

# Study on Elimination of Lift-off Effect in Barkhausen Noise Detection

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**Abstract:** The lift-off effect of the sensor has an influence on MBN signal during the process of Barkhausen noise detection. Therefore the way to eliminate the lift-off effect has become the emphasis of the study on the accuracy of the result of Barkhausen noise detection. The study improves the design of the sensor structure, and utilizes the spring structure to effectively eliminate the lift-off of the pick-up coil; it utilizes the induction coil to detect the lift-off information of the magnetizer, and adopts BP neural network to optimize the detected characteristic value of MBN. At last, it verifies that the new structure of the sensor and the optimization algorithm of BP neural network are available to the effective reduction of the detection error caused by the lift-off of the sensor.

## 1 Introduction

The Barkhausen Effect was found by German Professor Barkhausen in 1919. This effect explains the discontinuity of the changes of the magnetization intensity of ferromagnetic material in a changing magnetic field. Macroscopically, magnetize the ferromagnetic material with an alternating current magnetic field and observe the most clogged point of the curve; the magnetization here is an inevitable jump process. When placing a detecting coil on the surface of the ferromagnetic material, the detecting coil will receive a series of mutations and phase step jump pulse signals, which are Barkhausen Noise Signal (MBN) [1][2][3].

As an important technique in nondestructive testing, the Barkhausen Noise Detection Method can be used to detect the stress, residual stress and microstructure of ferromagnetic material components, to conduct effective diagnosis to fatigue failure and life evaluation of ferromagnetic materials [4].

Some foreign countries master more advanced MBN noise for nondestructive testing technique and have developed a series of Barkhausen noise detecting devices such as the ROOLSCAN developed by Finnish Stresstech Company and the 3MA-II developed by German Faye Rauen Hoff Nondestructive Testing Research Institute. Various colleges and universities as well as research institutes in our country have paid great attention to the application prospect of Barkhausen Noise Detection Method, and have conducted deep researches in relevant application field, and have obtained breakthrough development on the practicability of Barkhausen Detection Method.

Based on the theoretical analysis of Barkhausen Detection Method and a large number of experimental verifications, the laboratory has developed an industrial personal computer aiming at rail stress detection and a portable Barkhausen noise detector. But there are generally detection errors caused by the position statement of the sensor during the process of detecting.

## 2 Analysis on the Error Caused by the Position State of the Sensor

There may be lift-off between the pick-up coil and the test piece during the process of detecting, which generally

causes the reduction of the detected MBN signal.

During the process of detecting, the position statement of the magnetizers is generally not in line with each other, thus the magnetic fields generated in the test pieces are different, and the detected MBN signals are different. When there is no lift-off between the left and right feet of the magnetizer and the surface of the test piece, and there is no incline and rotation between the magnetizer and the test piece, the state is called as the standard state, noted as Sn (the lower corner mark n is the mark of the detecting point), as shown in Fig.1. ; and other states which are not in line with the standard state (for example, there is lift-off Hl and Hr between the left and right feet of the magnetizer and the surface of the test piece, and there is incline between the magnetizer and the test piece) are called as random states, noted as Rn (the lower corner mark n is the mark of the detecting point), as shown in Fig.1. Compared to the standard state, there is some leakage in the magnetizer in a random state and the magnetic line of force in the test piece, and the tested MBN signal will be reduced [5].

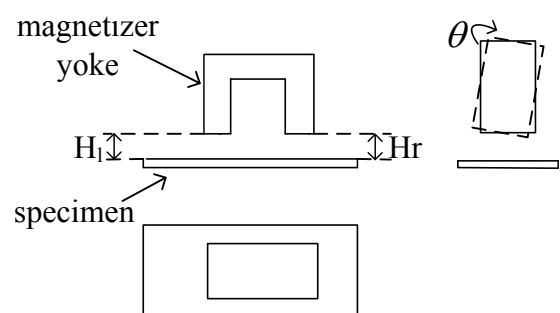
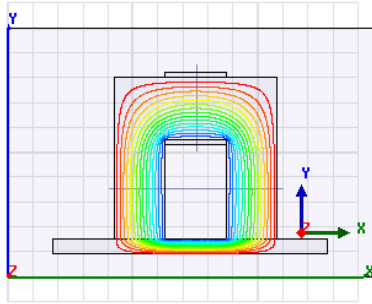


Fig.1. Explanation of Position State of Magnetizer

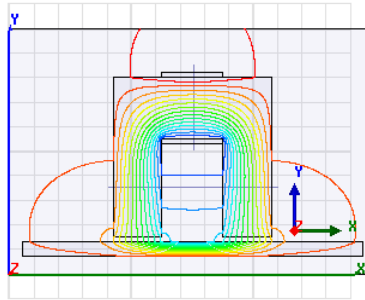
Ansoft electromagnetic simulation software is used to get the relations between the magnetization intensity and the lift-off of the yoke. Due to the use of the frequency of the excitation signal is very low, we can ignore the eddy current effect, dc excitation and steady-state field can be used to simplify the simulation.

Ansoft simulation implements three conditions of the yoke: no lift-off, same lift-off, the left lift-off greater than the right lift-off. Fig.2 lists distribution of magnetic flux lines of the three conditions. Fig.3 lists the magnetization intensity (MAG\_B) of left and right parts of the yoke of the three conditions. Fig.4 lists the

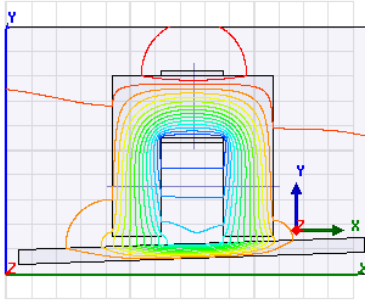
magnetization intensity (MAG\_B) of middle part of the yoke of the three conditions. From the figures, we can be found that when there is a lift-off, leakage of magnetic flux lines exist, and all parts of the magnetizing apparatus magnetization is smaller. Besides if left and right part of the yoke have the same lift-off, the magnetization intensity (MAG\_B) of left and right part is equal, and the magnetization intensity (MAG\_B) is smaller where the lift-off is larger.



( 1 ) no lift-off

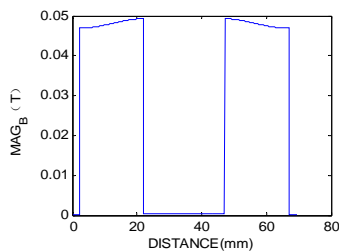


( 2 ) lift-off ( same distance )

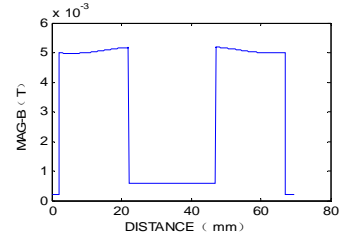


( 3 ) lift-off ( left > right )

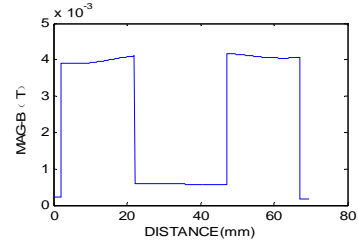
**Fig.2.** Distribution of Magnetic Flux Lines



( 1 ) no lift-off

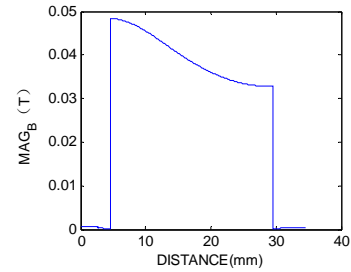


( 2 ) lift-off ( same distance )

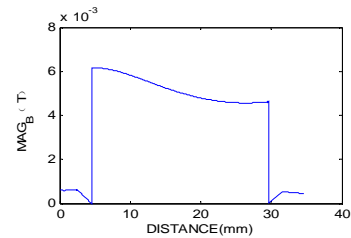


( 3 ) lift-off ( left > right )

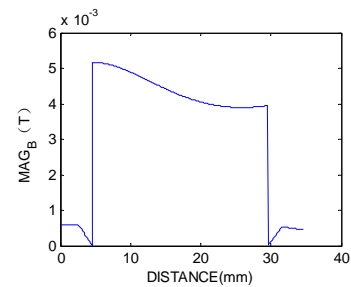
**Fig.3.** The MAG\_B of Left and Right Parts of the Yoke



( 1 ) no lift-off



( 2 ) lift-off ( same distance )



( 3 ) lift-off ( left > right )

**Fig.4.** The MAG\_B of Middle Part of the Yoke

Both of the above two conditions will result in the reduction of the tested MBN signal, that is, the position statement of the sensor will result in errors when detecting MBN.

### 3 Utilization of BP Neural Network to Reduce the Detection Error Caused by Position State of Magnetizer

A new type of Barkhausen noise signal detection sensor with innovative structure is designed aiming at the above two points. The following figure is the structural drawing of the sensor, in the receiving coil generally exceeding certain space from the bottom of the magnetizer, and the receiving coil is connected with the magnetizer through removable fixed part. When placing the sensor during the process of detecting MBN, it can be ensured that there is no lift-off between the pick-up coil and the test piece as long as making the magnetizer adjacent to and touching with the surface of the test piece<sup>[6]</sup>.

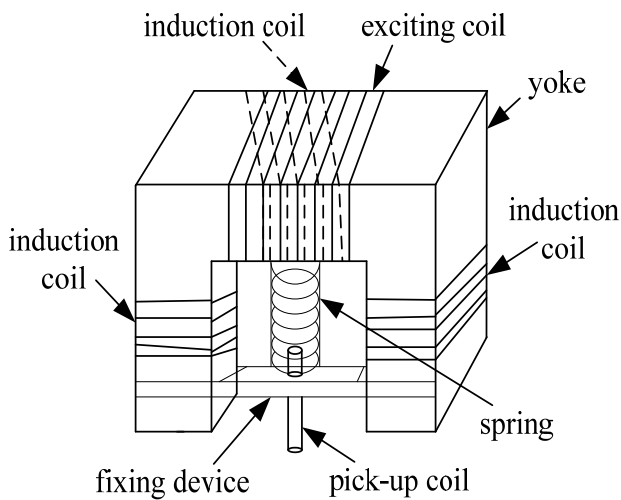


Fig.5. Structural Drawing of the Sensor

In Fig.5, the three parts, the left, center and right parts, of the magnet yoke of the magnetizer are all wound with the same coils<sup>[7]</sup>, which are used to detect the information of the position statement of the magnetizer. Fig.6 is the detailed functional block diagram, and the three induction coils 1, 2 and 3, will generate periodic induced voltage signal, which will be converted to the direct current signal through the AD637 root-mean-square converter. Corresponding voltage values are obtained by AD conversion and the procedure, and the detected voltage value should be multiple by 100 times; notes down the voltage values which reflect the three induction coils as  $V_L$ ,  $V_M$  and  $V_R$ . Compared to the standard state, there will be some leakage of the magnetic line of force between the magnetizer in a random state and the test piece, and  $V_L$ ,  $V_M$  and  $V_R$  will also change.

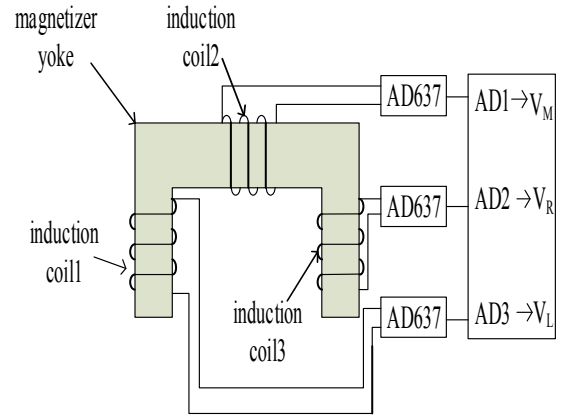


Fig.6. Drawing of Measuring Functions of Magnetizer of Position State

In order to reduce the detection error caused by inconformity of position states of magnetizers, it is proposed to optimize the detected MBN signal by utilizing BP neural network algorithm. The core of the scheme is to utilize BP neural network to optimize or compute the detected MBN signal in random state into the detected MBN signal in the standard state.

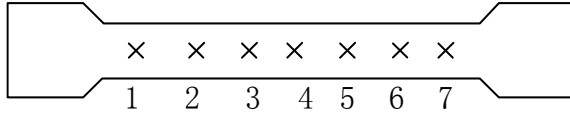
The BP neural network adopted in the scheme is 3-input and 1-output neural network, with the 3-input of  $V_L$ ,  $V_M$  and  $V_R$ , and 1-output of a proportionality coefficient  $k_{MBN}$ . The following is the calculation formula of  $k_{MBN}$  as shown in (1), the specific value between the detected  $\psi$  in some detecting point and the detected  $\psi$  (noted down as  $\psi_{S_n}$ ) of the point in standard state, with the range of 0 – 1, in which  $\psi$  represents the root-mean-square of the detected MBN signal<sup>[8]</sup>, with the value of 300 times of that of the root-mean-square of the detected MBN signal.

$$k_{MBN} = \frac{\psi}{\psi_{S_n}} \quad (1)$$

### 4 Experiments

The frequency of 40Hz and the amplitude of 4.4V are adopted as the drive signal of the magnetizer. Select 7 detecting points on Q235 test piece, as shown in Fig.7, and note down the four information of  $V_L$ ,  $V_M$ ,  $V_R$  and  $\psi$  for each statement<sup>[9]</sup>.

The detecting point 1 is adopted to conduct the collection of training data(as shown in Tab.1), and detecting points 2 -7 are adopted as the verification of the result of BP neural network<sup>[10]</sup>(as shown in Tab.2). Measure the information in standard state for each measurement point, and add different pieces of paper to generate lift-off and tilt the magnetizer, and then measure the information in corresponding states.



**Fig.7.** Diagrammatic Drawing of Detecting Point of Q235 Test Piece

**Tab.1.** Training Sample of BP Neural Network

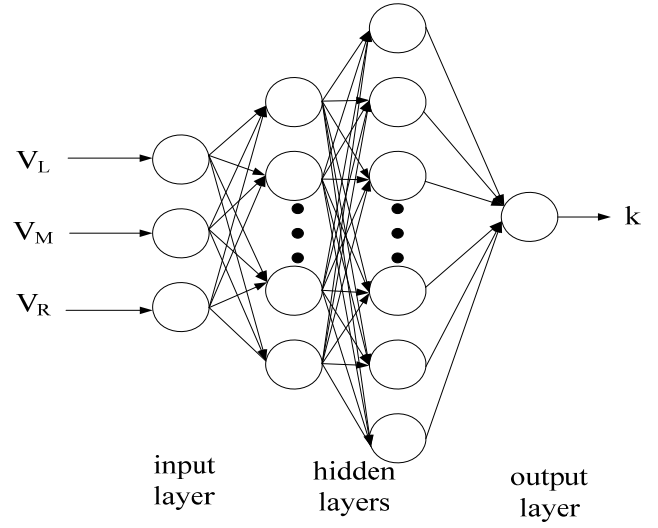
Number	$V_L$ (V)	$V_M$ (V)	$V_R$ (V)	$\psi$ (V)	$k_{MBN}$
$S_1$	128.59	150.87	131.39	49.82	1
$R_1$	119.37	146.11	124.56	46.21	0.928
	105.19	138.9	116.39	44.197	0.887
	118.43	141.37	110.85	45.803	0.919
	115.49	138.34	104.59	45	0.903
	114.94	141.71	115.23	46.127	0.926
	104.54	134.93	105.18	43.533	0.874
	96.99	129.77	97.89	41.557	0.834
	122.61	145.38	119.15	46.957	0.943
	110.35	141.35	118.47	44.8	0.899

**Tab.2.** Test Sample of BP Neural Network

Number	$V_L$ (V)	$V_M$ (V)	$V_R$ (V)	$\psi$ (V)	$k_{MBN}$
$S_2$	129.16	149.46	130.3	46.37	1
$S_3$	131.55	150.64	131.9	47.46	1
$S_4$	130.41	149.76	130.69	47.63	1
$S_5$	131.67	150.47	131.58	48.69	1
$S_5$	129.24	149.24	129.71	49.91	1
$S_7$	128.75	149.44	130.6	51.21	1
$R_7$	127.79	147.53	125.26	50.22	0.981
	125.61	145.34	120.52	48.91	0.955
	120.06	143.4	119.76	48.8	0.953
	118.02	142.29	118.41	47.86	0.935

As per the training speed and error magnitude of BP neural network, the structure of BP neural network is determined as shown in the fig.8; this is a 4-layer BP neural network<sup>[11]</sup>, in which the first layer is input unit, the second and the third layer are hidden layers and the fourth layer is output layer. The numbers of nodes of the two hidden layers are 8 and 12 respectively, and tansig is selected for all the transfer functions in the two hidden layers and the output layer. During training, the trainscg function (standardized conjugate gradient counter propagation algorithm) is selected as the training function, and the learngdm function (momentum gradient descent weight and threshold value learning function) is selected as the learning function, and mse (mean square error function) is selected as the performance function, and the main training parameters are as follows: the maximum training times is set as 200000, and the targeted error precision of training should be less than 0.0001, the

learning rate is 0.05, and the momentum coefficient is 0.9<sup>[12][13]</sup>.



**Fig.8.** Drawings of Neural Network Structure Adopted by the Test

## 5 Results

When using the above generated BP neural network, the following formula should be utilized to obtain the characteristic value  $\psi_{bp}$  (as shown in (2)) of the MBN signal which is optimized by BP neural network, and  $\psi$  is the characteristic value of the detected MBN signal, and  $k_{MBNbp}$  is the output of the neural network

$$\psi_{bp} = \frac{\psi}{k_{MBNbp}} \quad (2)$$

By comparing the relative error before the BP neural network optimization and that of after it, we can analyze whether the result of BP neural network can reduce the Barkhausen noise signal detection error caused by the inconformity of the position state of magnetizer.

The following tab.3 lists the standard states of 7 detecting points, in which the 9 random states of No. 1 detecting point and the 4 random states of No. 7 actually detect the characteristic value  $\psi_{sc}$  and the relative error  $\nu_{sc}$  (as shown in (3)) of MBN signal before the BP neural network optimization, the output coefficient  $k_{MBNbp}$  as well as the characteristic value  $\psi_{bp}$  and relative error  $\nu_{bp}$  (as shown in (4)) of MBN signal after BP neural network optimization.

$$\nu_{sc} = \frac{\psi_{sc} - \psi_{S_n}}{\psi_{S_n}} \times 100\% \quad (3)$$

$$\nu_{bp} = \frac{\psi_{bp} - \psi_{S_n}}{\psi_{S_n}} \times 100\% \quad (4)$$

When the magnetizer is placed in random state, make comparison between  $\psi_{sc}$  and  $\psi_{bp}$ , after BP neural network computing, the relative error of Barkhausen noise signal is obviously reduced and within 2%; although the relative error of the magnetizer with the standard position is increased, but still within 1%. Therefore, the BP neural network can greatly reduce the influence of the position state of the magnetizer to the Barkhausen noise signal, and the final detected relative error is maintained within 2%.

## 6 Conclusion

Aiming at the problem that the position state of the sensor will result in the MBN detection error, this paper proposes a new sensor structure, utilizing the mechanical structure of the spring to effectively eliminate the lift-off

**Tab.3.** Comparison of Results of BP Neural Network Training

Number	$\psi_{sc}$ (V)	$\psi_{sc}$ (%)	$k_{MBNbp}$	$\psi_{bp}$ (V)	$\psi_{bp}$ (%)
S <sub>1</sub>	49.82	0	0.996	50.036	0.434
R <sub>1</sub>	46.21	7.246	0.93	49.671	0.3
	44.197	11.287	0.879	50.259	0.882
	45.803	8.062	0.919	49.838	0.037
	45	9.675	0.892	50.45	1.265
	46.127	7.413	0.924	49.897	0.156
	43.533	12.619	0.87	50.03	0.421
	41.557	16.586	0.855	48.595	2.458
	46.957	5.747	0.943	49.79	0.06
	44.8	10.076	0.887	50.519	1.404
S <sub>2</sub>	46.37	0	0.993	46.689	0.688
S <sub>3</sub>	47.46	0	0.996	47.641	0.382
S <sub>4</sub>	47.63	0	0.994	47.912	0.592
S <sub>5</sub>	48.69	0	0.996	48.898	0.427
S <sub>6</sub>	49.91	0	0.991	50.348	0.878
S <sub>7</sub>	51.21	0	0.994	51.525	0.615
R <sub>7</sub>	50.22	1.933	0.963	52.124	1.785
	48.91	4.491	0.943	51.853	1.255
	48.8	4.706	0.934	52.221	1.973
	47.86	6.542	0.926	51.66	0.878

of the pick-up coil; the induction coil is utilized to detect the lift-off information of the magnetizer, the BP neural network is adopted to optimize the detected MBN characteristic value, and it verifies by tests that new structure of the sensor and the BP neural network optimization algorithm can effectively reduce the detection error caused by the lift-off of the sensor. To achieve more optimization effectiveness, it is available to add the number of the training samples of BP neural

network or appropriately modify the parameters of BP neural network.

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