SIGNAL PROCESSING METHODS FOR MAGNETIC FLUX LEAKAGE TESTING BASED ON BISPECTRUM

Xinjun WU, Jiang XU, Yanling WANG
School of Mechanical Science and Engineering
Huazhong University of Science and Technology,Wuhan, 430074, P.R. China

Abstract

Magnetic flux leakage (MFL) testing is widely used in ferromagnetic material on-line and in-service testing for its high efficiency, high speed, and ability of testing both outside and inside defects. However, it is an unsolved problem of identifying of types of defects. A signal analysis method based on Higher Order Statistics (HOS) is introduced for processing magnet leakage testing signals in this paper. Firstly, The Bispectra theory is introduced and its realization method for MFL signals is given. Secondly, the experimental setup and the specimen with through holes and grooves are developed in order to obtain the MFL signals. In the last, the signals of two different defects of the through hole and groove are extract form the original signal by the threshold method. Identification for through holes and grooves is realized by comparing the number of wave peaks of the bispectra diagonal slices for the signals obtained from the pipe testing system. There is no need to employ any complex classification system in this method and its correction proportion exceeds 70%.

Keywords: Magnetic flux leakage testing, Higher order statistics, Bispectrum, Non-destructive testing, Signal processing

1 Introduction

Magnetic flux leakage testing is widely used to test many types of ferromagnetic parts such as pipe, rod, storage tank plate et al. There are two different types of defects occurring in service. One is corrosion, the other is groove. Different defects may cause different accidents. It is important to classify defect patterns to evaluate the safety of components.

Most of researchers focused on differentiating the outside and inside defects. A. A. Carvalho studied pattern recognition of MFL signals obtained by the intelligent pig using the artifical neural networks[1]. Alicia Romero Ramı´rez presents experimental work specifically designed to asses the capability of current MFL based machines to distinguish defects located on the top and those on the bottom of the tank floor [2]. Kang employed the difference method to differentiate the internal and the external surface of a steel pipe [3]. The HOS-based signal processing was employed in ultrasonic nondestructive testing. Jiang proposed a regional integrated bispectra method to extract the feature vector and a threshold method for classifying the bonding quality of tiles for multiple impacting devices [4]. It is seldom used to classify the hole and groove in MFL Testing. Signal processing based on the bispectrum is employed to classify different types of the defects in this paper.

2 Bispectra theory

The traditional signal processing includes the first and second order statistics, for example mean, variance, autocorrelation and power spectrum. It is widely used to describe linear and Gaussian processes. It is phase-blind and therefore Higher-Order statistics method is proposed to recover the phase characters of the signals. High-order moments, higher-order cumulants and higher-order spectrum are the most employed in the statistical analysis for the non-Gaussian or the nonlinear data.

Bispectrum is the Fourier transform of the third-order cumulant. For the zero-mean stationary random signal{x(n)}, n=0,1,2,… N-1, its third cumulant is defined as

$$c_{3x}(k_1,k_2)=E[x(n)x(n+k_1)x(n+k_2)] \tag{1}$$

By the two dimension Fouier transform, the bispectrum is obtained as

$$B_x(f_1,f_2)=\frac{1}{N^2}\sum_{k_1=0}^{N-1}\sum_{k_2=0}^{N-1}c_{3x}(k_1,k_2)\exp[-j2\pi(f_1k_1+f_2k_2)/N] \tag{2}$$

By setting $k_1=k_2=k$, a diagonal slice can be obtain as

$$B_{xD}(f)=B_x(f_1,f_2)\big|_{f_1=f_2=f}=\frac{1}{N}X^2(f)X^*(2f) \tag{3}$$

The diagonal slice of the bispectrum is employed to classify holes and grooves according to the nature of the MFL signals obtained in our experiments. The proposed procedure involves the following steps:

1) Obtain the abnormal signals by the threshold method.
2) Extract the suitable length of the data in the center of the peak of the abnormal signal segment which includes the whole defect information.
3) Compute the mean of the data in the window, and then obtain the zero-mean data by the original subtract the mean.
4) Estimate t diagonal slice of the bispectrum by Eq.(3).
5) Classify the hole and groove signals by comparing the phase coupling points of the diagonal slice of the bispectrum.

3 Experiment setup

Figure 1 shows the Experimental setup for the MFL measurement. The permanent magnet is employed to provide power to magnetize the seamless pipe to saturation. If the defects take place, the magnetic flux leakage field is produced, because the air magnetic resistance is greater than the pipe. The electronic signal can be obtained by Hall elements, then it can be amplified and filtered. The analog signal can be digitalized by A/D converter and input to the computer.

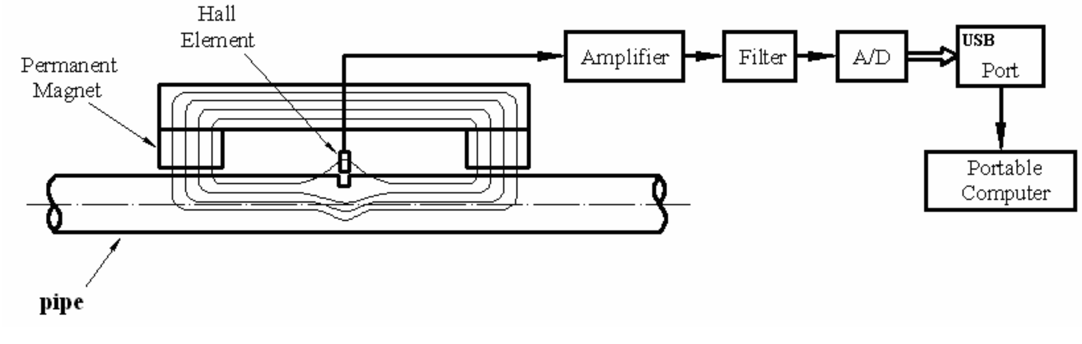


Figure 1 Experimental setup for the MFL measurement

Measurements have been performed on a seamless steel pipe as shown in the Figure 2. Table 1 gives the defect classification. There are six artificial defects on the seamless steel pipe.

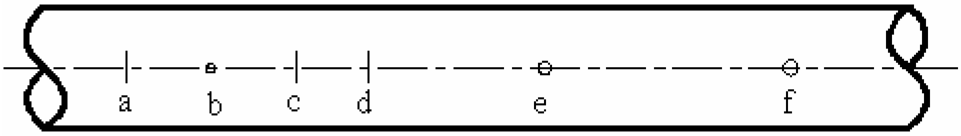


Figure 2 The arrangement of defects in the pipe

Table 1 Defect class

Symbol	Defect category	Widths (mm)	Depths (mm)	Lengths (mm)	Diameter (mm)
a	Groove	0.4	0.3	16	None
b	Through hole	None	None	None	0.8
c	Groove	0.4	0.6	17	None
d	Groove	0.7	0.9	25	None
e	Through hole	None	None	None	1.6
f	Through hole	None	None	None	3.2

4 Results and Discussion

Figure 3 shows the signal obtained when the sensor scans along designed defect. The signal a-f corresponds to the a-f defects from left to the right. There exists non-zero base line due to the output characteristics of the Hall element. The mean of the data can be obtained by choose normal signals in order to simplify the calculation of the bispectrum, firstly. And then we extract the data segment by setup the threshold line. Six defect signals can be obtained as shown in Figure 4. It is difficult to classify the defect types from the space domain.

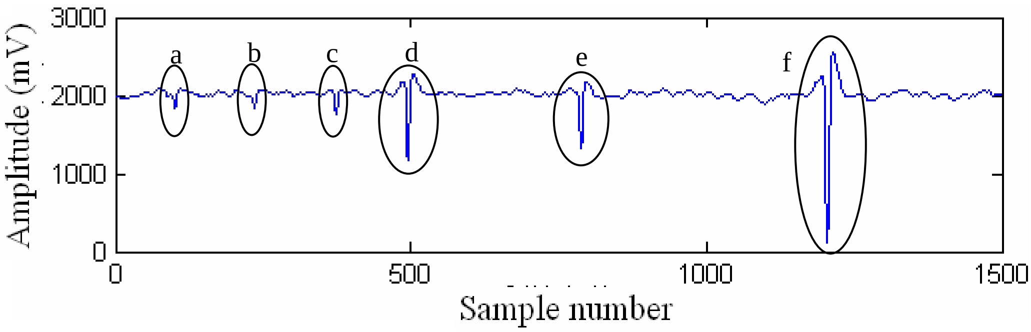
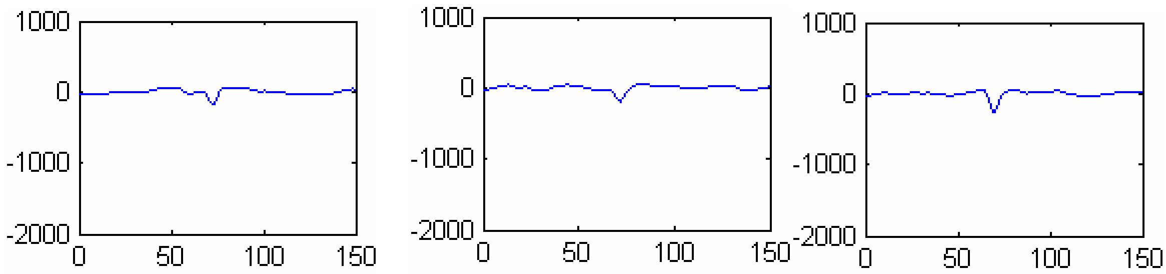
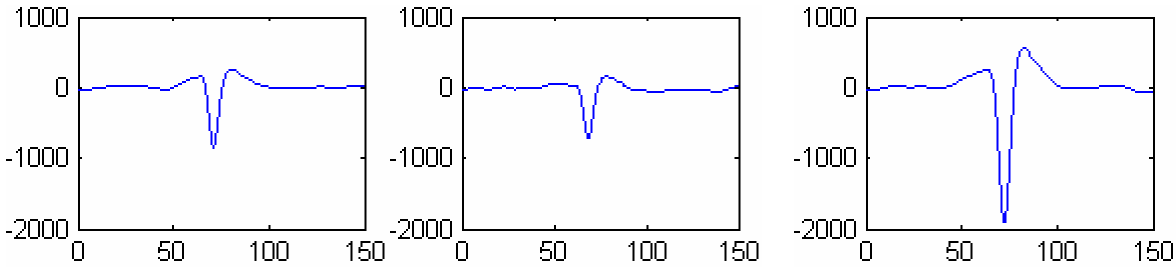


Figure 3 The signal obtained when the sensor scans along designed defect



(a) (b) (c)



(d) (e) (f)

Figure 4 Defect testing signals in the space domain

According to principle of the MFL testing, when the steel pipe is magnetized by the external magnetic field, most of the magnetic lines of flux flow into the steel pipe wall if there are no defects in the pipe and few leaks out from the tested component. If any defects on or near the surface are present, magnetic flux flowing through the pipe wall tends to leak out of the pipe and create a leakage field at the site of the defect. The reason is that the pipe has higher magnetic permeability than free space. The magnetic flux leakage contains information about the defect and can be measured by the sensor during its motion along the pipe. Suppose the defect signal is the result of the multiple source reciprocity, we could consider that the MFL is combination among multiple magnetic sources. From the characteristics of the signal forming, the signal of the groove which is involved in multiple signal, can affect more range, and it contains the more component of the frequencies and phases. The effect of the through hole signal is in a small range, there is less component of frequencies and phases.

According to the above mentioned analysis, bicesptra method is employed to process the defect data to obtain more frequency and phase information. Figure 5 shows the normalized bicesptra diagonal slice of the signal. The peak of the plot indicates the phase coupling phenomenon. If there is one peak, there is one phase coupling point that means the signal contain more phase information about the defect.

There is more than one peak in the a, c and d of the slice signal as shown in Figure 5. On the other hand, there is only one peak of the b, e and f. These experimental results indicate that the more phase component involved in the signal produced by the groove, and that the less is the through hole. We can find the number the peak of the groove signal bicesptra diagonal slice is more than the through hole. It can be employed to classify the groove and the through hole.

5 Conclusions

According to the signal characteristics of the MFL, bispectra-based signal processing method is developed. The principle of the bispectrum is given, firstly. And then the experimental setup is built. The abnormal signal is extracted by the threshold from the original data. The hole and groove defect signal are classified by comparing the phase couplings of the normalized bispectra diagonal slice.

References

[1] A.A. Carvalhoa, J.M.A. Rebelloa, L.V.S. Sagrilob, C.S. Camerinic, I.V.J. Miranda. MFL signals and artificial neural networks applied to detection and classification of pipe weld defects. NDT & E international 2006, 39: 661-667

[2] Alicia Romero Ramı´rez, John S.D. Mason, Neil Pearson. Experimental study to differentiate between top and bottom defects for MFL tank floor inspections. NDT & E international, 2009, 42:16-21

[3] KANG Yi-hua, LI Jiu-zheng, WU Xin-jun, A dynamics study of a magnetic flux leakage (MFL)

signal and its application to defect location discrimination in steel pipes MFL testing equipment. International Journal of Plant Engineering and Management, 14(2),2009,70-77.

[4] Z.D. Jiang, B.L.Luk, K.P.Liu. Bispectra-based impact acoustic non-destructive evaluation . NDT & E international, 2009, 42:652-657

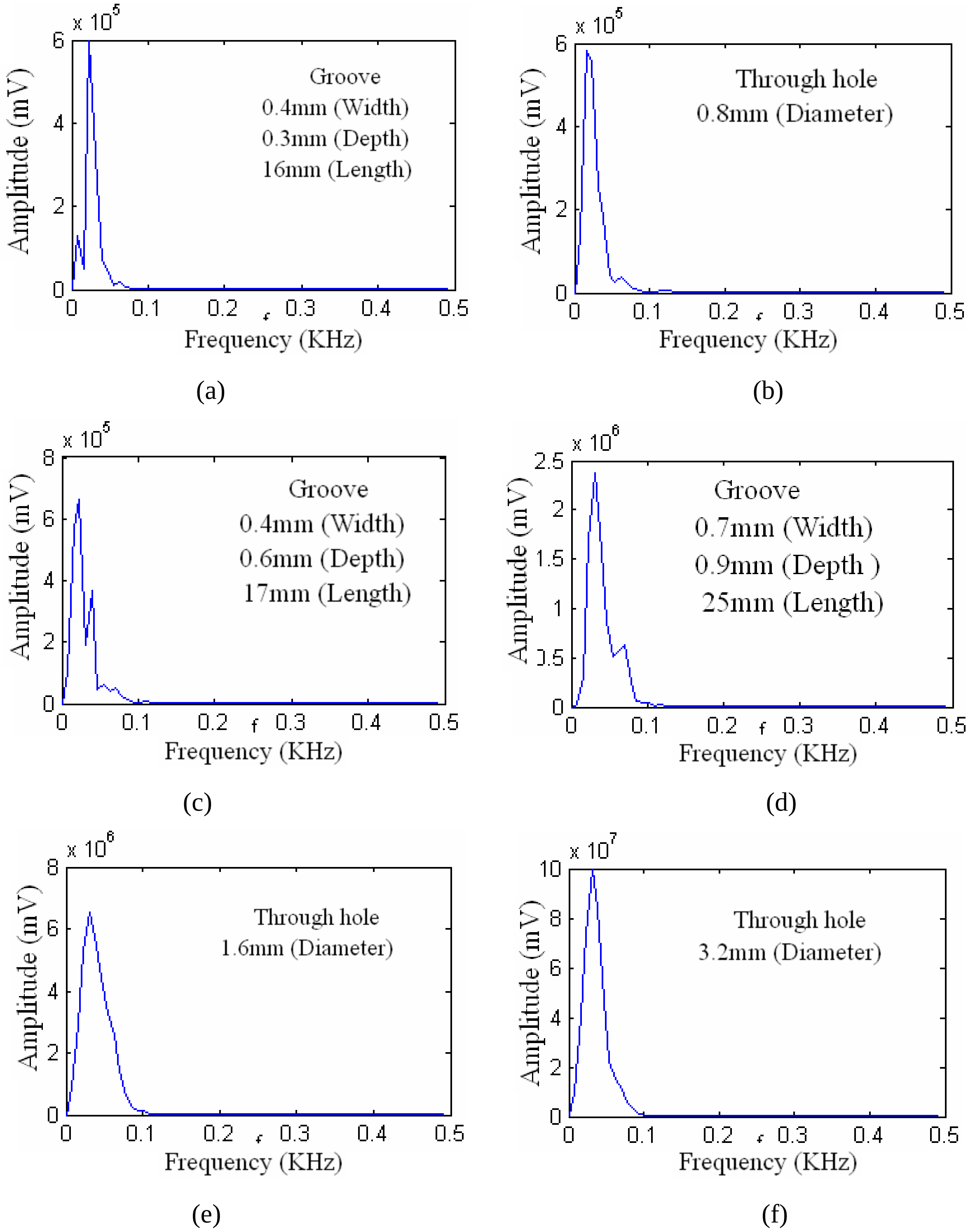


Figure 5 The normalized bicesptra diagonal slices of the signal