Controlled Cooling of Ultrasound Transducers

Technical White Paper

Technical and Economical Benefits in Ultrasonic Welding and Bonding by Controlled Cooling of Ultrasound Transducers

by Dr. Matthias Hunstig, Hesse Mechatronics, Paderborn, Germany
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Abstract

Hesse engineers have developed a system for controlling the cooling power in ultrasonic welding and bonding systems, which can increase process consistency and reduce the consumption of compressed air, and thus energy. The system will be available from Q4/2022. This paper describes the technical background, the functioning of the cooling control, and presents a real-world example.

Heat in Ultrasonic Joining

Heat plays an important role in many ultrasonic joining processes. In thermosonic wire bonding, adding heat facilitates increased throughput, improved process quality and, most importantly, increases weldability and thus allows material combinations which cannot be joined reliably at room temperature. These effects can be achieved using classic substrate heating or local heating using laser-heated tools as available in Hesse Lasersonic wire bonders [1].

In high-power ultrasonic joining processes (ultrasonic welding, heavy copper wire bonding, ribbon bonding), significant amounts of heat are also generated in the ultrasound transducer, mainly in the piezoelectric ceramics, due to internal losses. To avoid harmful overheating of the system, such transducers are actively cooled, for example by external or internal fluid cooling using air or water. Our tests and experience show that such active cooling is not necessary for typical processes realized on system with ultrasonic powers of 100 W or less.

Consequently, all Hesse Mechatronics ultrasonic joining systems (smart welders, wire bonders) with an ultrasonic power of more than 100 W are equipped with actively cooled transducers. The cooling mechanisms are based on compressed air.

At very high powers, significant heat is also generated by friction in the process zone, which can result in an undesired thermosonic effect or overheated welding tools. This is sometimes countered by cooling the welding tool, also known as the sonotrode, for example using internal fluid channels or forced heat conduction in phases without ultrasound application.

Temperature Effects in Ultrasound Transducers

The focus of this paper is heat generation in the ultrasound transducer. It not only bears the risk of damaging the transducer by excessive temperature, even much lower temperatures already have undesired effects: Due to the temperature-dependent, nonlinear characteristic of piezoelectric ceramics, the characteristic of the ultrasound transducer is also temperature-dependent. For example, increasing temperature may result in decreased resonance frequency and increased impedance. Thus, the working point of the ultrasound transducer shifts depending on temperature. For example, if a process is run with the ultrasound transducer in resonance frequency, the operating frequency changes. If it is operated with a set current (respectively voltage) amplitude profile, the applied voltage (resp. current) changes, and with it the resulting electrical power.

All those changes not necessarily result in lower quality joints, but at least process characteristics and joint quality will be different – fluctuations one generally tries to avoid in industrial production. One could try to counter changes of the transducer characteristic by appropriate changes of process parameters, such as time, force, vibration amplitude or frequency, as described in [2]. But such parameter adoption can only be a compromise solution – it may make process results more similar, but they will always be different if the ultrasonic system changes its characteristic.

All these undesired effects do not result from the increased temperature itself, but from the change of temperature over time due to varying boundary conditions, process orders, etc. Thus, what one really wants for a constant process is a constant transducer temperature.

Controlling Transducer Temperature

Maintaining a constant transducer temperature in all situations requires a controller which can both heat and cool. For this, the target temperature should ideally be chosen so that, without additional heating, it is both not exceeded at maximum cooling power during the highest expected ultrasonic power application, and safely reached without cooling when applying the lowest expected (mean) ultrasonic power. This temperature can then be reached in all production setups and there is no need to operate heating and ultrasound concurrently.

Heating of the transducer can be achieved by making it vibrate in air, using its internal losses to generate heat. Alternatively, heat can be generated externally, for example using an electric heater, and transported to the transducer by heat radiation, heat conduction, heat pipes, or using fluids such as air or water. Respective channels may be inside the transducer. A laser beam directed at the transducer could also be used as a heat source.

Transducer cooling can also be achieved in a multitude of ways. Forced air cooling using fans or compressed air is a classic option and often the best regarding cost and space requirement.

Other fluids, heat radiation, heat conduction, or heat pipes can also be used to transport heat away from the transducer and thus cool it. Hesse transducer cooling mechanisms currently operate with a constant compressed air flow rate, chosen high enough to safely keep the transducer below a transducer-specific temperature limit in all applications – which means that it is higher than necessary in many applications.

As detailed above, high-power ultrasound transducer can hardly be operated properly without a cooling mechanism. The considerations in this section also show that in a well designed system with active transducer cooling, additional transducer heating only has a positive effect after cold starts and longer production interruptions. Adding a controlled heating mechanism to such an ultrasound system thus adds complexity, and possibly cost and volume, with only a limited effect. Optimising the control of an already existing cooling mechanism, on the other hand, offers a number of benefits without any real drawbacks.

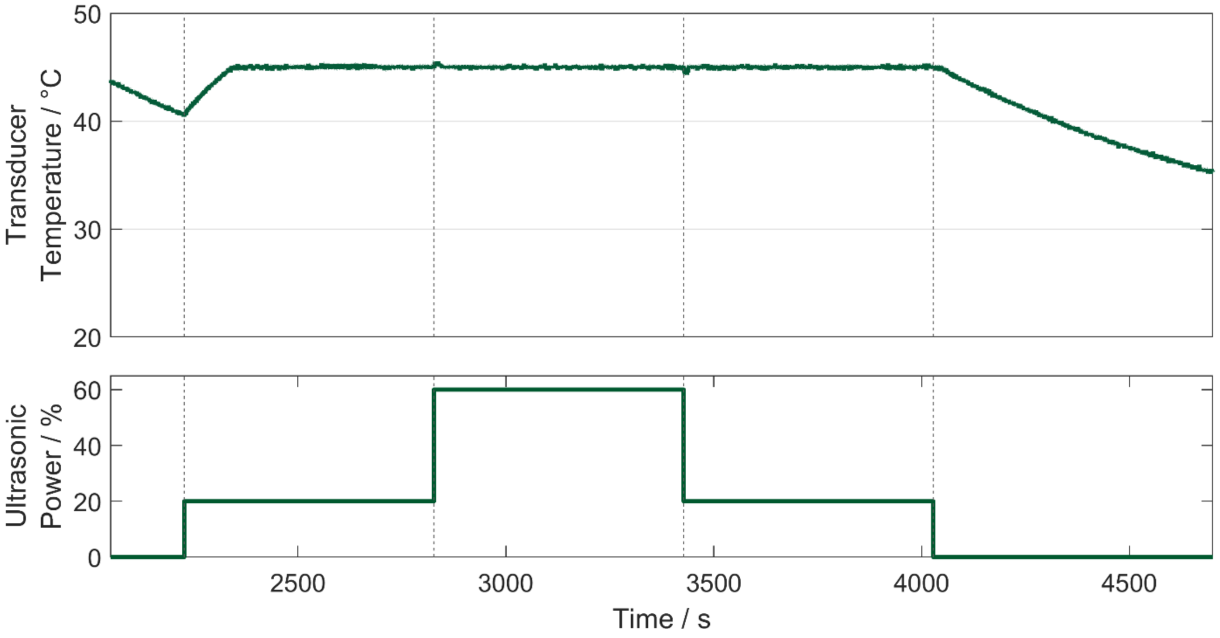
In low-power thermosonic systems, e.g. in ball-wedge bonding, the advantages of actively heating the transducer may be more relevant. Here, the main contributor to transducer heating is not internal or frictional losses, but heat radiation from the substrate heating. So active transducer heating can be beneficial to maintain a constant transducer temperature independent of its position relative to the substrate heating.

Realization in Hesse Machines

Active transducer cooling and automatic transducer temperature monitoring at one or more positions, including user notification upon reaching warning temperatures or shut-off temperatures, has been a standard with all actively cooled Hesse ultrasound transducers since their introduction to the market.

In order to maintain a constant transducer temperature, we now feed the temperature monitoring signals, averaging the signals if multiple positions are measured, into a closed-loop control of the airflow rate. This results in a very steady transducer temperature, maintained even if heat generation in the transducer changes abruptly.

The following figure shows an example of temperature control by regulated cooling in action: In this test, quickly varying heat generation is forced by stepping the freely vibrating transducer between power levels of 0 %, 20 %, and 60 %. The first step, from 0 % to 20 %, is made while the transducer is cooling down from a previous process. Its temperature quickly increases to the desired 45 °C. The cooling actives itself upon approaching 45 °C and controls the airflow to maintain this temperature. Only very small over- or undershoot is observed when the power changes to 60 % and back. When the ultrasonic power returns to 0 %, the airflow quickly returns to zero, while the transducer temperature slowly decreases.



This system will be available to increase process consistency and reduce compressed air consumption in all Hesse smart welders and wire bonders with more than 100 W ultrasonic system power from Q4/2022.

References

[1] https://www.hesse-mechatronics.com/en/products/heavy-wire-bonder/lsb959/
[2] United States Patent Application US 2018/0161914 A1, 2018

Hesse Mechatronics

Hesse Mechatronics is one of the world's leading producers of fully automated wedge-wedge wire bonders. It was founded in 1995, is based in Paderborn, Germany, and develops and manufactures fully automated machines for ultrasonic and thermosonic bonding and welding, software for monitoring these processes, as well as customized automation, tools and machines.

Contact: Hesse GmbH
Lise-Meitner-Str. 5
33104 Paderborn, Germany
phone: +49-5251-156-222
e-mail: sales@hesse-mechatronics.com