Active Power Stabilization in Ultrasonic Welding Process

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Abstract

This paper describes the concept and method for implementation of active power stabilization supplied to the ultrasonic stack in the ultrasonic welding system. Advantages of this approach over previously used methods to control the ultrasonic welding process are presented, with description of hardware and software architecture necessary to implement active power stabilization concept. Finally the results of research on the active power stabilization algorithm implemented in ultrasonic welding system prototype and the anticipated directions of future research are defined.

1. Introduction

Ultrasonic welding is more and more commonly used in industry for plastic bonding, metal bonding or cutting. In all this applications the architecture of ultrasonic welding system is the same. The system consists of ultrasonic generator and ultrasonic stack with anvil. Ultrasonic stack is build from three parts. First one is piezoelectric transducer called converter. It’s function is to convert electric signal in to mechanical vibrations. Converter is attached to booster which, amplifies vibrations generated by the converter. Last part is the sonotrode, also called tool or horn. From one end sonotrode id connected to a booster and at the other end touches the bonded material. Vibrations are evenly distributed across the face of the sonotrode which transfers them to the material thus creating a bond. The role of the generator is to power the ultrasonic stack with a signal of optimal frequency, while controlling the parameters of welding process. Ultrasonic stack usually operates at frequency of about 20 kHz, 30kHz or 40kHz.

Ultrasonic welding process can be characterized by following parameters:

- Vibration amplitude
- Level of active power applied to the welded material
- Voltage level on the piezoelectric transducer
- Current flowing thru piezoelectric transducer
- Energy absorbed in the bonded material during one welding cycle
- Time of one welding cycle

One of important things to consider while designing ultrasonic generators is the choice of leading parameter used in control of welding process. Manufacturers of ultrasonic generators, choose amplitude of vibrations on the face of a sonotrode as the leading parameter. However stabilization of vibration amplitude is hard to control and results in a number of adverse effects affecting the process of ultrasonic welding. Most significant effect is lack of reliable control over the level of power applied to the welded material. Absorption of power, change with thickness and temperature of the material, or pressure with which the sonotrode is pressed on to the welded material and many other parameters that vary between each welding cycle. This leads to decrease of repeatability of the welding process.

Method of active power stabilization, described in this paper solves above problem, and makes the welding process easier to design and manage.

2. Active Power Curve Method

Ultrasonic welding process can be described as set of points representing the instantaneous power, measured with a set time interval. Those points forma a curve that represent variation of power during each welding cycle. That curve can be used as a leading parameter for control of welding cycle. Operator can feed the ultrasonic generator with points described by values of active power and time. When the welding cycle starts the generator would calculate value of instantaneous power for a given moment of time based on those points and adjust the output signal so that the active power applied to the welded material would reach the desired level. This method is called the active power curve method and forms the basis for active power stabilization in ultrasonic welding process.
By following the shape of the active power curve, ultrasonic generator ensures that level of active power applied to the welded material would be the same with each cycle, and stabilization of that power would take place.

Another advantage is that in contrast to other methods used to control ultrasonic welding process, active power curve enables the user to design a welding cycle with different power levels, and even to turn off the power for some period of that cycle.

Finally in methods based on stabilization of vibration amplitude, and cycle mode set to amount of energy absorbed by the welded material, there is a problem with changing time of each cycle. Because energy is a function of power and time if the power level is varying between each cycles the time of each cycle would change also. Active power curve solves that problem because in this case energy absorbed by the welded material is defined as area under that curve. If between the cycles the curve itself is not changed, then the energy and the time will remain the same.

3. Hardware architecture

In ultrasonic welding active power level is a function of three parameters. First two are the amplitude of voltage on and current flowing thru piezoelectric transducer. Third one is the frequency of electric signal which powers the converter. In order to obtain sufficient accuracy of power stabilization ultrasonic generator must be capable of retuning these parameters by small extent and within very short period of time. This is most important in case of frequency control because even a shift of 0.1 Hz can have a significant effect on power output of ultrasonic stack. Also while keeping the 0.1 Hz accuracy the generator must be able to change the frequency in the range of 1 kHz above and below the nominal frequency.

Because of this requirements prototype generator was equipped with dual core digital signal processor (DSP) and direct digital synthesizer (DDS) working in a digital loopback. DSP monitors the output signal from power output and controls the DDS which in turn controls the power output by two signals so that the signal fed to piezoelectric transducer would meet the required level.

4. Stabilization algorithm

DDS control the power output with two signals with programmable frequencies and programmable duty cycle. This enables the power to be controlled with same accuracy over high and low power levels. For low power levels from 0 to about 20% of nominal power of the generator, algorithm is based on duty cycle control. It is used mainly during the beginning and end of weld cycle when the power isn't too high or when the weld area is small. Above 20% of the nominal power of the generator the control algorithm maintains the duty cycle of both signals at 50% and changes their frequency according to the needed power level. The working range is between series resonance frequency and parallel resonance frequency. The algorithm always starts from the higher frequency, which is the parallel resonance frequency and works downward until the desired or maximum output power level is reached.

5. Prototype test results

Test of the prototype generator were made on typical ultrasonic stack with nominal frequency of 20 kHz. The welded material was four layers of PP nonwoven fabric, or two tamamid block. Four layers of PP nonwoven were welded with power level of 500 W and the tamamid blocks were welded with power level o 1 kW. Figure 3 shows the weld cycle for PP nonwoven fabric. Because of low power level
only the duty cycle control is active. During the cycle pressure modulation was applied to the ultrasonic stack resulting in modulated load. It is visible how the duty cycle parameter is changed so that the load modulation can be compensated.

Figure 3 PP nonwoven fabric weld cycle with pressure modulation

Figure 4 shows the weld cycle for tarnamid blocks. The stabilization algorithm follows the designed active power curve within 5% of error, which is acceptable for ultrasonic welding process.

Figure 4 Tarnamid weld cycle
6. Conclusion

The algorithm for active power stabilization applied to the welded material allows precise power regulation regardless of working conditions of ultrasonic stack. Designing welding cycle in form of active power curve keeps energy loss at minimum level, and contributes to the production of high quality, repetitive welds. Test shows that the designed algorithm can compensate for varying conditions during each welding cycle, and is capable of fast and precise change of power level at any time. The concept and method of active power stabilization in ultrasonic welding system is successfully implemented in generators produced and sold by Tele and Radio Research Institute.

Bibliography


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