Research on Ultrasonic Positioning and Detection Method Based on MEMS Array Sensor

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ABSTRACT

In order to improve the accuracy of defect location and detection of metal components, an ultrasonic location and detection method based on MEMS array sensor is proposed. Firstly, the micro-electro-mechanical (MEMS) machining technology is analyzed in detail. An ultrasonic detection system based on MEMS array sensor is designed. Then, a SVM based ultrasonic localization and detection method for metal component near surface defects was proposed. The classification and recognition characteristics of SUPPORT vector machine (SVM) were used to accurately locate and detect metal component surface defects. The experimental results show that in the ultrasonic location and detection of metal component defects, the recognition accuracy of SVM is as high as 98.8%, which shows that the use of SVM can effectively improve the accuracy of location and detection, which is feasible and effective.

Keywords: MEMS array; Metal member; Defect detection; Ultrasonic positioning; SVM

1. INTRODUCTION

In recent years, with the continuous improvement of China's modernization level, the market demand for various metal components in the industrial field is increasing, and various metal components have been widely used in the aviation field, industrial field and power field. However, the traditional metal component defect detection method mainly adopts manual detection. This method has low detection efficiency, high work intensity, is greatly affected by subjective factors, and the defect detection speed and accuracy can not be guaranteed, which can not meet the needs of efficient defect detection in the current industrial market. with the rapid development of industrial production technology, the quality requirements of metal components are increasing day by day. In particular, the demand for rapid and accurate full inspection of metal components is put forward by the industry of large quantities of precision electromechanical materials. How to improve the detection efficiency and reduce the detection cost is an urgent problem to be solved in this industry.Yao Weiqiang et al [7]. applied EFPI optical fiber ultrasonic sensor to defect detection of metal components to improve the accuracy of defect detection. Zhang Jinpeng et al [9]. proposed a quantitative detection method for defect location based on the volume wave of laser ultrasonic diffraction. The laser ultrasonic technology was used to detect the defect location bars of metal components, which had high detection efficiency and reduced the workload of manual detection. Zuo Ouyang [10] proposed the numerical simulation study of laser ultrasonic crack detection based on COMSOL. The simulation verified that this method can accurately detect metal cracks and has certain feasibility. based on the above research results, an ultrasonic location detection method based on MEMS array sensor is proposed to achieve accurate location and detection of metal component defects, providing data reference for this field.

2. DESIGN OF ULTRASONIC POSITIONING AND TESTING SYSTEM.

2.1. Basic Methods

Micro electro mechanical system (MEMS, Micro-Electro-Mechanical System), also known as micro electro mechanical system, is a device with very

small size. MEMS has achieved good application results in handling the connection and communication of extremely small machines [4]. With the rapid development of the Internet of Things, artificial intelligence and other technologies, MEMS system has been vigorously promoted and popularized, and it is widely used in aviation, medical equipment, shipbuilding and other fields [2].

MEMS acoustic sensor is a commonly used sensor in this system, and its working principle is to convert the collected acoustic signals through MEMS technology, so as to obtain electrical signals. The operating status and performance of the system can be judged and evaluated according to the amplitude variation of electrical signals. The sensor has the advantages of small size, low power consumption and strong defensive, and has been used in the electronic fields such as smart phones and smart computers.

Combined with the characteristics of MEMS Micro equipment, it is applied to ultrasonic testing, and an ultrasonic defect detection system is designed as follows [1].
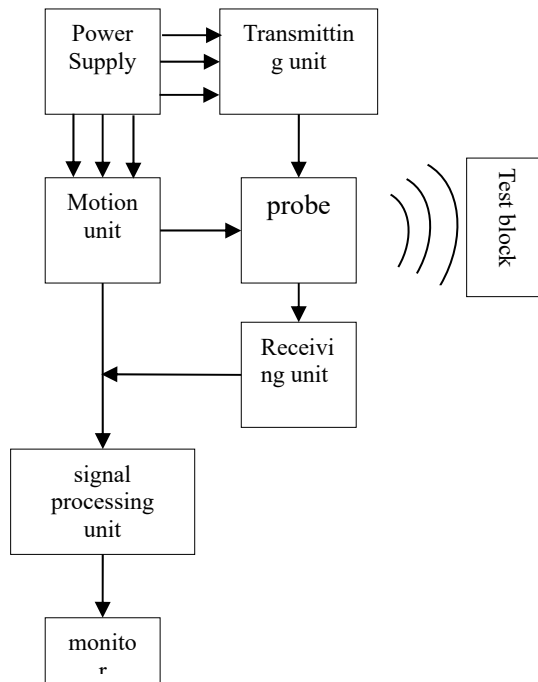

Figure 1: Overall framework of ultrasonic detection system

In the ultrasonic detection system, the single point a-wave signal contains less defect information, which is not conducive to the ultrasonic detection and positioning of the subsequent system, so it is necessary to conduct quantitative and qualitative research on the defect information of this signal. The work-piece can be comprehensively scanned by planning ultrasonic scanning path.by acquiring and analyzing the echo signal information of the whole scanning surface of the component, the defects can be characterized more

intuitively [5]. In order to study the influence of the focal spot size of focusing transducer on the detection of different defect sizes, transducer selection and detection system configuration are needed.

As can be seen from Figure 1, the ultrasonic testing system is composed of six parts, namely power supply, transmitting unit, motion unit, receiving unit, model unit and display. Through the cooperation of these six modules, the practical application of ultrasonic detection systems can be realized.

2.2.   Selection of ultrasonic transducer.

In the ultrasonic testing system, the main standard for evaluating the ability of ultrasonic transducer to identify defects is sensitivity. In defect detection, the higher the sensitivity, the smaller the size of identifiable defects. Sensitivity is correlated with the detection frequency of the transducer, and the minimum defect size that can be recognized by the transducer is about half of the detection frequency, namely $\lambda / 2$ [3]. For better quantitative detection of multi-ultrasonic defects, a suitable transducer will be selected, and the focal spot size of the acoustic beam will be calculated according to the transducer parameters. If the transducer is focused in water, the ultrasonic beam emitted by the focusing transducer forms an elliptical focal spot on the focal plane. The solution formula of focal spot diameter d of acoustic beam is:

$$d = 1.02 \frac{Fc_f}{fa}$$

（1）

In Formula (1), a represents the radius of the transducer; F represents the focusing length of the transducer; f represents the input frequency of the transducer; c_f is the speed of sound of water.

3.   ULTRASONIC LOCALIZATION AND DETECTION OF METAL COMPONENT NEAR SURFACE DEFECTS BASED ON SVM.

3.1.   Principle of ultrasonic testing

At present, the research of using ultrasonic to detect metal component defects mainly focuses on micron size. Therefore, in order to realize the detection of tiny defects, Olympus-V311-SU type water-immersion focusing 10MHz probe and Olympus-V319-SU type water-immersion focusing 15MHz probe are respectively used for experiments. Among them, the diameter of 10MHz probe is 12.7mm, the center frequency is 9.76mhz, and the focusing length is 50.8mm. -6dB bandwidth is 69.08%; The diameter of

15MHz probe is 12.8mm, the center frequency is 15.19mhz, and the focusing length is 39.27mm. -6dB bandwidth is 53.47%. According to the calculation, the focal spot diameter of the focused sound beam of 10MHz probe is 0.622mm, and the focal spot diameter of the focused sound beam of 15MHz probe is 0.308mm, in which the speed of ultrasonic propagation in water is 1483m/sfc [6]. Aiming at the problem of surface echo interference in the vertical incident pulse echo detection method, the ultrasonic detection of near surface defects of 440C stainless steel bearing inner ring was studied, and the quantitative calculation of defect location was realized.
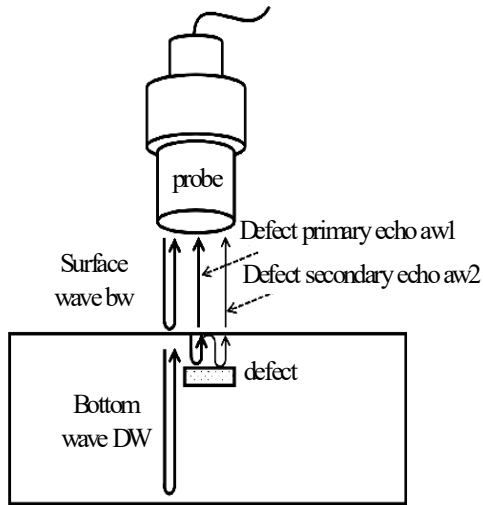

Figure 2: principle of ultrasonic testing

3.2. The SVM classification

Support vector machine (SVM) is a typical classifier in machine learning. It has achieved good application results in the fields of image data classification, recognition, regression and time series. SVM has good classification performance and generalization ability to high-dimensional small samples, and is increasingly used in classification problems. In classification, it is not susceptible to external interference, and the "tolerance" of local disturbance is the best.

The SVM algorithm converts the dimensions of an input space, that is, the nonlinear mapping into a high-dimensional space, so as to obtain the optimal hyperplane. Among them, the SVM algorithm is mainly divided into two forms of modeling, namely linear separability and linear inseparability [8]. SVM linearly separability means that the multipoint and data are divided by a straight line, and the maximum distance of hyperplane between classes is found in the dimensional feature space. If the linear separable SVM cannot be used to transform and classify the dimension of the space well, the linear inseparable SVM can be used to solve this problem. The basic principle is linear regression based on a linearly separable

high-dimensional feature space, which can solve the generalization problem in the predictive modeling process, so as to avoid data overfitting.

3.3. Ultrasonic positioning method for near surface defects of metal components.

In ultrasonic echo signal, the distance between the secondary echo of defect and the surface echo is usually twice as long as that between the primary echo of defect and the surface echo, which makes the secondary echo of defect less affected by the surface echo. therefore, according to the position information of the defect secondary echo signal and the transmission path of the sound wave in the component, the depth information of the defect in the component can be calculated by formula (2) and formula (3).

$$t_{F1} = \frac{1}{2}\left(t_{F2} - t_w\right) \qquad (2)$$

$$z_F = \frac{1}{2} \times t_{F1} \times c_L \qquad (3)$$

In the above formula, t_{F1} represents the time when a defect echo appears; t_{F2} represents the time of defect re-occurrence; t_w represents the time of surface echo; z_F represents the depth of the defect inside the component; c_L represents the sonic velocity of longitudinal wave in the construction of ultrasonic wave. therefore, SVM is used to classify and predict the defect echo signal, and the accurate calculation of the actual position of near surface defects is realized by identifying the defect primary echo and defect secondary echo.

4. EXPERIMENTAL RESULTS AND ANALYSIS.

4.1. Experimental environment

The experimental hardware is Multi2000 ultrasonic acquisition instrument, and the model of motion controller is ZMC206. Multi2000 ultrasonic acquisition software, motion control software compiled by Microsoft VS C# 2017 and ultrasonic signal processing software based on Matlab are selected as the system software.

4.2. Experimental data

To verify the validity of proposed method, the experiment will obtain 10 samples with different types of defects from a factory, the sample sizes are 50mm, 60mm and 10mm, respectively. The sample areas are defective area A and non-defective area B, and the experiment uses this method to ultrasonically detect the sample to obtain the overlap of defect echo and surface

echo, so as to judge the ultrasonic detection effect of this method.

4.3. SVM recognition of ultrasonic defect simulation signal.

In order to verify the effectiveness of ultrasonic defect detection method based on SVM, this experiment verifies the recognition ability of support vector machine to defect primary and secondary echoes through ultrasonic simulation signals. Set the center frequency of the transducer to 100Hz and the amplitude to 1; The bandwidth is set to 104; Translation time is 0.04; The initial phase is $\pi/6$ and the sampling frequency is set to 5KHz.By setting the time series of defect waves, the primary echo signal of defects overlaps with the surface wave, and the ultrasonic simulation signal of near-surface defects is shown in FIG. 3.
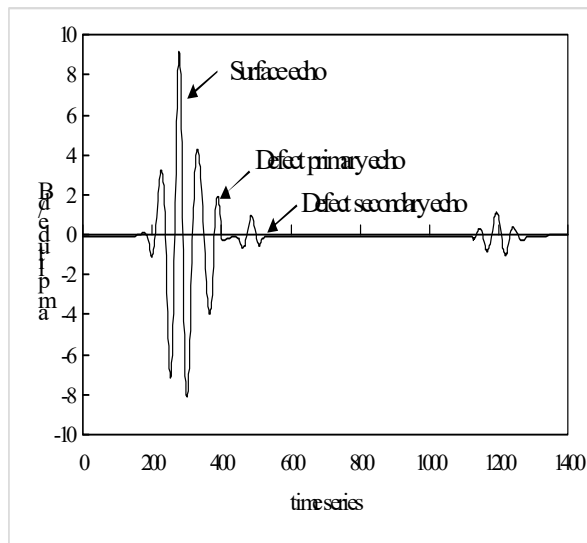

Figure 3: ultrasonic simulation signal of near surface defect

A total of 6 depths of near-surface defect echo signals A~F were designed in the simulation signal. The distance between the second echo of the defect and the surface wave was twice that of the first echo of the defect and the surface wave. The gain of the surface echo, the first echo of the defect and the second echo of the defect were 10dB, 6dB and 1dB respectively, and 100 data were simulated for each depth. The primary defect echo and secondary defect echo are extracted and put into support vector machine for classification, training and recognition, in which the training set accounts for 70% and the test set 30%. The test results are shown in Table 1.

Table 1: Recognition accuracy of echo signal of simulation defect

Depth gradient	SVM recognition accuracy
A	96.5%
B	97.2%
C	95.4%
D	98.3%
E	99.8%
F	97.5%

It can be seen from table 1 that for the designed near surface defects at six depths, the accuracy of ultrasonic defect location and detection based on SVM is more than 95%, and the detection accuracy is high, up to 99.89%. Therefore, the support vector machine SVM can be added to effectively identify and classify the primary and secondary echo signals of simulated ultrasonic defects, thus improving the defect location and detection effect of metal components, and further demonstrating the feasibility of the ultrasonic detection system designed.

5. CONCLUSION

In conclusion, the ultrasonic positioning detection method based on SUPPORT vector machine (SVM) can improve the accurate positioning and detection of external surface defects of metal components, and the ultrasonic positioning and recognition effect can be improved after the selection of appropriate transducers. Through the ultrasonic simulation signal, the recognition ability of support vector machine to the primary and secondary echoes of defects is tested. The experimental results show that under six different construction defect depths, the recognition accuracy of ultrasonic defect detection based on support vector machine SVM is as high as 99.8%, indicating that the designed ultrasonic positioning and detection system can achieve good recognition effect. It can be popularized and applied in this field. the above work, however, has made certain research results, but in the system design to only consider the simple metal component surface defects, without considering the more complicated components of the inner surface defects such as problem, therefore, the future will be even more complex defects on the surface of the metal artifacts further in-depth study and analysis on the detection and recognition, so as to improve the ultrasonic detection and localization of complex metal internal and external defects.

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