Journal of Computing and Electronic Information Management
ISSN: 2413-1660 | Vol. 12, No. 2, 2024

Enhancing Preamplifier Design for Acoustic Emission Detection Instrument

Wenhao Hu *, Long Chen [a], Xiang Shi [b] and Qingyuan Huang [c]

School of Automation and Information Engineering, Sichuan University of Science and Engineering, Zigong 643000, China

[*] **Corresponding author**: Wenhao Hu (Email: 321085404304@stu.suse.edu.cn), [a] 321085404308@stu.suse.edu.cn,
[b] 322085404205@stu.suse.edu.cn, [c] qyhuang@suse.edu.cn

Abstract: With the development of the industry, the safety of pressure vessels is crucial for both production and personnel safety. The application of acoustic emission testing technology as a dynamic non-destructive testing method in the detection of pressure vessels is becoming increasingly prevalent. This paper presents the design of a low-frequency acoustic emission preamplifier with a frequency range of 30KHz to 200KHz and a gain of 20dB. The preamplifier is composed of amplification circuits, power supply circuits, and filtering components. By utilizing the PXR04 series high-sensitivity resonant acoustic emission sensor and Texas Instruments' OPA333 operational amplifier, along with a clever power supply design, effective signal amplification and system stability are ensured. Experimental results validate the correctness of the design, providing a feasible and effective solution for enhancing the performance of acoustic emission testing equipment.

Keywords: Acoustic Emission; Preamplifier; Power Supply Circuit.

1. Introduction

In pressure vessel materials and structures, when subjected to internal or external pressure, deformation or cracking phenomena may occur. This phenomenon, during its occurrence, is characterized by the manifestation of strain energy in the form of instantaneous elastic waves, commonly referred to as acoustic emission. The sites releasing strain energy are termed acoustic emission sources. The generation of acoustic emission [1] sources in pressure vessels can be attributed to factors such as plastic deformation, the formation and propagation of cracks, and the fracture of fiber-reinforced composite materials. AE is based on monitoring the stress waves that are generated by rapid local redistributions of stress, which accompany the operation of many damage mechanisms. However, due to the requirement for the momentary release of variables inside the vessel to reach a certain level before being audible to the human ear, high-precision equipment is needed to detect elastic waves. This monitoring is crucial as the release of strain energy needs to reach a certain level before becoming audible. Therefore, high-precision equipment becomes necessary for the timely detection of acoustic emission, providing valuable insights into the condition of pressure vessels. AE offers a non-intrusive method for identifying and assessing potential structural issues, enhancing the safety and reliability of pressure vessel systems through the analysis of acoustic emission signals.

Acoustic emission detection technology converts the elastic waves carrying defect information released by the acoustic emission source inside the container into electrical signals. It is then processed, displayed, and recorded using electronic amplification devices to gain a detailed understanding of the internal structure of the container. Additionally, the application of multi-channel acoustic emission systems allows for timely detection and precise localization of defects within the container. Unlike conventional static non-destructive testing methods, acoustic emission detection technology is a dynamic approach. This is because the signal originates from the defects within the container itself. If the defects inside the container are in a stationary state, no deformation or cracking of defects will occur, and consequently, there will be no release of elastic energy waves. The research on acoustic emission (AE) as a diagnostic tool is increasingly growing [2]. According to the Chinese national standard "Non-destructive Testing of Pressure Equipment" NB/T47013.10, the frequency band range of the acoustic emission sensor should be within 5kHz~60kHz, which filters out some useful low-frequency characteristics not compliant with national standards. Therefore, designing a preamplifier with low-frequency [3] characteristics becomes crucial [4]. This paper introduces a low-frequency acoustic emission preamplifier designed with a frequency range of 30kHz~200kHz and a gain of 20dB.

2. Principle of Acoustic Emission

The challenge faced by acoustic emission sensors in detecting defects within pressure vessels lies in the weak nature of the signals they receive [5]. To ensure the reliable capture of these weak acoustic emission signals by subsequent circuits, it is essential to introduce a preamplifier to increase signal amplitude. This is crucial for enhancing detection sensitivity, making it easier to capture subtle defect information within the vessel. Due to impedance differences between various components and media involved in signal transmission, failure to match impedances may result in signal reflections and energy loss.

The preamplifier plays a crucial role in an acoustic emission detection system. Its primary tasks include:

Signal Amplification: Signals generated by acoustic emission sensors are typically very weak. The preamplifier amplifies the signal to increase the signal-to-noise ratio, ensuring subsequent circuits can effectively process these signals. This is vital for improving the system's detection sensitivity and capturing subtle defect information within the vessel.

Impedance Matching: Due to impedance differences in signal transmission involving various components and media, the preamplifier is designed with impedance matching to minimize reflections and energy loss during signal transmission. This helps maintain signal integrity and enhances overall system performance.

Frequency Range Coverage: The preamplifier is designed to cover a frequency range between 5kHz and 300kHz, ensuring effective amplification of acoustic emission signals within this frequency range. Since acoustic emission signals typically reside in this low-frequency range, carrying essential information about vessel defects.

Power Supply Voltage: It operates on a 12V DC power supply to meet the operational requirements of the preamplifier, ensuring stable operation under different working conditions.

With these design considerations, this preamplifier can effectively enhance signal amplitude while minimizing signal reflections and energy loss. This improves the performance of the acoustic emission detection system, making it more suitable for detecting weak defect signals within pressure vessels. Therefore, compared to similar products, the impedance matching capability of this preamplifier in our design further optimizes the performance of the acoustic emission detection system. In summary, our preamplifier design offers a higher frequency range and impedance matching functionality compared to similar products, contributing to an innovative enhancement of the acoustic emission detection system's performance.

Fig. 1 Preamplifier

The appearance of the preamplifier is illustrated in Figure 1, comprising an input interface, an output interface, and a power supply interface. Acoustic emission signals enter the preamplifier through the input port and are transmitted via a high-speed cable. The output interface connects to the data acquisition system of the acoustic emission detection system, transmitting the processed acoustic emission signals to the data acquisition system.

3. Pre-amplifier Design Proposal

In this design, the pre-amplifier consists of two main parts: the amplification circuit section and the power supply circuit section. The amplification circuit is responsible for amplifying the small acoustic emission signals, and its design quality directly influences the operational characteristics of the amplifier. The power supply circuit section is responsible for providing power to the entire circuit, and the smooth operation of the entire system depends significantly on the design of the power supply circuit.

3.1. Amplification Circuit Design

The amplification circuit section employs the PXR04 series high-sensitivity resonant acoustic emission sensor produced by Changsha Pengxiang Electronic Technology Co., Ltd. Since the sensor signal is in the millivolt range, this preamplifier needs to amplify the signal by 20dB, and the frequency range is from 5kHz to 300kHz. Obviously, using a single operational amplifier cannot achieve this, so a zero-drift operational amplifier needs to be selected. Then, choose a suitable voltage feedback high-speed operational amplifier that is powered by a power supply, has a high bandwidth, and meets the requirement of amplifying 100 times at 100kHz without distortion. After comparison and selection, the operational amplifier chip OPA333 from Texas Instruments (TI) is chosen. Schematic diagram of OPA333 operational amplifier in Figure 2. The following diagram is the Amplifier Circuit Diagram shown in Figure 3.

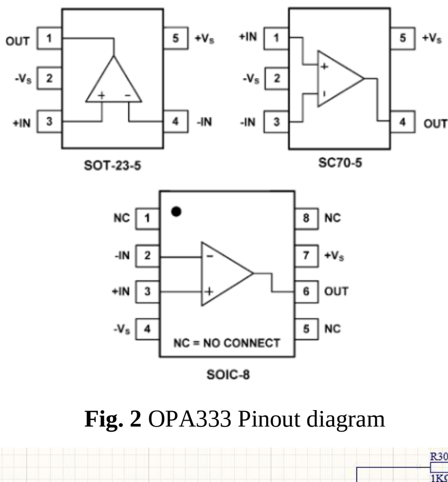

Fig. 2 OPA333 Pinout diagram

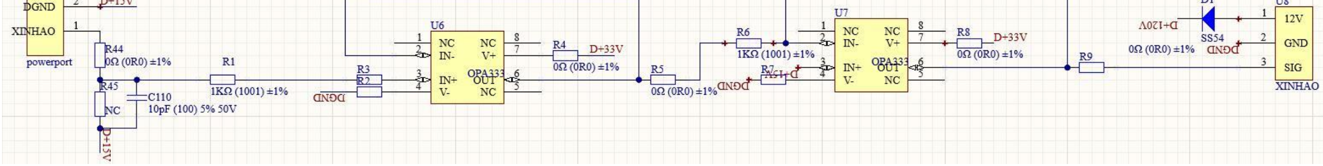

Fig. 3 Amplifier Circuit Diagram

The attached circuit diagram depicts an amplification circuit, where the U6 module initially performs impedance matching on the signal, followed by signal amplification through the U7 module. This design ensures that the signal undergoes proper impedance matching during transmission in the circuit, subsequently being subject to controlled amplification via the U7 module. Such a configuration helps optimize signal transmission, enabling the system to handle and amplify input signals more effectively.

In order to prevent signal distortion caused by mismatched source impedance and transmission line impedance when the signal enters the operational amplifier, leading to increased signal-to-noise ratio, it is essential to achieve impedance matching for optimal power transfer performance. The impedance values of the transistor input and output should be matched to be equal in magnitude and in phase. The impedance matching network is designed to address the issue of impedance mismatch during power transmission and can be implemented using an OPA333 oscillator, which is then connected to the OPA333 operational amplifier.

3.2. Power Supply Circuit Design

In this power supply design, choosing the SP1117 chip as the voltage regulator is a reasonable and reliable choice. The SP1117 features low power consumption, high efficiency, and a compact package, making it well-suited for power supply applications. By step-down regulation from an input voltage of 12V, we ensure that the amplifier OPA333 operates within a safe voltage range while maintaining the stability of the output voltage.

In the power system design, the application of the first SP1117 chip achieves the critical voltage adjustment from 12V to 5.5V. This step lays a solid foundation for subsequent voltage regulation processes, providing a reliable operating voltage for the entire system. The low static current and low dropout voltage of 1.1V at full load ensure efficient energy conversion, automatically adjusting the static current with load changes to enhance system efficiency.

The use of the second SP1117 chip further stabilizes the output voltage to 1.5V, forming a dual-stage voltage regulation design. This staged voltage regulation strategy enhances the robustness of the system, adapting to different loads and input conditions, providing strong support for the stability and performance of the circuit. Meanwhile, proper heat dissipation design ensures the reliability of the chip during operation, guaranteeing the long-term stable operation of the power supply system.

Throughout the design, attention to power supply stability and efficiency reflects a scientific design philosophy. Multiple safety mechanisms, such as input overvoltage, overcurrent, and short-circuit protection, further enhance the system's reliability. The flexibility of this power supply design allows adjustments to input voltage and output current according to the requirements of different devices, making it more versatile.

In summary, through the clever connection of two SP1117 voltage regulator chips, this power supply system excels in stability, efficiency, and safety, providing reliable power support for the entire circuit. This approach is more rigorous and reliable, aligning with scientific design principles.

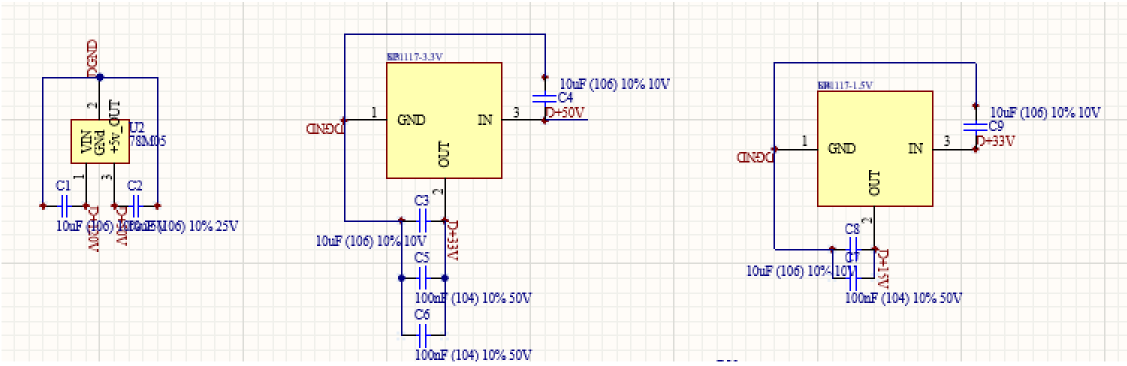

Fig. 4 The power supply circuit

The circuit diagram in Figure 4 illustrates the power supply circuit, employing a multi-stage step-down design to effectively prevent circuit overheating and enhance system stability. Initially, the 12V DC power supply is regulated to 5V through the 78M05 voltage regulator module. Subsequently, the voltage is further reduced to 3.3V via the U3 module, and finally adjusted to 1.5V through the U4 module, providing stable power to the entire system. This design ensures the circuit operates within an appropriate temperature range, thereby promoting the improvement of system performance and reliability.

4. System Performance Testing

The circuit diagram of the designed preamplifier is shown in Figure 5, with the right end (U111) representing the input terminal for the signal, and the left end representing the output terminal for the amplified signal. To conduct comprehensive testing of the entire preamplifier and ensure measurement accuracy, the signal input terminal is substituted with a signal generator instead of an acoustic emission sensor. where the DC circuit at the top is connected to a 12V DC power supply. The oscilloscope input is connected to the right end (U8), forming a complete measurement circuit.

The system is powered by a 12V DC power supply, and a sinusoidal signal with an amplitude of 20mVpp is input using a signal generator. The input is connected to the input terminal of the preamplifier, and a frequency sweep test is conducted on the preamplifier at frequencies of 40kHz, 100kHz, and 200kHz [6]. The output signal waveforms are observed using an oscilloscope.

The results of the frequency sweep test for the preamplifier, along with the output waveforms observed on the oscilloscope, are shown in the above Figure 6. It can be observed that at 40kHz, 100kHz, and 200kHz, the output achieves a signal amplification of 20dB, furthermore, the signal is distortion-free, with a flat amplitude-frequency response.

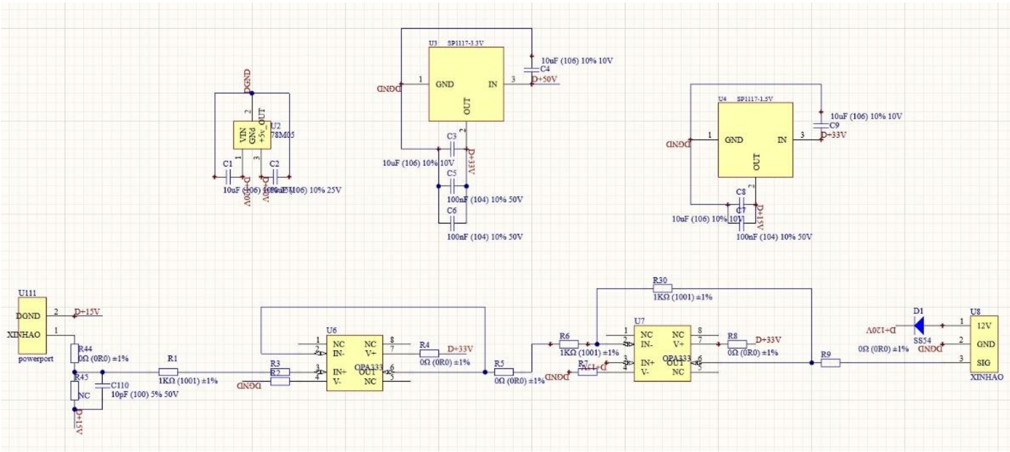

Fig. 5 System circuit diagram

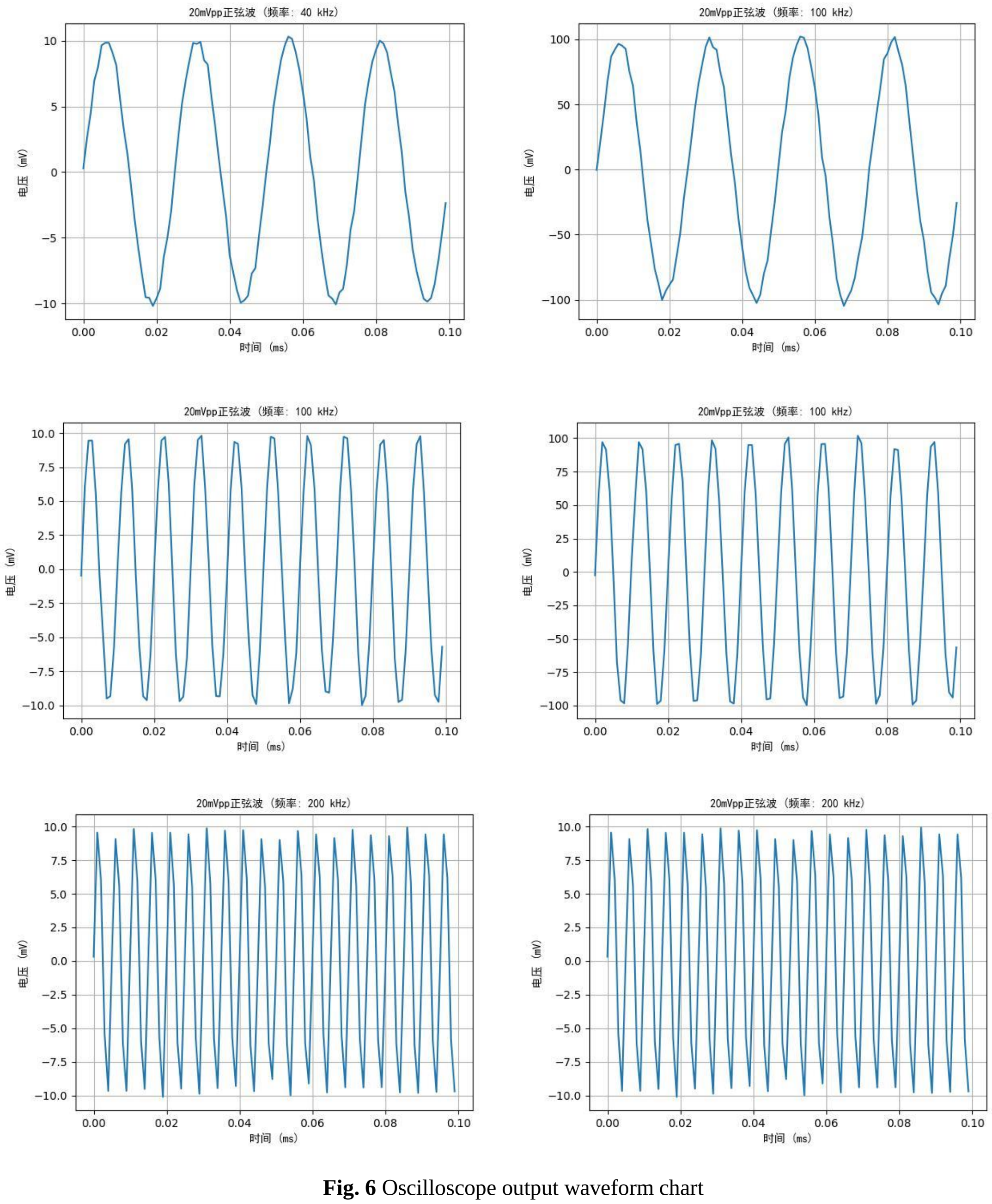

Fig. 6 Oscilloscope output waveform chart

5. Conclusion

To address the signal amplification requirements of acoustic emission detection devices based on pressure vessels, this study utilizes the SP1117 voltage regulator chip, OPA333 low-power CMOS operational amplifier, and the 78M05 voltage regulator module to design a preamplifier with impedance matching capabilities. Experimental test results demonstrate the outstanding stability of this circuit. Within the operating bandwidth range of 40~200KHz, a 20dB output gain can be achieved, showcasing high signal fidelity, smooth operation, and low noise levels, fully meeting the design specifications. In practical use, the preamplifier performs well, indicating extensive application prospects.

Acknowledgements

This paper was funded by Innovation Fund of Postgraduate, Sichuan University of Science & Engineering (Grant No. Y2022159 and Grant No. Y2022149).

References

[1] Nazarchuk Z, Skalskyi V, Serhiyenko O. Acoustic emission methodology and application [M]. Foundations of Engineering Mechanics, 2017.

[2] Ohtsu M. The history and development of acoustic emission in concrete engineering [J]. Magazine of concrete research, 1996, 48(177): 321-330.Chen Youqiang, Song Yongxiang. Application of non-destructive testing in pressure-bearing type special equipment [J]. Chemical Enterprise Management, 2023, 35: 21-23. (In Chinese)

[3] Kim K H, Kim S J. Noise performance design of CMOS preamplifier for the active semiconductor neural probe [J]. IEEE Transactions on Biomedical Engineering, 2000, 47(8): 1097-1105.

[4] Sun Tao, Han Dongxuan, Luo Shoupin, et al. Acoustic emission detector preamplifier design [J]. Microcomputer & Its Applications, 2016, 35(01): 33-35. (In Chinese)

[5] Cheng Hua, Chen Kejun, Wang Xuguang. Design of low noise underwater acoustic signal preamplifier [J/OL]. Journal of Hubei University (Natural Science Edition), 2024, 46(2). (In Chinese)

[6] Liu Xinxiang, Gu Yujiong, Ma Jiwei, et al. Sliding bearing fault diagnosis based on acoustic emission signal feature extraction technology [J]. Turbine Technology, 2024, 66(01): 1-6+28+52. (In Chinese)