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Full Length Research Paper

New frequency-tracking control method for ultrasound welding system by the FPGA Chip

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A new control method to catch the optimal working frequency (or driving frequency) for the high power ultrasonic welding system has been developed. During the high power operation, an ultrasonic resonant will induce high temperature and then change the working frequency. Therefore, a control method with a FPGA chip to track the optimal working frequency becomes very attractive and it has been practically implemented in this study. Generally, the FPGA chip includes two logic circuits, i.e. a logic circuit which manages the finding of optimal working frequency and the other one is to adjust the working frequency by detecting the working current simultaneously. Experimental results exhibit that the new method can effectively control and track frequency in the high power ultrasonic welding system. Due to this kind of study based on the FPGA design, it will enhance us the understanding of the physical realization in the ultrasound welding system.

Key words: Ultrasonic welding system, FPGA.

INTRODUCTION

An ultrasound welding system is basically like a piezoelectric structure resonator working at high power. All of the ultrasonic transducers have different characteristics, that is, to determine their parameters, it is necessary to sweep frequency and then catch frequency. In the ultrasound welding system, it usually induces undesirable heat and then results in high temperatures and changes of the impedance-frequency characteristics. To control and track frequency in a high power ultrasonic welding system, an effective control method to track the resonating frequency becomes very important for stabilizing the ultrasound welding system.

There are many studies including of an analog tracking circuit, phase-lock loop (PLL) frequency technology (Suzuki et al., 1994; Mizutani et al., 1996; Ishikawa et al., 1997; Mizutani et al 1998; Ishikawa et al 1998; Mizutani et al 1998; Pons et al 2006; Peng et al., 2008) have been published. Although the system with PLL is stable but the functions of the analogue IC and the tunable range of in the circuits is needed to be considered and limited by the characteristics of the analogue IC. Therefore, to solve this problem with digital control method becomes a new topic in the ultrasound welding field. In this study, a digital feedback method with a FPGA chip has been developed and effectively control and track the working frequency. This kind of research is still limited in the literature.

CIRCUIT AND SYSTEM

The measured frequency range is set from 39.5K Hz to 40 KHz in the frequency tracking circuit. The resonant frequency is 39.75 KHz at the lowest impedance. The setting is to make the system work at the optimal working frequencies with the highest stability. The feedback control method of ultrasound welding system is implemented with a VHDL program in a FPGA chip. The FPGA chip has two major logic circuits. One is designed to sweep and catch the working frequency and the other one to adjust the working frequency simultaneously. In this study, the feedback control method of an ultrasonic machine at the working frequency (40 KHz) and the working power (550 W) is controlled by the output current.

The overall blocks of the driving system are schematically shown in Figure 1. The brief functional blocks of two logic circuits method are shown in Figure 2. The method consists of frequency-sweeping function, frequency-catching function (catch the working frequency), frequency-tracking (adjust the working frequency) and logic operation, respectively. A complete cycle of periodical signal of

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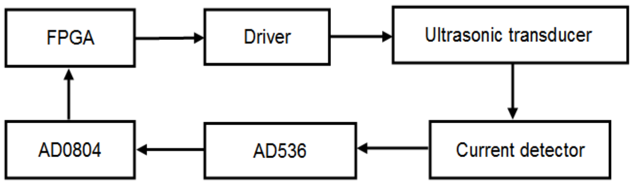

Figure 1. The overall block diagrams of the ultrasonic transducer based driving system.

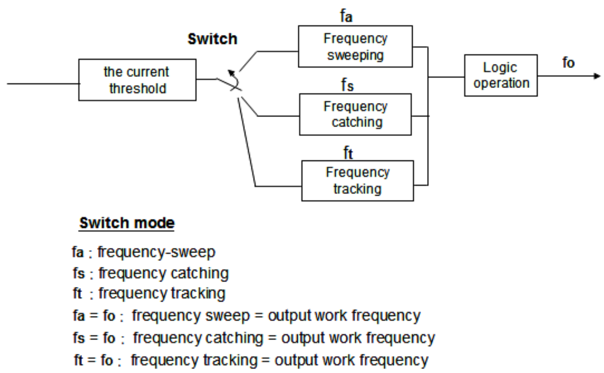

Figure 2. Brief functional blocks of the FPGA chip.

oscillator used to catch the working frequency which is attained with the counter and then transferred into discrete binary data for the digital operation. This procedure is therefore acted as a periodical time to frequency converter. The converter generates a time sequence control program to control whole systematic movements. The output working frequency of this feedback control method is dependent of the working current which is detected by the current sensor. The frequency catching method in the FPGA chip with current frequency sweeping is very practical and high reliability.

Frequency-sweeping based current sensor to catch the working frequency

In the main system, AD0804 is controlled by the data output current of the ultrasonic welding system and communicates with the FPGA chip through an AD536 to detect the amount of working current. The function of AD536 can be fetched any alternating signal to change into root mean square (RMS) value. Then, the current threshold is set and transmitted to the FPGA chip to launch the frequency-sweeping circuit. When repeating the sweeping of ultrasonic transducer frequency, it catches the ultrasonic working frequency simultaneously. The control module will sweep several frequency ranges in sequence with the default sweeping time to access the working frequency value. Then, the normal working frequency value is sent to the driver. At this point, the current value of the working current is smaller or the same as the default threshold. The sweeping function of FPGA built-in frequency sweeps several frequency ranges in sequence with the default sweeping time. The FPGA chip will sweep at 1,300 different frequencies from 40600 (f_1) to 39300 Hz (f_{1300}) and then decrease 1Hz per time by a logic AND gate in Figure 3. There is ten cycles with 0.025µs/cycle in each frequency [x(t)] and the total time [m(t)] is about 333.5µs. The circuit will count in every 333.5µs y(t) to get the normal working frequency value. The time of ten cycles is

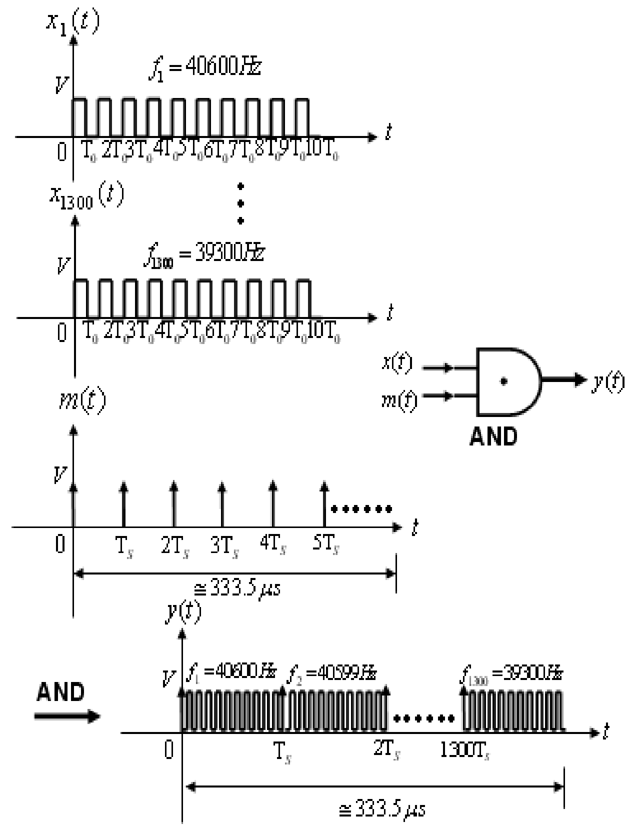

Figure 3. Frequency sweeping with 1,300 different ranges from 40600Hz (f_1) to 39300Hz (f_{1300}) in the FPGA chip and decreased 1Hz per cycle by a logic AND gate.

enough to drive the whole ultrasound welding system.

These ranges are used to obtain the normal working frequency value and deliver the driving voltage to the loading according to the normal working frequency value. The current value of working current will be smaller or the same as the default threshold. The sensor will sense the current value of the ultrasonic transducer output current and read the current level with A/D converter. It controls its built-in A/D conversion function to set the threshold and send the parameter to the FPGA chip. Then, it will launch the frequency-sweeping circuit. When the ultrasonic transducer is working, the FPGA chip will catch the current signal parameters and launch the frequency-sweeping function. When an appropriate frequency value is captured, the frequency data will deliver to output port and the original system will be switched.

Frequency-tracking to adjust the working frequency

When the FPGA chip catches an appropriate frequency by the current sensor, it will convert the frequency to the A/D converter with AD0804 and also read the difference values between the working current. If the difference is in a working current range, the output frequency will be the same. If the difference is out of the working current range, the FPGA chip will send a signal to make the square wave with certain frequency value to the driver circuit. The driver circuit will drive the ultrasonic transducer to make the difference be in the reasonable range. If the temperature of the sensor increases, the current will rise sharply and cause frequency drift. At this point, the FPGA chip will launch the current sensor

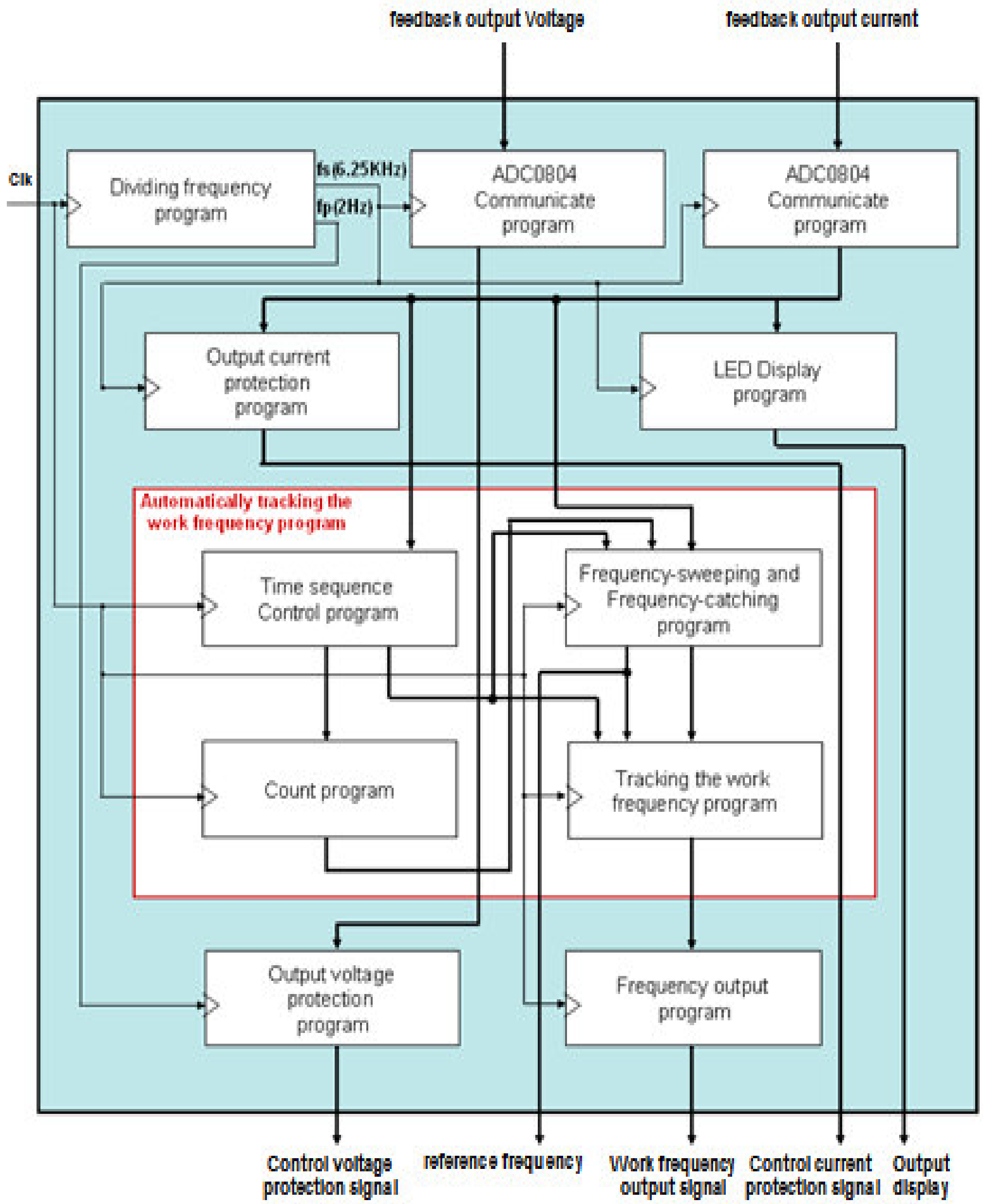

Figure 4. The VHDL program blocks with feedback control method in the FPGA chip.

frequency-sweeping and frequency-catching circuits to catch an appropriate frequency. This will catch the frequency signal of the ultrasonic transducer and the frequency value to input the driver from the FPGA chip. The FPGA chip can calculate the value of the working current and according to the difference range, it will repeat to calculate the difference value of the working current and adjust the output working frequency.

Principle of feedback control method with VHDL program in the FPGA chip

Figure 4 shows the VHDL program blocks of feedback control method in the FPGA chip for the ultrasound welding system. The accurate working frequency of feedback control method is important to drive the ultrasound welding system because the output current of the transducer of ultrasound welding system is very sensitive to the input working frequency. The analogy output feedback current is changed into be a digital signal by the ADC0804 communication program. The output digital signal is sent to an automatically tracking frequency program to control the working frequency. The automatically tracking frequency program is consisted of four blocks including a time sequence control program, a frequency-catching program, a counting program and a working frequency-tracking program.

The time sequence control program is a judgment program. When this program receives the digital value of the feedback output current from ADC0804 and it will start to produce the time intervals signal m(t) and the sweeping frequency signal x(t) as shown in Figure 3. These two signals will be combined to be a signal y(t)

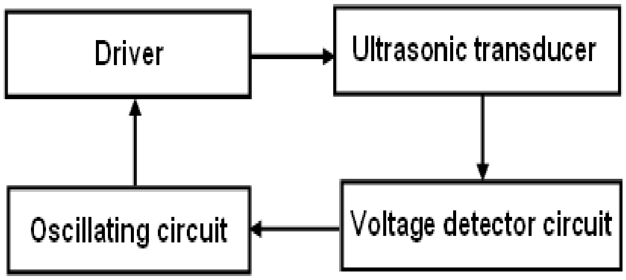

Figure 5. The driving feedback circuit in the ultrasonic welding system.

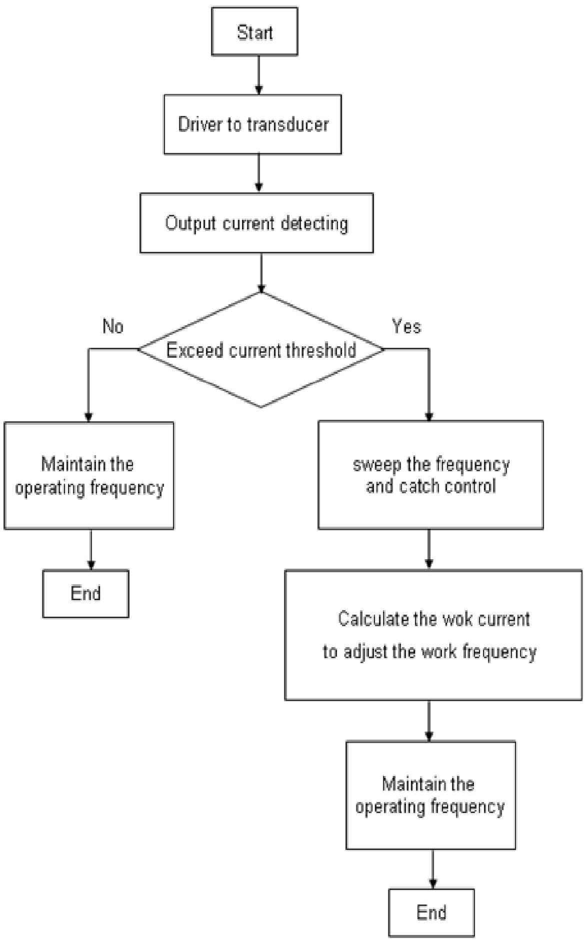

Figure 6. The program block diagrams and processes.

through a AND logic gate. The signal y(t) will be delivered to the frequency-sweeping and the frequency-catching programs and then start to catch the working frequency. The working frequency will be delivered to adjust the working frequency program. The working frequency program will accurately adjust the output work frequency by the feedback output current of ADC0804 and comparing with the reference frequency. The output frequency program translates the value of working frequency to the periodic signal of working frequency. In addition, the system also has the output current

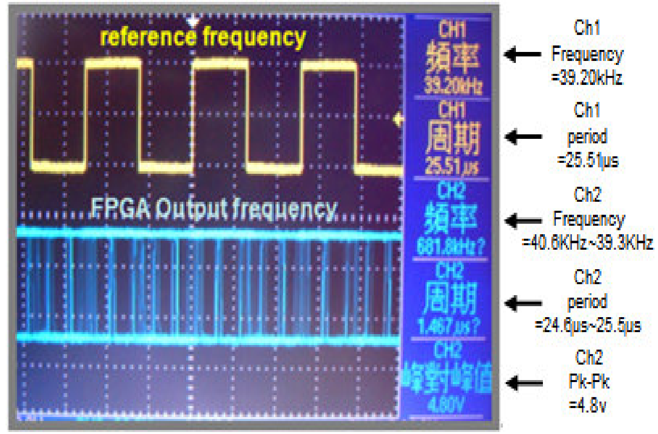

Figure 7. The frequency sweeping setup by the FPGA chip.

protection and output voltage protection programs to protect the system.

RESULTS AND DISCUSSION

In the ultrasonic welding system, the working frequency is very important issue to control the impedance of the ultrasonic transducer. The other issue is the temperature effect of the ultrasonic transducer. The temperature of the ultrasonic transducer increases as the working time increases. The increased temperature will shift the impedance properties of the ultrasonic transducer and make the impedance too low. The low impedance will make the large output current and power to burn the device and system. Therefore, it is necessary to adjust the working frequency to follow the correct impedance of the ultrasonic transducer to maintain the stable output power. A traditional feedback circuit of ultrasonic welding system is shown in Figure 5. In this system, the analog feedback circuit uses the voltage detector circuit to adjust the driving frequency. The oscillator circuit to drive ultrasonic transducer is controlled by the feedback circuit. A digital feedback circuit of ultrasonic welding system is a new tracking method.

If the ultrasonic welding machine becomes unstable, the current will increase and the current sensor circuit also will measure the amount of the current through A/D converter with AD0804. If the feedback output current exceeds the normal value, the adjustable working frequency can be kept the normal value by comparing with the reference frequency. Figure 6 shows the program blocks and processes. When the current exceeds the current threshold, the frequency sweeping circuit will start to operate as shown in Figure 7. When repeating to sweep the working frequency stage of the ultrasonic transducer, it catches the ultrasonic resonance frequency and simultaneously calculates the working current difference. In Figure 8, it is found that t the output

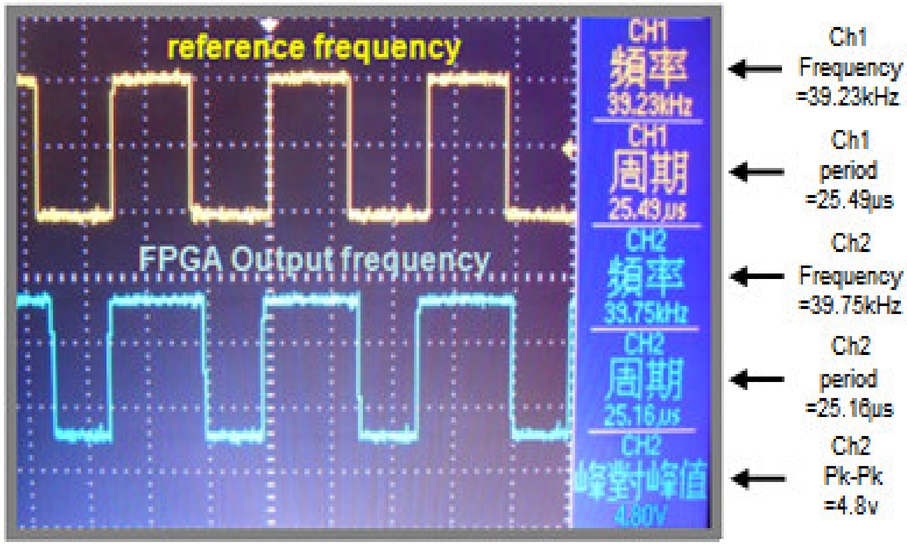

Figure 8. The adjustment of the output frequency for driving the circuits by the FPGA feedback output current.

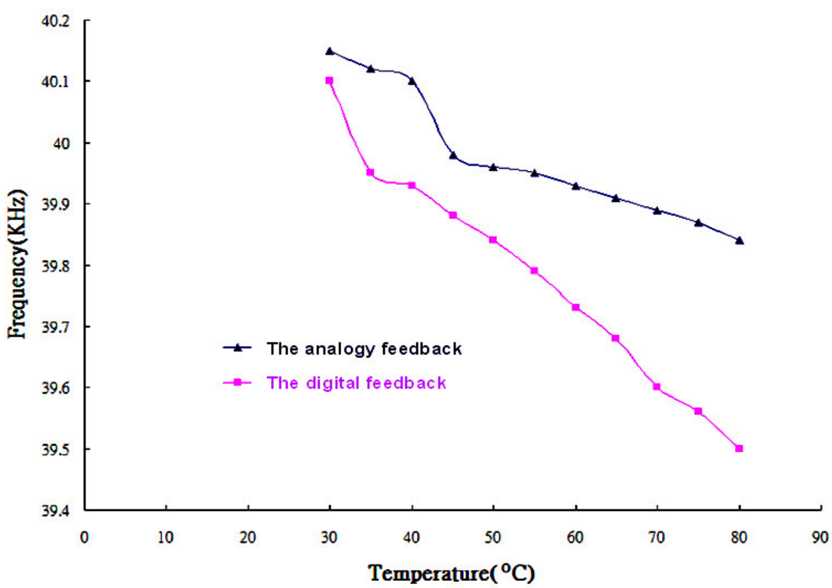

Figure 9. Characteristics of frequency vs. temperature of the ultrasound welding system with the digital feedback and traditional feedback circuits, respectively.

frequency can be adjusted to driver the circuits by the feedback output current through the FPGA chip.

A comparison is also made between a traditional feedback circuit of ultrasonic welding system and our new digital feedback circuit of ultrasound welding system. The test ultrasonic welding system is in the automation machine platform. The test period is 7 s (weld time 3 s and cool time 4 s) and it works 5000 times. The temperature of the ultrasonic transducer is increased from 30℃ to 80℃ after working 5000 times. The characteristics of frequency vs. temperature of the ultrasound welding system with the digital feedback circuit and the ultrasonic welding system with the traditional feedback circuit are shown in Figure 9. It is found that the new digital feedback circuit can do the wider sweeping frequency range than that of the traditional feedback circuit. A wider sweeping frequency range can be easier to find the suitable working frequency and increase the accuracy and the efficiency of the system. The output power curves of the ultrasound

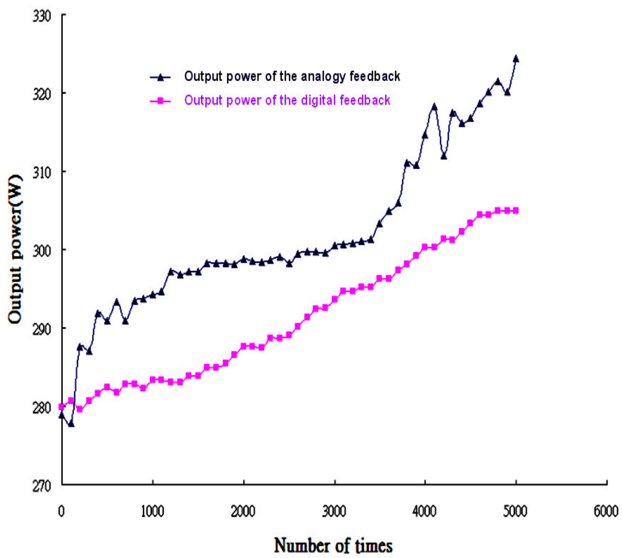

Figure 10. Output power curves of the ultrasound welding system with the digital feedback and traditional feedback circuits after 5000 tests.

welding system with the digital feedback circuit and the ultrasonic welding system with the traditional feedback circuit during 5000 test times are also shown in Figure 10. It is found the output powers of the ultrasound welding system are more stable than those of the ultrasonic welding system with the traditional feedback circuit. That is because the digital feedback circuit can find the appropriate working frequency immediately to get an appropriate impedance of the ultrasonic transducer. It makes the output power in a more stable than the traditional feedback circuit and gets a longer life time.

Conclusion

A periodical time-control and frequency-sweeping method is used in the high power ultrasonic feedback system. Nowadays, this control method is implemented on a practical ultrasound welding system and broadly used in the industry applications. Experimental results prove that the new method can effectively control and automatically track a proper frequency for the ultrasound welding system.

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