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Fault Diagnosis Based on Enhancement of Barkhausen Noise Using Hybrid Method Empirical Mode Decomposition-Savitzky-Golay Filter

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Abstract:

The Barkhausen Noise (BN) contains important information that can be used in early detection and diagnosis of faults. The BN signal is corrupted by interference signals from other sources during measurement and information on the state of the material may be lost. In this work, a new hybrid technique based on Empirical Mode Decomposition (EMD) and Savitzky-Golay (SG) filter is proposed to extract the information about the state of materials from a measured BN signals. Firstly, using EMD to decompose the BN signal into oscillation functions called IMF. Secondly, the energy of each IMF is calculated in order to select the useful modes, these selected IMFs are filtered by the SG filter and the reconstructed signal is obtained by IMFs treated. Finally, the envelope spectrum analysis is used to test the performance and effectiveness of the proposed method in enhancement the quality of BN signal. The proposed technique is applied to signals acquired from a BN measurement chain and the results obtained show that this technique makes it possible to efficiently extract information on the state of

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1. INTRODUCTION

The Barkhausen noise signal (BN) is a powerful tool in material characterization and fault diagnosis. It was first discovered in 1919 by the German scientist Dr. Barkhausen [1]. Several works have used the non-destructive test based on the Barkhausen effect to assess the conditions of ferromagnetic materials in the macrostructure, stresses, grain size, and fatigue. In 1987, Kirsti Tiitto et al. measured the residual stress in ferromagnetic materials by using the Barkhausen effect and obtained good consistency compared to other techniques [2]. Stefanita et al. analyzed the principle of the BN test technology from micro-theory and sought the relation between the stress of the material of plastic deformation and elastic deformation and of BN signal [3]. The relationship between BN and stress is presented in [4-5] and a mathematical model of the predicted hardness, stress and BN signal is constructed by [6]. Other work has used BN to assess the stress state of steel in different carbon contents [7], and the stress at different depths by piezoelectric stress checking. [8]. The BN weld residual stress detector was developed by Qi xin et al., Which can accurately detect the distribution of weld stresses and the residual stress value. They showed that the distribution of the residual weld stress is symmetrical and then gave the mathematical model of BN [9-11]. Chen Ligong et al. studied the welding part of steel in the BN changes before heat treatment or after. They analyzed the power spectrum for the BN signal, and prove the level of the signal BN is falling when the residual weld stress is decrease before or after the heat treatment [12-13].

The BN signal is masked by signals from other sources and therefore the use of the BN signal without preprocessing is useless and useful information on the state of the material may be lost [14-16]. A denoising

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Acta Materialia Turcica

Volume 4, June 2020, Pages 33-38

technique is necessary to enhance signal quality. In this work, we propose a BN signal denoising technique based on the combination between EMD algorithm and the SG filter. Firstly, the BN signal is decomposed by the EMD algorithm into several elementary functions called intrinsic mode function (IMFs), and thereafter the energy of each IMF is calculated in order to select the useful components. The selected IMFs are processed by the Saviszky-Golay filter in order to obtain the reconstructed signal. Finally, we use envelope analysis to extract information on the state of the material.

2. EMD TECHNIQUE

The EMD technique decomposes the signal into a series of IMFs. An IMF is a function must meet the following conditions [17-19]:

(1) The number of extrema and the number of zero-crossings must either equal or differ at most by one,

(2) The average value of the envelopes obtained by the local maximums and minimums is zero.

For a signal $x(t)$, the EMD technique is summarized as following:

1. Identify all local extrema of the signal $x(t)$.
2. Interpolate the extrema in order to construct the lower and upper envelope $e_{\min}$, $e_{\max}$ respectivement.
3. Calculate the average of two envelopes:

$$m_1 = \frac{e_{\max} + e_{\min}}{2} \tag{2.1}$$

4. Calculate :

$$h_1 = x - m_1 \tag{2.2}$$

5. If h_1 satisfies both conditions of MFIs, then h_1 is the first IMF. Otherwise h_1 is not an MFI, then repeat steps (1-4), replacing $x(t)$ with h_1:

$$h_{11} = h_1 - m_{11} \tag{2.3}$$

where $m_{11}(t)$ is the average of the lower and upper envelopes of $h_1(t)$.

6. Repeat the previous steps k times until h_{1k} is an IMF.

$$h_{1k} = h_{1(k-1)} - m_{1k} \tag{2.4}$$

7. Register the first IMF as follows:

$$IMF_1 = h_{1k} \tag{2.5}$$

8. Calculate the residue $r_1(t)$ as follows:

$$r_1 = x(t) - IMF_1 \tag{2.6}$$

Treat $r_1(t)$ as a new signal.

9. Repeat steps (1-8) L times to calculate $IMF_2, IMF_3, ..., IMF_L$:

$$\begin{aligned} &r_1 - IMF_2 = r_2 \\ &\vdots \\ &r_{(L-1)} - IMF_L = r_L \end{aligned} \tag{2.7}$$

10. The decomposition is complete when the number of extrema in r_L is less than 2.

From equations (2.6) and (2.7), we will finally have a decomposition of the form:

$$x(t) = \sum_{i=1}^{L} IMF_i + r_L \tag{2.8}$$

L is the number of IMFs, r_L the final residue, IMF_i represent the different frequency bands from high to low.

3. HYBRID TECHNIQUE BASED ON SG FILTER and EMD

The optimal Savitzky-Golay (SG) filter is used to remove some noise from the raw signal [20]; the hybrid technique is described as follows:

1. Use the EMD algorithm to decompose the measured signal,

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Acta Materialia Turcica

Volume 4, June 2020, Pages 33-38

2. Calculate the energy of each IMF and choose the IMF that has the highest energy value,
3. Filter the selected IMF using the Savitzky-Golay filter,
4. Reconstruct the signal by summing up the filtered IMFs.

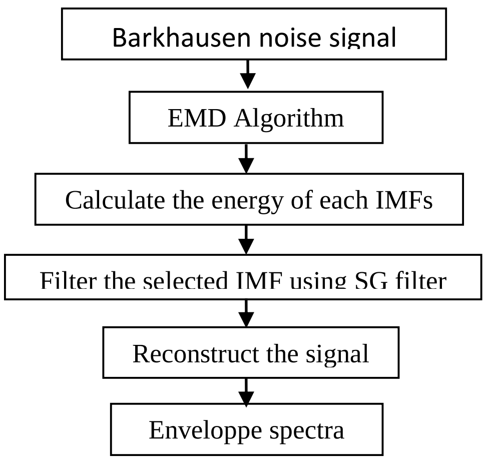


Figure 1. The process of diagnosis.

4. EXPERIMENTS and APPLICATION

Fig 2 shows the test bench for measuring the BN signal; it is consist a sensor magnetic, amplifier, oscilloscope, generator triangle pulse.

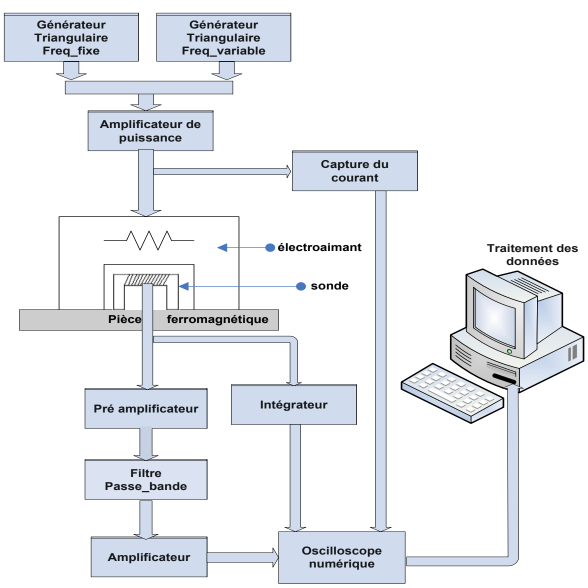


Figure 2. Measuring chain of BN signal

The measured signals are show in Fig (3, 4) for the pieces without stress and with stress respectively. Fig (5, 6) show the energy of each IMF in both cases, we note that the second IMF (IMF_2) having a higher energy value than the others and therefore, it is a mode relevant. The results of applying the SG filter to the selected IMF (IMF_2) are presented in Fig (7, 8) for the pieces without stress and with stress respectively.

The envelope spectra of reconstructed signals are presented in Fig (10, 11) for the two cases. We note on the envelope spectra of the measured signal the total absence of the peaks and consequently no information on the state of the material can be extracted, this due to the masking of BN signal by other sources of noise. When the hybrid technique EMD-SG is applied, the peaks appear clearly in the envelope spectra. This peak takes a very important value in the case of parts with stress compared to the case of parts without stress; it means that the state of the material is modified during the application of a stress, i.e. that defects are created in the piece when the stress is applied.

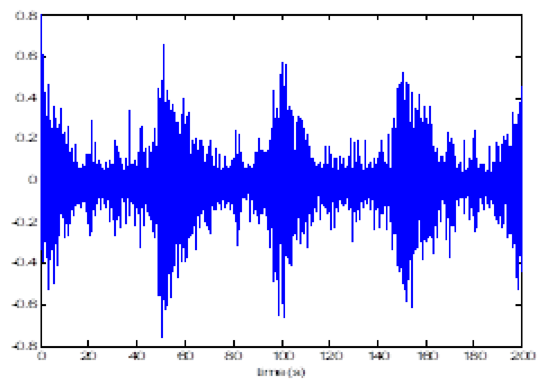
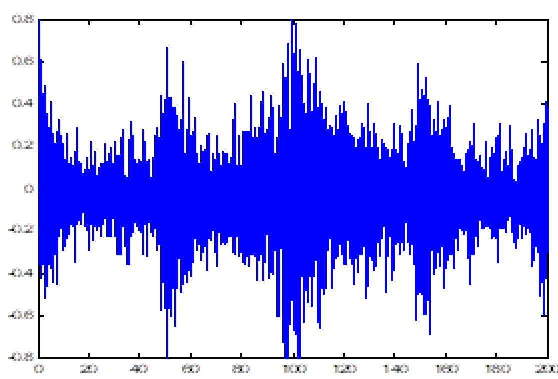


Figure 3. BN signal of pieces without stress.



*Corresponding Author E-mail: rabahabdelkader475@yahoo.fr

Acta Materialia Turcica

Volume 4, June 2020, Pages 33-38

Figure 4. BN signal of pieces with stress F=21 KN

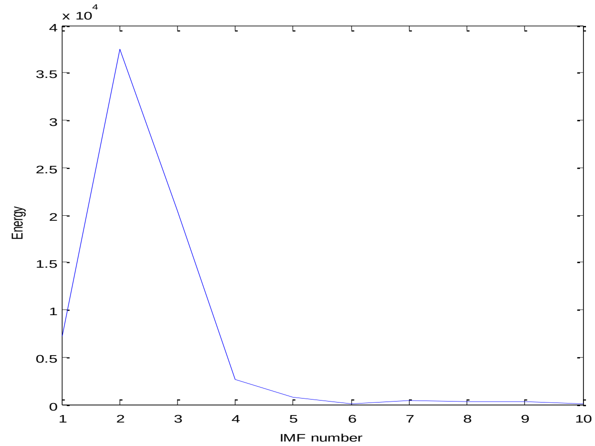


Figure 5. The Energy of IMFs obtained by EMD of signal of pieces without stress

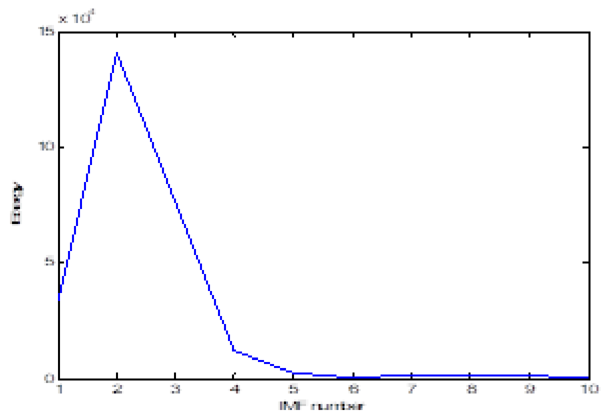


Figure 6. The Energy of IMFs obtained by EMD of signal of pieces with stress

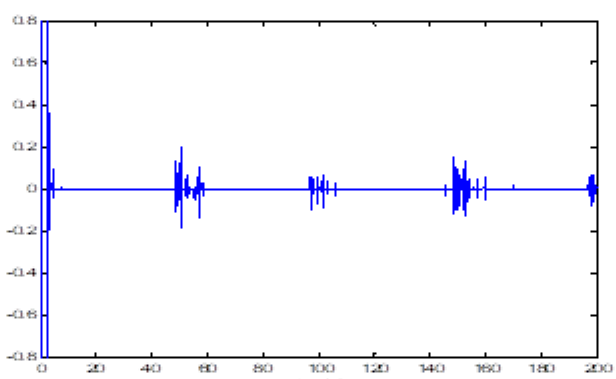


Figure 7. The reconstructed signal of pieces without stress

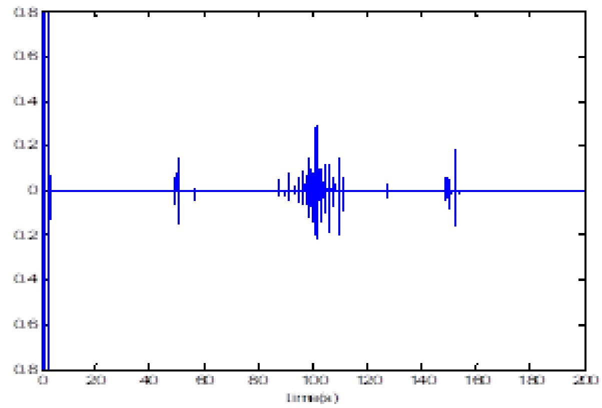


Figure 8. The reconstructed of signal of pieces with stress

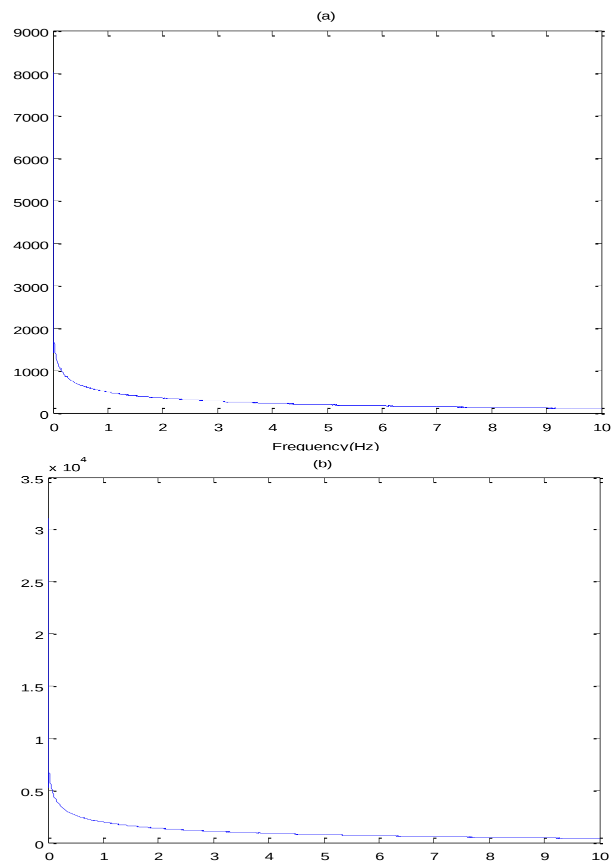


Figure 9. Envelope spectra of measured signal,

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Acta Materialia Turcica

Volume 4, June 2020, Pages 33-38

(a) Without stress, **(b)** With stress

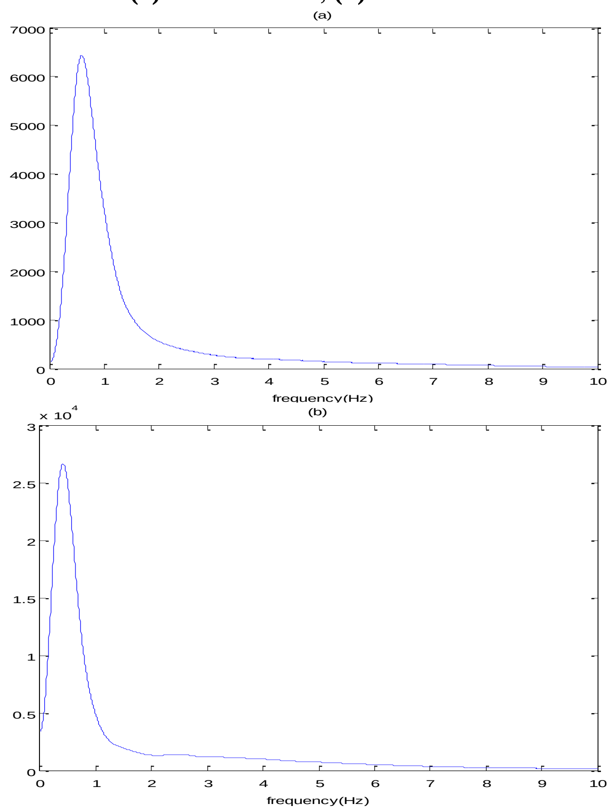

Figure 11. Envelope spectra of reconstructed signal, **(a)** Without stress, **(b)** With stress

5. CONCLUSION

In this work, a hybrid fault diagnosis technique based on the EMD and SG Filter is proposed. The BN signal is decomposed by EMD into several functions (IMF) and depending on the energy of each IMF, the useful components are selected. A filtering operation based on SG Filter is performed in order to reconstruct the signal. Finally, the envelope analysis is used to test the efficiency of this technique in improvement of the BN signal for the diagnosis of faults. The results obtained by the proposed technique prove that the information about the state of materials has been extracted in an efficient manner compared to the use of the measured signal.

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