A Design of Wide-range Frequency-tracking Ultrasonic Power Supply

Yu Fu¹, Tie Fu² and Aimin Wang¹∗

¹School of Mechanical Engineering, Beijing Institute of Technology, Beijing, 100081, China
²School of Mechanical Engineering, Beijing Institute of Technology, Beijing, 100081, China
∗Corresponding author’s e-mail: futie@bit.edu.cn

Abstract. Aiming at the problem that the frequency tracking range of commercial ultrasonic power supply on the market is narrow, which makes the load of ultrasonic power supply, a structure of transducer-horn-tool, difficult to match. This paper presents a kind of ultrasonic power supply based on TMS320F28335, which can track the frequency in a wide range (15-21 kHz). The advantages, theory, software and hardware structure of the power supply are introduced, which can realize the functions of wide range frequency tracking, power regulation, human-computer interaction and so on. Experiments show that the power supply can well match the ultrasonic vibration load with a wide range of resonant frequencies, and has good human-computer interaction function.

1. Introduction

In recent years, ultrasonic vibration assistant processing has developed rapidly, and it has been proved that it has more advantages than traditional processing in processing hard and brittle materials. In order to study the technology of ultrasonic vibration assistant processing, the first step is to design the equipment of ultrasonic vibration assistant processing. The frequency tracking range of commercial ultrasonic power supply is low, so the structure of transducer-horn-tool used in experimental research needs to be slightly changed several times to match the ultrasonic power supply, which leads to the increase of the experimental period and costs. In serious cases, the horn-tool may be scrapped. From the perspective of ultrasonic power supply instead of the traditional method of changing the structure of transducer-horn-tool, this paper designed a large-scale frequency tracking ultrasonic power supply matching the transducer-horn-tool, to reduce the experimental period, reduce costs and track the load’s resonant frequency accurately.

2. Theory of the power supply

Ultrasonic vibration assistant processing system consists of ultrasonic power supply, transducer, horn, tool, connect joint and so on. This paper used the system shown in figure 1. Connect joint can be rotating joint or non-rotating joint.

The ultrasonic power supply provides the electric energy for the transducer to work in its resonant frequency. Ultrasonic transducer can convert electrical energy into ultrasonic vibration and transmit it to the tool, so the ultrasonic power supply should have the following functions:

A. Real-time tracking of resonant frequency of transducer-horn-tool;
B. An output power negative feedback control is adopted and the output power can be continuously adjusted.

C. The power supply can display the current resonant frequency and power in real time. It can manually input power set value (0~300W). Power can be adjusted to the set value, track resonant frequency roughly and precisely in the frequency tracking range.

![Figure 1. Schematic diagram of ultrasonic vibration assistant processing system](image)

2.1. Compose of the power supply

Ultrasonic power supply is mainly composed of AC-220V, rectifier circuit, BUCK circuit, half-bridge inverter, transformer, matching circuit, voltage and current sampling circuit, control circuit, direct digital synthesizer (DDS) AD9850, driving circuit, touch screen and so on, as shown in figure 2. The control circuit takes the digital processor TMS320F28335 as the core to realize the PWM output, the processing of voltage and current sampling data, and the control of AD9850 output.

![Figure 2. Principle diagram of ultrasonic power supply](image)

AC-220V is converted into adjustable DC voltage through the rectifier circuit and BUCK circuit, then the high frequency voltage which meets the load requirements can be obtained through the half-bridge inverter. MOSFET is chosen as power switching device, which has the advantages of easy driving, fast switching speed, high operating frequency and good thermal stability. IR21844 is a half-bridge driver chip, which can realize that one signal input can output two complementary waveforms with dead zone. An IR21844 can drive both the upper and lower arms of half-bridge inverters, so only a small number of discrete components and one control signal can be used to realize the drive circuit of the half-bridge inverter, which greatly reduces its cost and volume.
AD9850 contains 32-bit phase accumulator and high-speed comparator, which can realize frequency synthesis controlled by full digital programming. The phase accumulator can output two complementary sine waves and square waves after truncation, low-pass filtering and high-speed comparator. The square waves can control the frequency of half-bridge inverter output by driving circuit. Its output frequency resolution can reach 0.0291 Hz, which can effectively guarantee the accuracy of frequency tracking.

The touch screen of Samkoon EA-043A is chosen, which integrates CPU unit, input and output unit, display screen, memory and other modules to support serial communication. The configuration software SATOOL can be used to realize the functions of picture configuration, driver setting and control[1].

The core processor of the control circuit is TMS320F28335. TMS320F28335 is a 32-bit floating-point DSP controller developed by TI Company. Its main frequency can reach 150 MHz, which greatly improves the processing speed of the program. This ultrasonic power supply mainly uses the general digital input/output (GPIO), enhanced pulse width modulation (ePWM), ADC conversion module, serial communication module (SCI) of the chip. GPIO is mainly used to control the output frequency of AD9850 and some components; ePWM module is mainly used to adjust the duty cycle of BUCK circuit to regulate DC voltage; ADC module is mainly used to collect the voltage and current sampling waveform after the sampling circuit, and prepare for data post-processing; SCI module is mainly used for serial communication with touch screen to achieve specific data input and output.

2.2. Realization of human-computer interaction
The serial communication between TMS320F28335 and touch screen is based on MODBUS-RTU protocol. TMS320F28335 is the main device and Samkoon touch screen is the slave device. After a certain period of time, the request frame will be sent by TMS320F28335, then the touch screen will return the response frame to realize information exchange. The touch screen can display the current output frequency and power in real time, and input the power setting value to change the current power.

2.3. Realization of wide range frequency tracking
a. Accurate sampling. Accurate sampling of voltage and current is vital for frequency tracking and power control. The sampling circuit is required to accurately collect the magnitude and phase of output voltage and current (frequency 15-21 kHz). Resistance sampling method is adopted here. The schematic diagram of voltage and current sampling circuit is shown in figure 3. The sampling resistance distribution diagram is shown in figure 4.

![Figure 3. Sampling circuit diagram](image-url)
Figure 4. Sampling resistance distribution diagram

The equivalent circuit of the load of the ultrasonic power supply near the resonant frequency is shown in the dotted frame in figure 4[2], where $C_0$ is the static capacitance, $C_1$ is the dynamic capacitance, $L_1$ is the dynamic inductance and $R_1$ is the dynamic resistance. The load can be either a transducer or a transducer-horn-tool under light condition.

Voltage sampling resistors $R_2$, $R_3$ are in parallel with the output voltage $U_0$ of the ultrasonic power supply. The voltage $U_{1-DGND}$ between point 1 and DGND equals the output voltage $U_0$. The current sampling resistance $R_4$ is connected in series with the load, and its voltage $U_{3-DGND}$ is proportional to the current flowing through the load.

Band-pass filter allows waveforms in specific frequency bands to pass through and shield waveforms in other frequency bands. The band-pass filter designed here allows waveforms at frequencies of 15 to 21 kHz to pass through, which can effectively filter clutters in other frequency bands and obtain high precision voltage and current sampling waveforms. The band-pass filter is a 12-order band-pass filter. The theoretical amplitude-frequency and phase-frequency characteristics are shown in figure 5. The red line represents the phase-frequency characteristic curve and the blue represents the amplitude-frequency characteristic curve.

b. Rough tracking. Rough tracking is based on the principle that the impedance of the load is the smallest near the resonant frequency[3]. When the power supply is turned on, it sweeps the frequency in the frequency range of 15-21 kHz and sets the frequency of maximum current as the current output frequency. It is noticed that its output frequency is not the resonant frequency.

c. Precise tracking. The resonant frequency of transducer-horn-tool drifts with the change of working condition[4]. The real resonant frequency when the load of transducer-horn-tool is working is different from the result of rough tracking. The method of precise tracking is to process the data after FIR and FFT and extract the phase difference, and to change the current frequency by a fixed frequency step according to the phase-frequency characteristic of transducer-horn-tool.

Figure 5. Frequency characteristic chart of band-pass filter
2.4. Realization of power control
Incremental PI method is used for power feedback. When the current working frequency is the resonant frequency of the load, the power feedback will trigger, because the power feedback has a great relationship with the load impedance, and the load impedance is the smallest near the resonant frequency[5].

3. Demonstration of experimental results
Here are the labeled loads and the ultrasonic power supply, as shown in figure 6 and figure 7. The two results of resonance frequency Fs analyzed by impedance analyzer and Fr got in conditions where the power supply is switched on with 5% duty cycle of BUCK circuit are shown in table 1, proving that the power supply can track the load resonant frequency in a wide frequency range.

Figure 8 is the impedance analysis result of load No. 4. Figure 9 shows the waveforms of voltage U1-DGND and voltage U3-DGND when the load is No. 4. The two waveforms are in phase. According to figure 4, the waveforms reflect the real output voltage and current, that means the output voltage and the load current are in phase, that is, the matching circuit and the ultrasonic load reach the resonance state. The U1-DGND positive amplitude decreases gradually and slightly because central voltage drift of two voltage divider capacitors in the front of half-bridge inverter.

Table 1. The resonant frequency of the loads.

| The label | Fs/Hz | Fr/Hz |
|-----------|-------|-------|
| 1         | 20496 | 20455 |
| 2         | 19785 | 19705 |
| 3         | 18512 | 18446 |
| 4         | 19830 | 19821 |

4. Conclusions and future work
This paper presents a wide range frequency tracking power supply, and proves that it can track and maintain the resonant frequency of the load in a wide range. The disadvantage of power supply lies in the midpoint voltage drift of the half-bridge inverter, and it will be improved later by replacing it with a full-bridge inverter. In the future, the ultrasonic vibration system based on the power supply will be developed and more experiments will be carried out.
Figure 8. The impedance analyzer result

Figure 9. Waveforms of sampling resistors

Acknowledgments
This work has received a lot of help, suggestions and guidance. Mr.Wang, Mr.Fu and Mr.Liu really helped me a lot, and I appreciate that.

References
[1] Zhang X H, Xia H B, Lin R. Communication Interface Design of Mitsubishi Touch Screen and DSP[J]. Applied Mechanics and Materials, 2014, 687-691:4174-4179.
[2] Bao HS, Wang YD. Impedance matching circuit of ultrasonic cleaning machine. Washing Technology 2(5): 11-14, 2004. (in Chinese)
[3] Liu LH, Gu YJ, Yang K. Development of intelligent power ultrasonic generator. Chinese Journal of Electron Devices 25(1): 67-70, 2002. (in Chinese)
[4] Kuang Y, Jin Y, Cochran S, et al. Resonance tracking and vibration stabilization for high power ultrasonic transducers[J]. Ultrasonics, 2014, 54(1):187-194.
[5] A. Ramos-Fernandez et al., Automatic system for dynamic control of resonance in high power and high Q ultrasonic transducers, Ultrasonics 23 (1985) 151–156.