

Research On the Design of a Device for Testing the Resonance Characteristics of Ultrasound Vibration Heads

Pham Tuong Minh Duong, Khoa Ngo Nhu, Lien Tien Dao*

Faculty of Mechanical Engineering, Thai Nguyen University of Technology, Vietnam

**Corresponding Author*

ABSTRACT: *Ultrasonic vibration is widely applied in precision machining, ultrasonic welding, and modern manufacturing systems due to its ability to improve surface quality, reduce cutting forces, and increase technological efficiency. However, accurately assessing the vibration characteristics of ultrasonic vibrators remains a challenge due to the high demands for measurement accuracy and the ability to operate over a wide frequency range. This paper presents the design, fabrication, and evaluation of an experimental system for measuring the resonant frequency and amplitude of an ultrasonic vibrator. The system includes an ultrasonic generator, a displacement sensor, a data acquisition circuit, and signal processing software. Experimental results show that the system can accurately determine the resonant frequency and amplitude characteristics of the vibrator within the investigated frequency range. The difference between measurements is less than 0.5%, demonstrating the stability and applicability of the device in research and training.*

Date of Submission: 17-05-2026

Date of acceptance: 31-05-2026

I. INTRODUCTION

In recent years, ultrasonic vibration technology has been widely applied in the fields of mechanical processing and precision manufacturing. Integrating ultrasonic vibration into traditional machining processes such as turning, milling, drilling, and grinding helps reduce cutting forces, improve surface quality, and increase cutting tool life. According to research by Ahmed et al. [1], ultrasonic vibration-assisted machining allows for a significant improvement in machining efficiency for difficult-to-cut materials such as titanium alloys, nickel alloys, and composite materials.

Besides mechanical processing, ultrasonic technology is also widely applied in ultrasonic welding. Ultrasonic welding uses high-frequency mechanical vibration energy to create local friction at the contact area, thereby forming a weld without the need for filler material. According to studies by Sun et al. [2], ultrasonic welding has outstanding advantages such as high speed, small heat-affected zone, and good automation capabilities.

The efficiency of an ultrasonic system depends heavily on the vibration characteristics of the ultrasonic vibrator head, especially the resonant frequency and amplitude. When the vibrator head operates correctly at the resonant frequency, the energy transfer reaches its maximum value, while energy losses are minimized. Therefore, building an experimental system to accurately measure and evaluate the vibration characteristics of the vibrator head is a crucial requirement in the research and development of ultrasonic systems. This study focuses on designing and fabricating an experimental device capable of determining the resonant frequency and amplitude of the ultrasonic vibrator head to serve research, training, and development of high-power ultrasonic systems.

II. THEORETICAL BASIS

1. Ultrasonic vibration principle

Ultrasonic vibration is a mechanical oscillation with a frequency greater than 20 kHz. In industrial systems, ultrasonic vibrations are often generated using piezoelectric transducers. When an alternating voltage is applied to piezoelectric ceramic elements, they convert electrical energy into mechanical vibrations with a corresponding frequency.

A typical ultrasonic vibration system consists of the following main components: an ultrasonic generator, converter, booster, and horn. The mechanical vibrations generated at the transducer are transmitted and amplified through the booster and horn to achieve the required oscillation amplitude.

2. Resonant frequency

The resonant frequency is the most important parameter of an ultrasonic system. When operating at the resonant frequency, the amplitude of the vibrating head reaches its maximum value and the energy loss is minimized. According to the Butterworth-Van Dyke model, the ultrasonic vibrating head can be modeled

using an equivalent circuit consisting of resistors, inductors, and capacitors.

In this study, the resonant frequency was determined through a frequency scanning method combined with measuring the amplitude of the vibrating head's oscillation. The frequency at which the amplitude reaches its maximum is considered the resonant frequency of the system.

3. Applications of ultrasonic vibration in mechanics

Ultrasonic vibration is widely used in ultrasonic machining and welding. For cutting, ultrasonic vibration helps reduce cutting force, reduce cutting heat, and improve surface roughness. In ultrasonic welding, high-frequency mechanical vibrations combined with pressure create a material bond at the contact area.

The outstanding advantages of ultrasound technology include::

- Improved surface finish quality;
- Reduced cutting force and energy consumption;
- Efficient machining of difficult-to-cut materials;
- Increased tool life;
- High degree of automation

III. EXPERIMENTAL SYSTEM DESIGN

The experimental system was designed with the following main components (Figure 1):

- Ultrasonic source with frequency scanning capability;
- Ultrasonic vibrating head using a piezoelectric element;
- Displacement sensor;
- Signal acquisition and processing circuit;
- Control computer and data analysis software

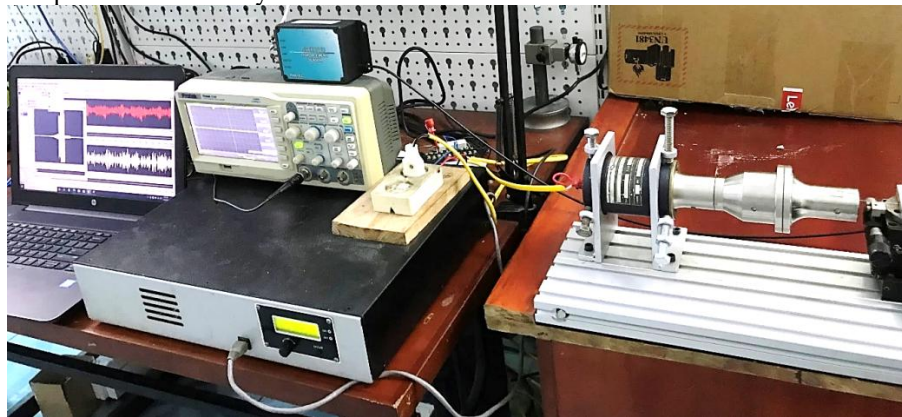


Fig. 1 Building the experimental system

The ultrasonic generator is designed with adjustable frequency in the range of 15 kHz to 40 kHz. The output signal is power-amplified to stimulate the vibrating head.

The vibrating head mounting structure is designed to ensure rigidity and minimize the effects of external vibrations. Materials are selected to reduce vibration loss and increase stability during the experiment. The ultrasonic vibrating head is designed in a stepped shape to increase the amplitude amplification factor. Stress and strain distribution are considered to avoid fatigue failure during high-frequency operation.

The vibration amplitude of the vibrating head is measured using a non-contact displacement sensor. The acquired signal is processed through a signal converter and computer analysis software. The measured data is processed using the FFT method to determine the resonant frequency and vibration spectrum of the system. Frequency scanning is performed continuously to determine the location of the resonance peak.

IV. RESULTS AND DISCUSSION

The experimental results obtained are shown in Figure 2 and Table 1

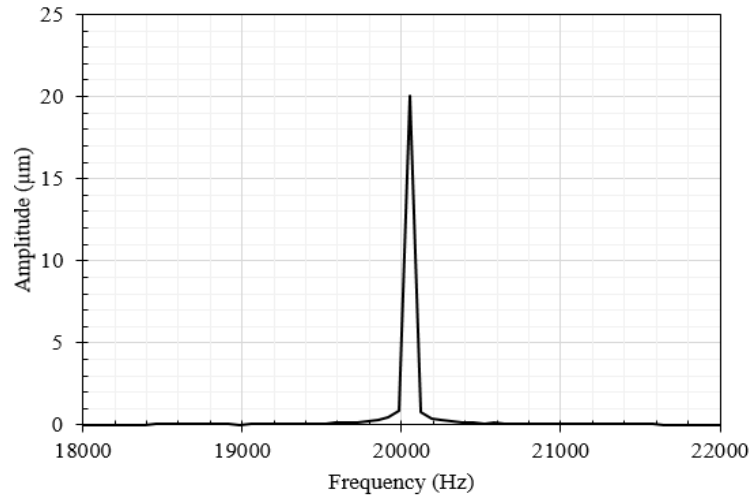


Figure 2. Relationship between Resonant Frequency and Amplitude

Table 1. Synthesis of resonant frequencies and vibration amplitudes

Graph segment	Resonant frequency (Hz)	Vibration amplitudes (μm)
1	20248.98	1.29
2	20224.72	1.55
3	20199.93	1.93
4	20179.82	2.61
5	20151.52	3.85
6	20145.19	6.76
7	20125.00	12.18
8	20079.92	17.98
9	20053.29	20.07

Frequency scanning revealed a significant variation in oscillation amplitude with excitation frequency. At the resonance region, the oscillation amplitude increased sharply and reached a maximum value.

Experimental results showed that the resonant frequency of the vibrating head was within the initial design range. The difference between measurements was less than 0.35%, demonstrating the system's high stability.

The relationship between oscillation amplitude and excitation frequency was established through experimental measurements. The characteristic curve shows that the amplitude gradually increases as it approaches the resonance frequency and decreases rapidly after passing the resonance region.

During the measurement process, the received signal exhibited electromagnetic interference due to the influence of the high-power power supply. To overcome this phenomenon, the research team applied digital filtering and signal processing using FFT. The results after processing showed a stable signal that accurately reflected the oscillation characteristics of the system.

The experimental system was evaluated as capable of stable operation within the investigated frequency range. The device allows for rapid determination of the resonant frequency and oscillation amplitude of the ultrasonic vibrating head.

The system's outstanding advantages include:

- Simple structure, easy to manufacture;
- High measurement accuracy;

- Scalability and integration with other control systems;
- Suitable for research and training in the field of ultrasound.

However, the system still has some limitations such as the influence of electromagnetic interference and the high requirement for stability of the power supply

V. CONCLUSION

This paper presents the successful design and fabrication of an experimental device for measuring the vibration characteristics of an ultrasonic vibrating head. The system consists of an ultrasonic generator, a displacement sensor, a data acquisition system, and signal processing software.

Experimental results show that the device can accurately determine the resonant frequency and oscillation amplitude of the ultrasonic vibrating head. The difference between measurements is less than 0.5%, demonstrating the system's high stability and reliability. This research provides a basis for the development of ultrasonic systems for machining, ultrasonic welding, and future mechatronic applications

Acknowledgments

This research is supported by the Thai Nguyen University of Technology

REFERENCES

- [1] Ahmed N., Mitrofanov A. V., Babitsky V. I., "Ultrasonic assisted turning of aviation materials", *Journal of Materials Processing Technology*, Vol. 132, 2007.
- [2] Sun X., Stephens E. V., Khaleel M. A., "Effects of sonotrode tip profile on ultrasonic welding of aluminum alloy", *Welding Journal*, Vol. 86, 2007.
- [3] Gallego-Juarez J. A., "Piezoelectric ceramics and ultrasonic transducers", *Journal of Physics E: Scientific Instruments*, Vol. 22, 1989.
- [4] Nguyen DacLoc, *Modern Machining Technology*, Science and Technics Publishing House, Hanoi, 2015.
- [5] Ngo NhuKhoa, *Research on Ultrasonic Vibration in Precision Mechanical Machining*, Thai Nguyen University of Technology, 2020.
- [6] Tran Hoai Nam, *Design and Fabrication of an Experimental Device for Measuring the Vibration Characteristics of an Ultrasonic Vibrator*, Master's Thesis in Mechanical Engineering, Thai Nguyen University of Technology, 2021.