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Research Article

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Design of digitized ultrasonic testing system for axles of express locomotive

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ABSTRACT

Along with the rapid development of China's railway, express locomotive has gradually become the backbone of railway transportation. The flaw-detecting test for axles of express locomotive directly affects on the safety of express railway transportation. The digitized ultrasonic testing system is designed against the flaw-detecting test for axles of express locomotive. This paper will focus on the study of key technical problems in design, including ultrasonic emission, receiving module, express A/D acquisition model and upper computer signal-processing software. The stability and reliability of such system is tested by test of artificial defects which have the capacity to satisfy the locomotive axle inspection accuracy and adapt to test all kinds of express locomotive axle.

Keywords: ultrasonic testing, digital filtering, express locomotive axle, envelope extraction, and digital signal processing (DSP)

INTRODUCTION

Locomotive axle constitutes the key running part of locomotive. It both bears great quality and load of static loads, and supports shock, stretching, distortion and other kinds of alternating stress caused by track rail, rail welding seam and surface corrosion [1]. Express locomotive is required to run long time and distance under the condition of high speed and heavy load. Under the action of all kinds of destructive stresses for a long period [2], the stress concentration area of the locomotive axles is very easy to produce fatigue cracks led by bearing ultimate strength of the overloaded materials. In this case, the use of such damaged axle will further expand and deepen the fatigue cracks, or even cause fracture of axle to incur accident. This will bring in huge hidden trouble to the safety of railway transportation. Therefore, in order to ensure driving safety, the status of axle must be tested periodically to identify the defects timely and to repair or replace the parts in time [3]. Therefore, ultrasonic flaw detection of locomotive axle has very important significance to the safe operation of the train and to improve the running speed.

The digitized ultrasonic testing system for axles of express locomotive is composed by ultrasonic emission model, ultrasonic receiving module, express A/D acquisition model and signal-processing software. The system diagram as shown in Fig. 1.

Impulse reflection method is introduced in the testing. The ultrasonic wave is generated by exciting the detector via high voltage reverse pulse from the ultrasonic emission circuit. The ultrasonic wave will generate echo signal at the front and defect location of the axle. If the axle has no internal defects, the received reflection wave will have head wave and one backwall echo; if the axle has minor defect, it can receive head wave, one backwall echo, and defect wave. The defect wave is located at between the head wave and backwall echo [4]. The ultrasonic emission receiving module will exercise limiting and amplitude processing against the echo signal to make it within the scope of express collection of stimulant signal. Thus, the storage of express A/D conversion and digital quantity is achieved; finally, the USB will transmit the converted digital signal to the upper computer. Then, the upper computer may display and achieve analysis in the form of waveform.

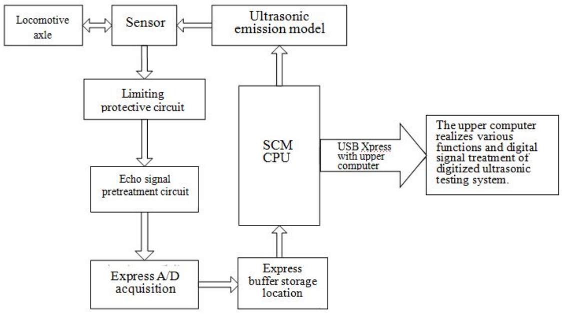


Fig. 1: Schematic diagram of locomotive axle testing system

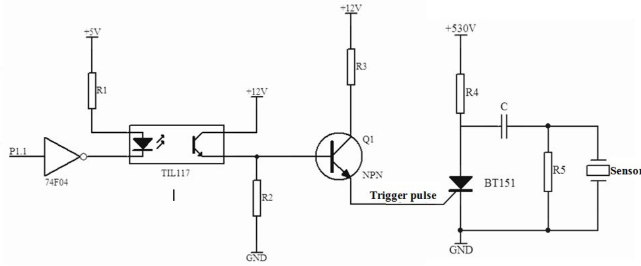


Fig. 2: Schematic diagram of transmission circuit

2 Design of ultrasonic emission module

The transmission circuit of express locomotive axle testing system uses inharmonic mode impulse circuit. The basic principle is to manage thyristor open and close by using trigger signal for the purpose of control the generation of high-pressure negative pulse discharged by capacitor in the transmission circuit and of inducing the probe to produce ultrasonic. The schematic diagram is shown in Fig. 2.

The transmission circuit of thyristor should be the high voltage circuit of above 500v. In order to separate the low and high voltage, TIL117 optocoupler is adopted for photoelectric isolation. Low level driving is used for optocoupler. The current signal from Q1 transistor will trigger thyristor open. Thus, high pressure negative pulse may excite the probe to generate ultrasonic.

3 Design of ultrasonic receiving module

Its main function is to limit and expand the axle inspection signal output from the transducer, in order to meet the requirements of the input of secondary side post A/D acquisition module.

3.1 Limiting protective circuit

The testing method uses single probe impulse reflection method. The emission circuit is connected with the receiving circuit directly. In this way, the high voltage negative pulse trigger signal will enter into the receiving circuit, causing millivolt level echo signal in the receiving circuit and hundreds of volts of high voltage negative pulses. In order to protect the electronic components in secondary side post receiving module and to enable it to receive echo signal normally, it is better to conduct limiting process against the high voltage pulse signal. The design introduces zener diode in paralleling the limiting protective circuit. The output signal range is ±2V.

3.2 Variable gain amplifier

The radio frequency voltage of ultrasonic echo signal converted by piezoelectric crystal plate is generally only of hundreds or even dozens of millivolts. After inputting into the receiving circuit, it should be disposed of amplification. In addition, the locomotive axle manufacturing material's uniformity degree, coupling status, surface roughness and other various factors may make the amplitude size of the ultrasonic echo signal unstable. This requires the variable of the gain amplifier circuit.

The AD603 VGA of Analog Devices Company used in the design is featured by ultra-low input noise and broadband. In addition, the bandwidth does not change with the altering of the gain. It is widely used in various kinds of ultrasonic testing systems. The maximum gain of AD603 can reach 51 dB. The gain size is controlled by the difference VG（VGPOS-VGENG）of GPOS and GNEG port. The gain control area will control the movement of "contact slider" of ladder resistance network subject to the size of VG to the corresponding "nodes" location. The available attenuation range is between 0 to 42.14 dB [5].

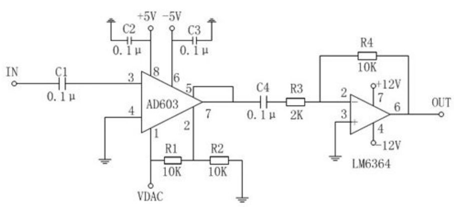


Fig. 3: Diagram of VGA

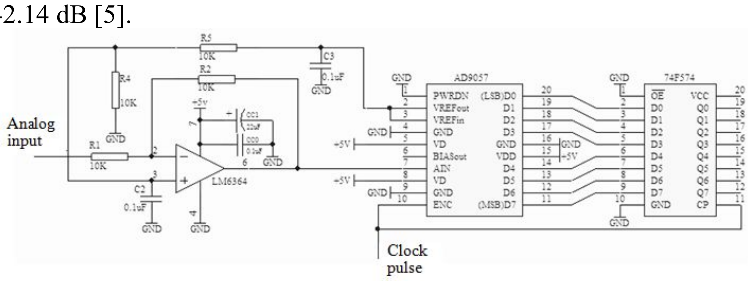


Fig. 4: AD9057 sampling circuit

The design of VGA is shown in Fig. 3. The FDBK is short circuited with VOUT. Broadband work mode is selected; the range of gain control voltage VDAC is ±1V. After dividing R1 and R2, the differential voltage form is input into the gain control of GPOS and GNEG. The advantage of such design is to reduce the affects of gain control voltage fluctuation against the gain coefficient; the secondary side post is connected with an operational amplifier with fixed magnification by coupling capacitor. Thus, the voltage signal is output by A/D acquisition module [6].

4 Express A/D acquisition module

The work frequency of the system is generally 2.5 MHz. According to Nyquist sampling theorem, when the sampling frequency is greater than twice of the highest frequency of the signal, the digital signal after sampling will completely keep the information in the original signal. In general practice, it is usually to ensure that the sampling frequency is 5 ~ 10 times of the highest signal frequency. This is because that the system work frequency is likely to change with the altering of different axle. Therefore, 40 MHz express ad converter AD9057 is used [7]. Under such high-speed acquisition frequency, the real-time data processing by SCM will greatly increase the difficulties of control, complicate the hardware circuit, increase product cost, and unable to get good economic benefit [8]. Taking into consideration of the lower requirements on real-time and synchronization of locomotive axle testing system, time-sharing access processing method is used to complete data caching and transmission [9].

4.1 AD9057 sampling circuit

The principle diagram of sampling circuit is shown in Fig. 4. The analog input signal V_i, processed by limiting and amplification by the receiving module, is transmitted to AD9057 via voltage regulating circuit. When V_i is too large or small, the gain that can adjust the receiving module make Vo at the input range of AD9057 and ensure V_O within the input range of AD. The too large capacitive load may increase the internal noise of AD9057. Therefore, the AD9057 digital signal port will output the secondary side post access circuit by data latch 74F574. This method can reduce the capacitive load of AD9057 and improve SNR of signal [10].

4.2 Circuit of data cache

Time-sharing access is adopted in echo signal. One static RAM HM62832 manufactured by HITACHI Company is used to achieve real-time storage of digital signal of AD9057 conversion circuit output. HM62832 is 8-digit high-speed RAM. Its storage capacity is 32k. The principle of data storage circuit is shown in Fig. 5:

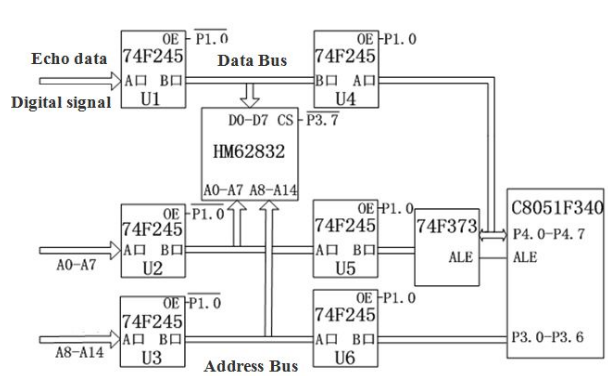


Fig. 5: Data storage circuit

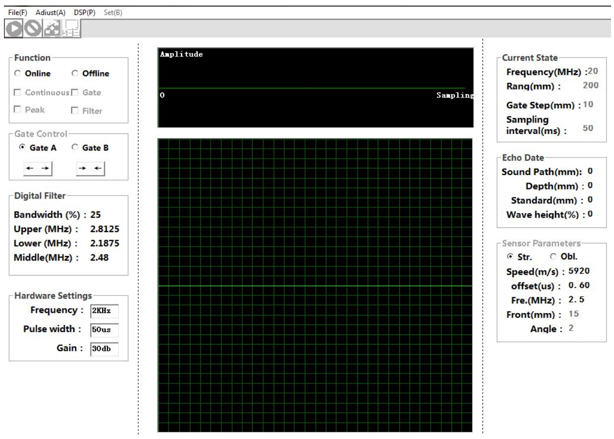


Fig. 6: Main interface of the upper computer software

When upper computer orders the task of acquisition, P1.0 will output high electric potential. The data bus driver U1 will enter conducting work with address bus driver U2. P3.7 will output high electric potential. $\overline{WE}$ is the low electric potential. When HM62832 is conducted, the data storage procedure will be initiated. When the data storage reaches 32 KB, the SCM will be interrupted. P1.0 outputs low electric potential, P3.7 of high electric potential, $\overline{OE}$ of low electric potential. The data bus driver U4 will enter conducting work with address bus driver U5/U6. The SCM will read the external RAM data. The echo data of HM62832 is transmitted to the upper computer.

5 Signal processing software of upper computer

In order to realize waveform display, data storage, and data analysis of such testing system, it is needed to develop the upper computer software [11]. The upper computer software should satisfy the characteristics of friendly users' graphical interface, simplify operation and modularization. Therefore, Visual Basic 6.0 is used as the software development platform. The main interface of the upper computer software is shown in Fig. 6:

The core functional modules of the software are composed by signal acquisition, hardware settings, system calibration, defect judgment, signal processing, etc. Signal acquisition module delivers order by the upper machine; the lower computer uploads the waveform data in the form of data array to the upper machines by USB and displays it in the form of A-typed scan. Meanwhile, the waveform and probe parameters storage can be done at the same time. The data display module exercises the calculation of acoustic distance and amplitude via gate functions to obtain the height of echo wave, the defect acoustic distance, and the level and depth in order to judge the position and size of defects. Signal processing module can conduct digital bandpass filter against the echo signal with different center frequency and envelope extraction against high frequency echo, in order to conclude its time-domain specification and convenient for signal analysis and defect judgment.

RESULTS AND DISCUSSION

In locomotive axle testing experiment, SS4 improved axle is used as experimental object. Two artificial defects are processed by 2 mm in depth where 400 mm and 600 mm to the end respectively and by 1 mm in width. As shown in Fig. 7, flaw detection is made by adopting K1.8 and K1 of angle probe. The waveform obtained is shown in Fig. 8.

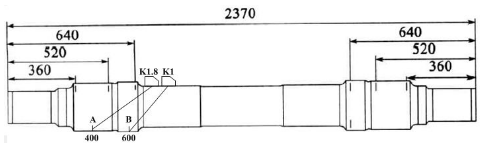
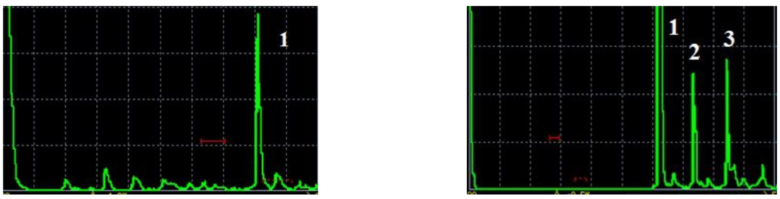


Fig. 7: Schematic diagram of artificial defects



(a) Oscillogram of defects at 400mm **(b) Oscillogram of defects at 600mm**

Fig. 8: Oscillogram of artificial defects

The echo 1 in Fig. 8 (a) is the reflection echo at the location of 400 mm defects. Its test data is as shown in Table 1; the echo 1 in Fig. 8 (b) is the reflection echo at low electric potential 600 mm defects; echo 2 of gear hub reflection wave; echo 3 of bearing inner sharp angle wave. The defect detection data is as shown in Table 2:

Table 1 Oscillogram of artificial defects at 400mm

Test number	Gain (dB)	Wave height (%)	Level (mm)	Depth (mm)
1	10	12.5	400.1	231.4
2	15	37.5	415.6	240.7
3	30	89.1	409.7	236.5

Table 2 Oscillogram of artificial defects at 400mm

Test number	Gain (dB)	Wave height (%)	Level (mm)	Depth (mm)
1	10	20.6	242.3	242.3
2	20	56.8	241.6	241.6
3	30	100.0	243.5	243.5

From the above data, we can see that when using the angle detection method for locomotive axle test, the system can well detect the location of the defects with minor errors which may satisfy the requirement of detection precision.

CONCLUSION

Approved by several testing experiments of the digitized ultrasonic testing system for axles of express locomotive, such testing system can reach the detection requirements of express locomotive axle. The ultrasonic released by the emission circuit can better meet the needs of the flaw detection of existing power. In addition, it has narrow pulse width and minor system blind area; the receiving module effectively realizes the protection and amplification effects. The variable gain amplifier circuit output signal is stability with small distortion; the express A/D acquisition module completes echo data caching and transmission by using the method of time-sharing access with accurate sampling results; the upper computer completely achieves the key functions of the digital ultrasonic testing system, and the echo data is accurate and reliable.

REFERENCES

[1] Zou C, Sun Z, Ma Q, et al. An enhanced ultrasonic automatic detecting system for locomotive axles.*Artificial Intelligence, Management Science and Electronic Commerce (AIMSEC), 2011 2nd International Conference on. IEEE*, **2011**: 3724-3727.
[2] Gao X, Peng J, Zhang Y, et al. Wheel and axle defect detecting technique using phased array ultrasonic.*Nondestructive Evaluation/Testing: New Technology & Application (FENDT), 2013 Far East Forum on. IEEE*, **2013**: 40-45.
[3] Wang Y, LI X, SONG Y, et al. *Journal of Railway Science and Engineering*, **2012**, 3: 024.
[4] Lynnworth L C. Ultrasonic measurements for process control: theory, techniques, applications. Academic press, **2013**.
[5] Zhu X F, Zhu X F, Li X M, et al. A Small System of Program-Controlled Amplification Amplifier Based on AD603.*Advances in Computer Science, Environment, Ecoinformatics, and Education*. Springer Berlin Heidelberg, **2011**: 23-27.
[6] Du Y, Jiang X, Mei M, et al. *Foreign Electronic Measurement Technology*, **2010**, 11: 47-50.
[7] MA H, MAO Q, ZHANG X. *Instrument Technique and Sensor*, **2011**, 1: 012.
[8] Demore C, Yang Z, Volovick A, et al. A sonic screwdriver: Acoustic angular momentum transfer for ultrasonic manipulation.Ultrasonics Symposium (IUS), *2011 IEEE International. IEEE*, **2011**: 180-183.
[9] Edwards R S, Holmes C, Fan Y. *Insight-Non-Destructive Testing and Condition Monitoring*, **2008**, 50(7): 369-373
[10] Nenov N, Dimitrov E, Vasilev V . *Electronics Technology*,**2011**: 577-582
[11] Wang Y, Zhang L J, Han X. *Automation & Instrumentation*, **2011**, 7: 007.