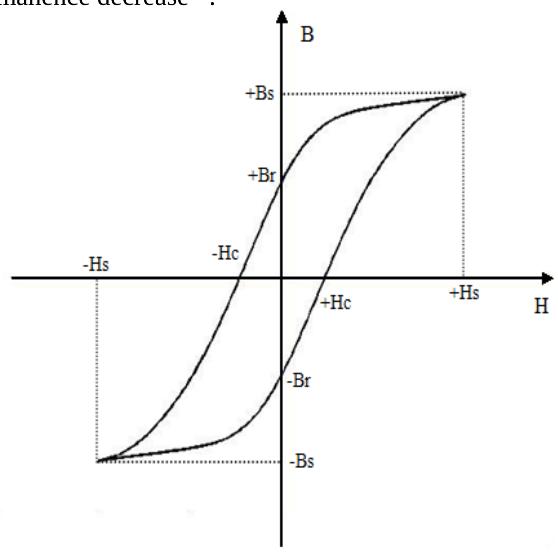

Fig.1. B-H curve

When we extracted the envelope of MBN signal, we found that the envelope trend is similar to the slope trend of B-H curve. We assume that: a) at any point, the amplitude of the MBN signal reflects the number of the domain movement of the ferromagnetic material. b) The number of the domain movement at this point results in a change of B in the magnetization process. c) Total number of the domain movement results in the accumulation of B. Based on these assumptions, we believe that we can get some information about B from the integration of the amplitude of the MBN signal. And we can also extract new features from integration curve to evaluate stress level.

3 Hysteresis loop projection and features extraction

Two methods can be considered to realize curve integration, one is integrate over time, the other is over amplitude of excitation signal. When time is used as independent variable, samples are at equal intervals and can be easily calculated. As the sinusoidal signal is used as excitation, if amplitude of excitation signal is used as independent variable, the excitation signal should be smoothed, and corresponded to the envelope of MBN signal. Since there is a phase shift between the excitation and the MBN signal after smoothing and filtering, it’s hard to correspond them exactly. And the Calculation process will be very complicated. So we decided to integrate over time.

After the pretreatment of MBN signal, we set the peak of excitation signal as outset to intercept ten cycles of MBN signal. Then extract its envelope and seek 10 cycles average as the envelope to be integrated. We integrate the first half cycle of the envelope curve and then integrate the last half but with a shift of a certain value, which is determined by the integral value of the first half cycle.After that, the last half cycle integration curve is flipped to form a loop with the last half cycle integration curve. Fig.2 shows the envelope curve before integration and the integration loop.The integration curve is unclosed because the MBN signal is asymmetric, which is caused by the remanence in specimen. To eliminate the influence of remanence in specimen, demagnetization of specimen is required before experiment.

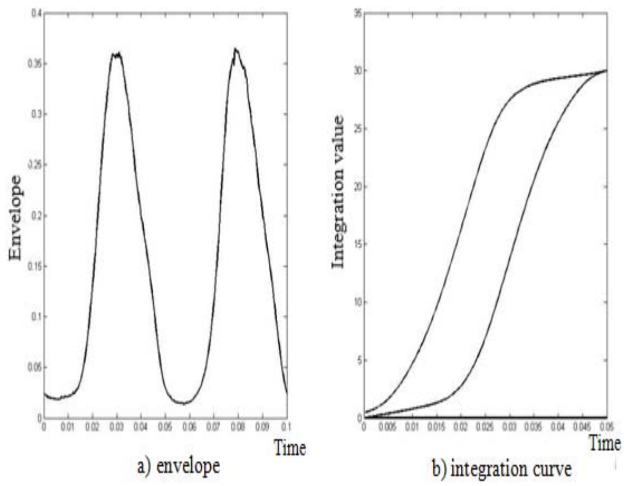

Fig.2. Envelope of MBN signal and its integration curve

Since B-H curve is obtained by integrating MBN signal envelope, we can get maps of envelope features from integration curve. Obviously, maximum slope of the curve is the peak of MBN signal, and the location of maximum slope is the peak time. Furthermore, we extracted new features as follows, which are based on the shape of the integration curve and the parameters of B-H curve.

a) Envelope Area(Ea): value of last point of integration curve (see Fig.3)

b) Center Width(Wc): time difference between first half curve and last half curve when the integration value reach Ea/2. And the center width of B-H curve is twice of coercivity (Hc) . (see Fig.3)

c) Center Height Difference(Hdc): height difference between half curve and last half curve at Ts/4(Ts is cycle time) . And the center height difference of B-H curve is twice of remanence(Br). (see Fig.3)

d) Maximum Width(Wm): maximum time difference between first half curve and last half curve (see Fig.3)

e) Maximum Height Difference(Hdm): maximum height difference between half curve and last half curve (see Fig.3)

f) Loop Area(La): area of integration loop (see Fig.3)

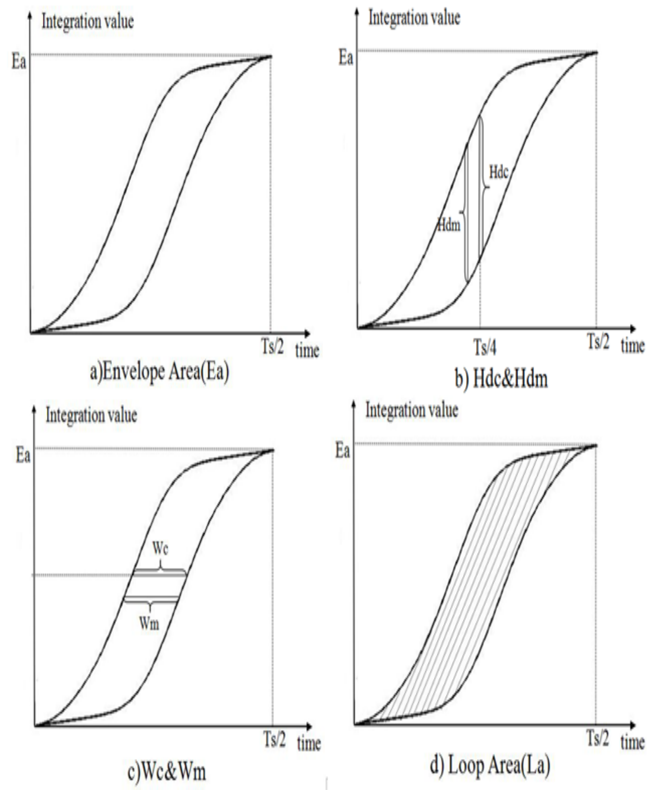

Fig.3. New features

4 Experimental verification

The experimental platform is composed with a four-point bending load platform(see Fig.4) and our stress detection system which is based on Barkhausen effect(see Fig.5). We use A3 steel block as load specimen, whose size is 660 mm×30 mm×10 mm. In order to test both the tensile and compressive stress of the specimen, the MBN probe is placed on the middle surface of both the top and the bottom of the specimen. And we use equation 1 to calculation stress in the position of the probe. F means the force we load on the specimen, c means the distance between point A and point B(the distance between point A’ and point B’ is also c). b means the width of specimen and h is the thickness of specimen. When the force loaded on the specimen range from 0 to 800N, the stress change from 0 to 120MPa.The frequency of sinusoidal excitation applied on the drive coil is 10Hz with different amplitude of 1.6V, 2.1V and 2.6V.

$$\sigma = E\varepsilon = \frac{3Fc}{bh^2} \qquad (1)$$

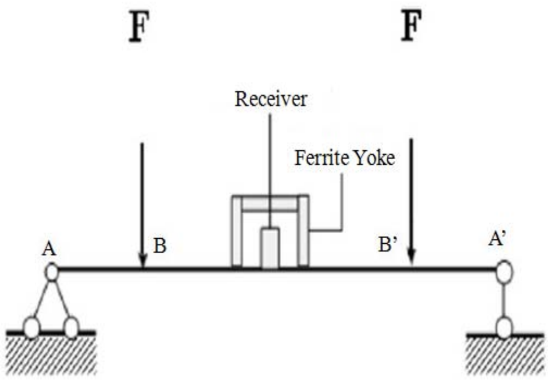

Fig.4. Stress loading model diagram

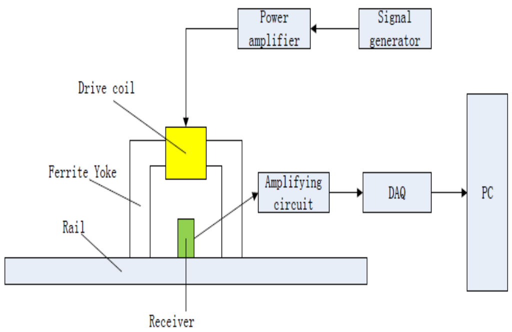

Figure.5. Measurement system structure diagram

4.1 New features extraction

The parameters illustrated before were used in the experiment. Then we normalized data to see how the features change when the stress changed(see Fig.6). The negative stress means compressive stress and the positive stress is tensile. As the figure illustrate, each feature increase with the increase of tensile stress or with the decrease of compressive stress under 120MPa.And there is a linear relationship between envelope area and stress. Besides, Wc and Hdc show the same variation trend as Hc and Br when the stress change.

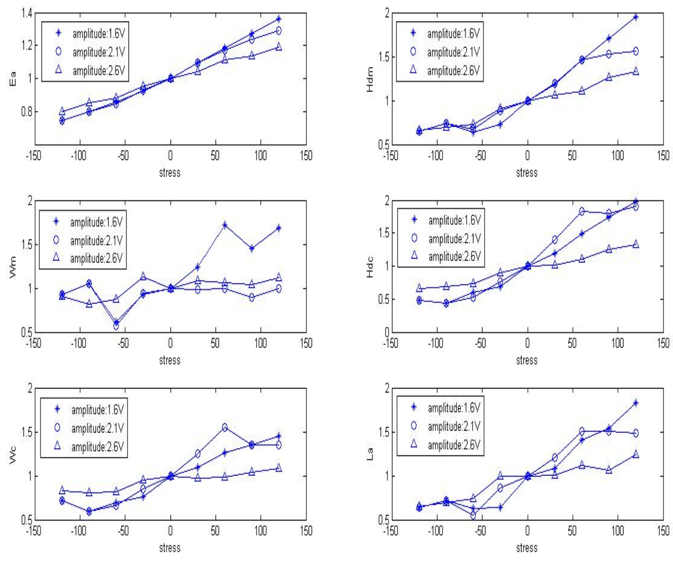

Fig.6. Features and stress

4.2 Features comparison

It is known that the volatility of feature value which caused by randomness of MBN signal is the obstacle when evaluate stress via MBN signal. In order to evaluate the effect of volatility of feature value on certainty of stress evaluation, we integrated the envelope every single cycle and extracted mean and standard deviation of features in each cycle. And we also obtained the variation and maximum standard deviation of mean when stress changes from 0MPa to 120MPa. Variation of mean illustrate variation range of features when stress changes while maximum standard deviation of mean shows certainty of data we get. The ratio of delta mean and maximum standard deviation of mean can used as a weigh of the effect of volatility of feature value, when we use it to evaluate the magnitude of stress.

Tab.1 shows the result of above-mentioned method with excitation amplitude of 1.6V loaded with compressive stress. Tab.2 shows the result loaded with tensile stress. The table illustrate that, Ea, Hdc and Hdm show minor volatility than others in new features.They have better capability to decrease the uncertainty which caused by randomness of MBN signal and evaluate stress much more accurate than peak time, FWHM and ring numbers.

5 Conclusions

In this paper, the relationship between Barkhausen noise and hysteresis loop is analyzed, and some hypothesis are proposed for the calculation of magnetic hysteresis ‘minor’ Loop. we proposes and investigates a new method to calculate this curve by the integration of envelope of MBN signal and some new features are extracted from the above integrated B-H curve and concluded as follows:

a) It is possible to calculate magnetic hysteresis loop by intercept, average and integrate the envelope of MBN signal.

b) The remanence in specimen cause the asymmetric of MBN signal and misclosure of integration curve. To eliminate the influence of remanence in specimen, demagnetization of specimen is required before experiment.

c) The features extracted from integration curve show monotonic trend with stress significantly: each feature increase with the increase of tensile stress or with the decrease of compressive stress under 120MPa.And there is a linear relationship between envelope area and stress.

d) Wc and Hdc show the same variation trend as Hc and Br when the stress change. With the increase of tensile stress, they all increase.While with the increase of compressive stress, they all decrease.

e)When the ratio of delta mean and maximum standard deviation of mean is uesd as a weigh of the effect of volatility of feature value, Ea, Hdc and Hdm have statistical properties to improve the uncertainty which caused by randomness of noise, when it is used to evaluate the magnitude of stress.

Tab.1. Comparison of Features with compressive stress loaded

Features	Ea	Hdm	Wm	Hdc	Wc	La	Vp	Tp	FWHM	RMS	Mean	Nr
Max Std	0.617	0.471	37.296	0.515	3.838	189.024	0.009	399.56	336.66	0.289	0.123	14.157
Delta Mean	5.925	2.35	30.646	2.54	11.434	492.11	0.042	125	240	2.772	1.354	18.7
ratio	0.104	0.2	1.217	0.203	0.336	0.334	0.221	3.196	1.403	0.104	0.091	0.757

Tab.2. Comparison of Features with tensile stress loaded

Features	Ea	Hdm	Wm	Hdc	Wc	La	Vp	Tp	FWHM	RMS	Mean	Nr
Max Std	0.903	0.958	41.775	0.902	4.337	302.08	0.012	459.14	332.12	0.351	0.145	19.622
Delta Mean	8.712	4.784	38.012	4.831	12.953	647.26	0.07	592	240	4.354	2.109	18.7
ratio	0.104	0.2	1.099	0.187	0.335	0.467	0.166	0.776	1.333	0.081	0.069	1.055

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