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Optimized quality control in induction hardening

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Induction hardening is well known for its good reproducibility. Nevertheless, the quality can also be influenced by several disturbances. In addition to factors like geometry, chemistry and the heat treatment history of the workpiece, the heat treatment parameters during heating and quenching have a major impact. We will show how the inductors and the heating process must be monitored in order to ensure reproducible heating sequences and which factors influence the heating quality. Cooling and quenching media, whose properties can be automatically monitored and stabilized within narrow bounds, ensure good inductor life time and constant quenching properties.

Product quality is measured at the level of fulfilment of the specified customer requirements and is linked to a long product life cycle. The induction hardening requirements are laid down in the hardness specification tailored to the work piece. In this context, especially the hardening zone, the required hardness and the microstructure play an essential role. These properties can still not be measured both in-time and in-place, in particular not in a detailed spatial resolution along the hardened surface of the workpiece. Thus, product quality is achieved based on previously selected and verified process by the reapplication of the related set parameters. Its stability is then checked within a predefined timeline of measured data of both heating and quenching. The data processing and visualization is done on an industrial PC with the system EloProcess, specially developed for this purpose. This will be the central element for further steps into using big production data sets to assist for a more detailed process data analysis and improvements in predictive maintenance.

During the heating phase it is the inductor that determines the hardening zone mostly by its geometry and its position towards the work piece. The copper as well as the flux concentrators are exposed to high thermal stress in heating and recooling. Even small changes, such as a slightly modified position of the heating coil relative to the workpiece, can have a significant impact on the quality of the product.

Interestingly enough, the quenching head – as the only other tool next to the inductor – is only indirectly responsible for the process safety. Constant properties of the quenching medium are much more important. The quench water circuit is open to the environment and therefore vulnerable to the entry of oil and chips and tends to germ proliferation. As a result, the shower is easily clogged followed by the need for frequent cleaning. Quenching properties are subject to fluctuation due to the significant water losses by evaporation and takeout of polymer by the parts surface. EloFresh, the water analysis and maintenance system of SMS Elotherm, can be used to continuously check and stabilize the media properties within narrow limits.

MONITORING OF HEATING AND QUENCHING

Fig. 1 shows the results of a machine capability study showing the good reproducibility of the induction hardening within the narrow tolerance range of +/- 1.5 kW (yellow range).

Below the effects of different error situations, which can occur in reality, are analyzed. The monitoring of the heating process takes place in two stages, since otherwise the distinction between errors which solely relate to the inductor and those relating to the relative position of the inductor and workpiece is not possible.

In a first step, the inductor test, each inductor is measured individually without a workpiece before the beginning of a production lot. The determined power without a workpiece is therefore the sum of all losses in the entire machine with the inductor contributing to the majority of 80–90 %. These losses depend only on the frequency and current and can be represented by a frequency-weighted Equivalent Resistance.

A change in the inductor can already be detected without a hardening operation. **Fig. 2** shows, for example, the change in the measurable inductor properties even when a small quantity of the flux concentrators is not in place. Flux concentrators are used in inductors in many cases to con-

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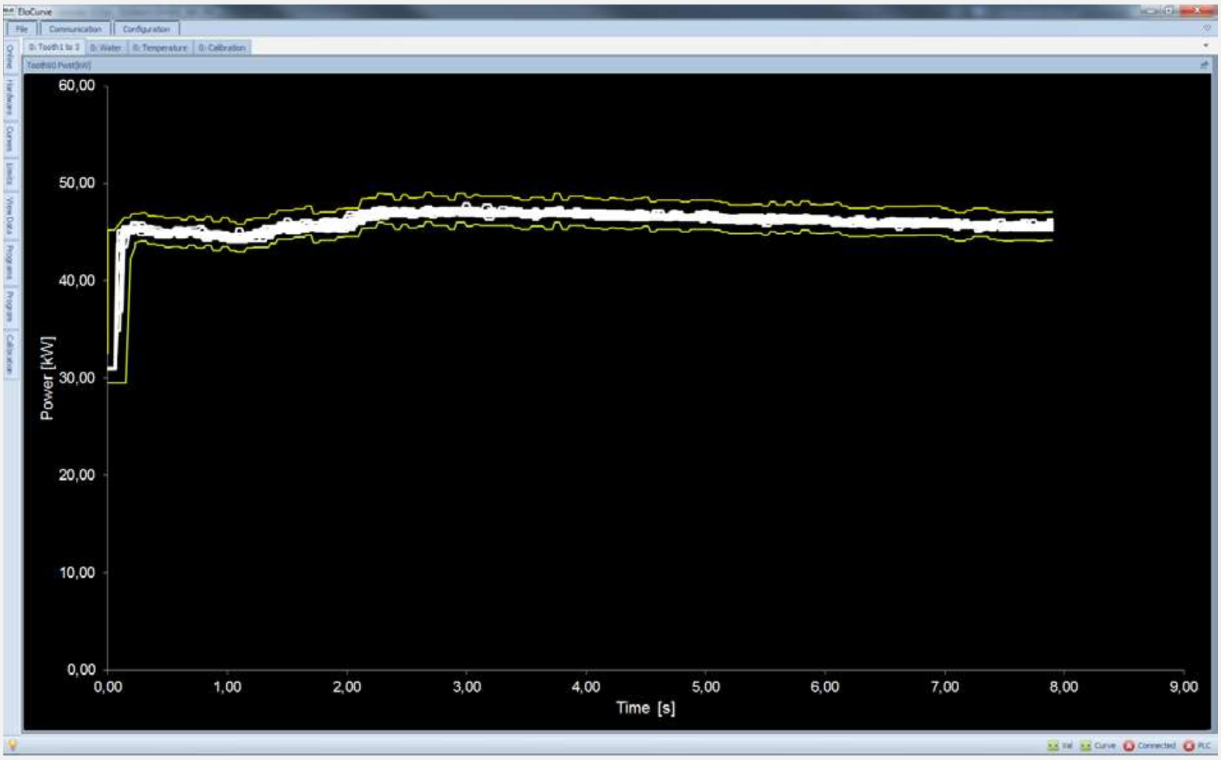

Fig. 1: Machine capability study: yellow – range of tolerance; white – overlay of 50 heating curves

centrate the magnetic field on the surface to be hardened. The concentrators consist of laminated iron packages being put onto the heating coil and fixed as required. However, by loosening some of the lamination the magnetic field is changed and the inductor is reduced in its power.

In a second step, the online quality analysis, the heating process is monitored. In addition to the power output from the inverter, the power loss in the machine from the Equivalent Resistance is also determined during runtime. As a byproduct, the power induced into the workpiece results as the difference between the two power values.

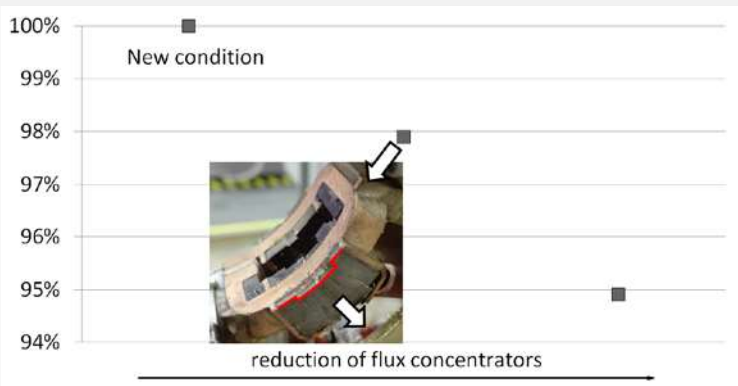

Fig. 2: Change of inductor output due to a partial reduction of flux concentrators

Error analysis during induction hardening

For a stable product quality, a precise process analysis is necessary to describe quality-limiting factors and the associated range of influence factors. Based on a crankshaft hardening, possible faults were simulated and evaluated in the development laboratory.

The workpiece is hardened with the set parameters from the process development and the electrical data are measured in time. This so-called power curve is spread to a tolerance window (shown in yellow in the following pictures), the tolerance width of which has previously been determined via the boundary samples. If the curve of the actual hardening in production mode overshoots the tolerance range, the hardening process is interrupted and the machine reacts according to a previously defined scheme (quenching, non-quenching, reworking). For this publication, this reaction is switched off in order to be able to represent the differences of the provoked errors.

Missing oil holes

The induction hardening system does not have to be used solely for the hardening and tempering of workpieces, but can also serve as an initial check for upstream production steps, such as the drilling of oil holes. **Fig. 3** shows the performance curves for a main journal with oil hole (red) and without oil hole (white), and a recurring effect at the same time intervals is observed. The oil hole passes through

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the inductor heating coil loop and becomes apparent as a power drop due to the increased coupling gap. This means that manufacturing errors can be detected at an early stage.

Rework

The term "reworking" encompasses situations in which process disturbances do not necessarily have to lead to a scrap part, but may end as a good part through a repeated process – e. g. heavily soiled workpieces which lead to a contact between the inductor and the workpiece and thus initiate a process interrupt to protect the inductor. Situations such as double hardening of a part or hardening of an already heated part must in this case be evaluated particularly critically and should be subjected to a 100 % crack test. **Fig. 4** shows a double hardening, which can be seen with a locally steeper curve. Since the permeability for a martensitic microstructure is smaller than for a ferritic perlitic microstructure [1], a change in the curve can be observed especially around the Curie temperature. The Curie temperature is reached more quickly with a preheated part, which has not yet been hardened, but has merely been heated up, so that an earlier power rise can be observed (**Fig. 5**).

Smaller coupling distance for guide-shoe wear

The inductors for crankshafts are workpiece-contacting parts, which are guided on the journal by six support points. The support is realized by means of carbide or ceramic guiding shoes which are intended to guarantee a constant coupling gap to the workpiece. In the course of the inductor life, the sliding shoe wears, so that the coupling gap reduces. The air gap between inductor and workpiece is the transmission medium of the electromagnetic field and has a considerable influence on the hardening zone and thus on the required product quality. The smaller the gap, the better the induction transfer into the workpiece. **Fig. 6** shows the signal that was measured for an already advanced wear of 0.2 mm. The raised performance curve also corresponds quantitatively to the results that could be obtained by means of a numerical calculation by ANSYS.

Inductor position and clamping

During crankshaft hardening, the pin journal inductors run on a circle with the diameter of the double stroke. The resulting centrifugal forces must be compensated by an increased weight force. If these presettings are changed and reduced to such an extent that the inductors take off during rotation, the product quality is highly endangered. The same fault pattern can occur when the journal width is too narrow so that the inductor may be lifted up, as shown in **Fig. 7**. Clear signal spikes are recorded when the inductor lifts off and does not properly orbit the workpiece. Other typical faults which can also be detected are poor inductor contact, reduced cooling in the inductor or transformer and chips on the workpiece.

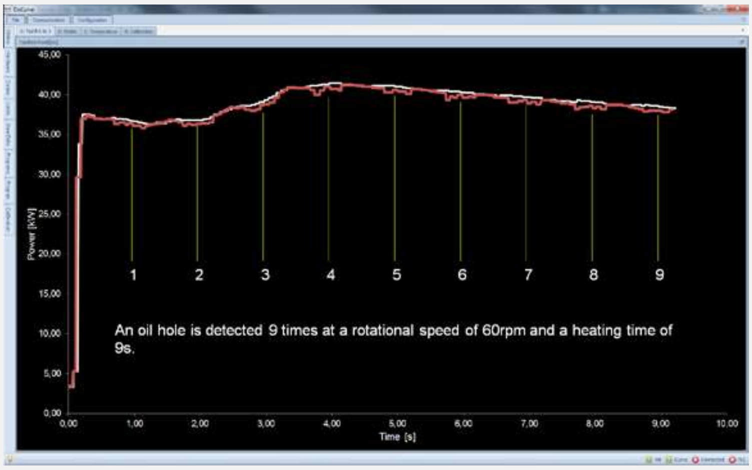

Fig. 3: Recognition of oil holes: white – power curve without oil hole; red – power curve with oil hole

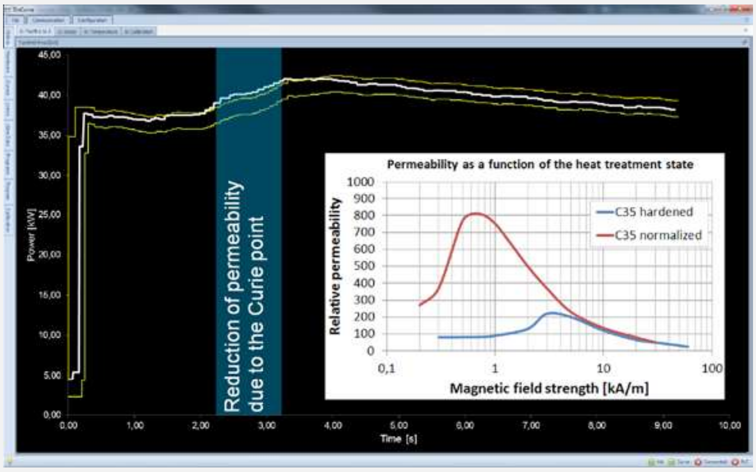

Fig. 4: Re-hardening of a previously hardened part

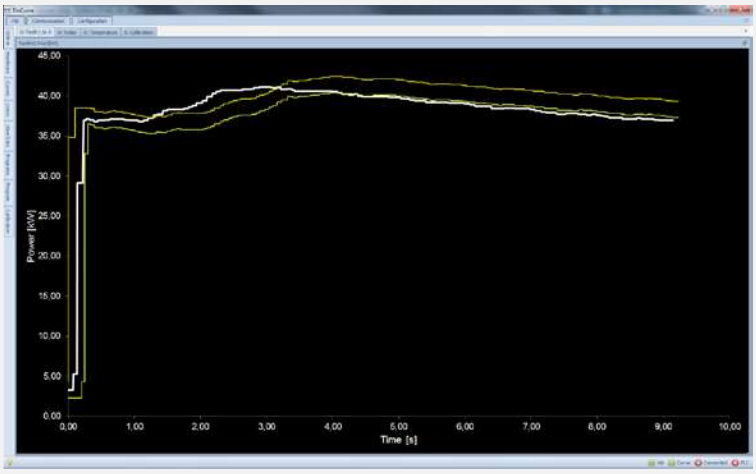

Fig. 5: Hardening of a preheated part

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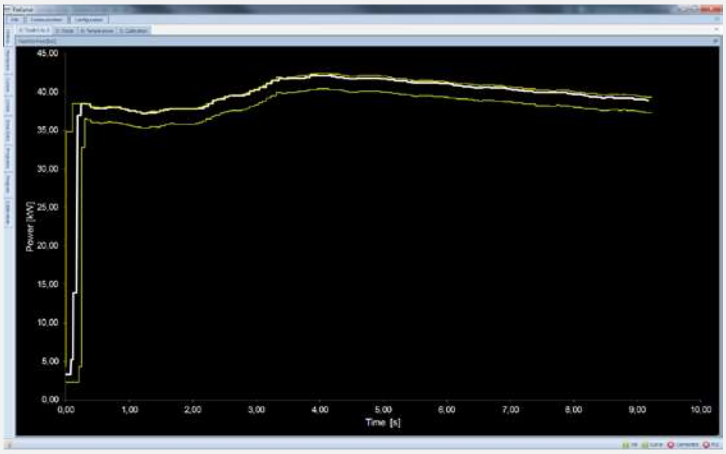

Fig. 6: Hardening of a part at reduced air gap

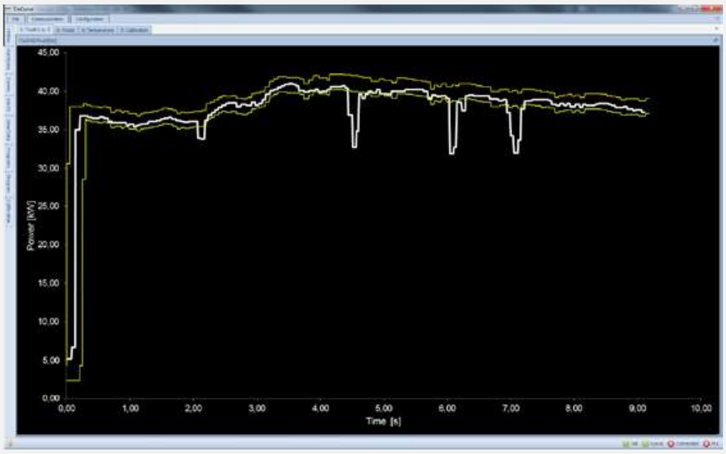

Fig. 7: Hardening of a part at randomly increased air gap

ELOFRESH

The cooling and the associated media are an often underestimated issue at the induction hardening. As a hardened workpiece entering the machine usually cold and taken off also cold, the induced thermal energy is almost completely removed through the cooling media. Both cooling circuits (electric cooling and quenching medium cooling) take an equally high importance in terms of inductor life, production safety and product quality.

With EloFresh a customized system exists that can be operated independently from the machine and is thus suitable for retrofits in both media circuits. Laboratory analyses of water can be reduced significantly. Furthermore, it allows for a quick overview of the water consumption and leaks in the system will be detected, which otherwise would not be noticed.

Electric cooling quality

The water used for the electric cooling must fulfil certain requirements. Chloride (max. 150 mg/l) and sulfates (max. 50 mg/l) are restricted due to their corrosive nature. Dissolved minerals can lead to deposits on the insides of the water-cooled profiles, which will reduce the heat transfer. Moreover, the pH value (pH 7…8.5) should be noted, which is an indicator for cooling problems related to germs in the water. In many cases, the use of de-mineralized (DI) water is therefore recommended to be used in combination with an inhibitor due to its constant quality. As the electric cooling is circulated in a closed loop, it is exposed to less environmental impact. Nevertheless, it tends to alterations (e. g. bacterial growth and deposition of the inhibitor on the inner walls of the cooling system) and must therefore be continuously monitored and re-adjusted.

Poor water quality is often the cause of a small inductor durability and corrosion problems in the cooling circuit, especially on the copper.

With EloFresh, the essential characteristics of the electric coolant are measured and re-adjusted, if necessary (**Fig. 8**). The chemical removal of brass and copper is also monitored by a corrosion measurement line.

Quench media quality

The quenching medium circuit differs significantly from the electric cooling circuit. The workpieces and the large surface open to the environment make for an ongoing contamination. Washed off dirt and metal chips may be removed through filters and magnetic separators but a prewashing of workpieces leads to more stable processes and a significantly reduced inductor incrustation.

Significant loss, in particular of water and to a lesser extent of the polymer on the workpiece surface requires a permanent dosage to maintain the set concentration of the polymer.

Due to the ongoing measurement of the polymer concentration and the automatic water refill, EloFresh takes over this task (**Fig. 9**). Manual measurements to determine the concentration can be omitted. The problematic microbial grows is prevented by automated biocide dosing.

QUALITY PRESERVATION BY PROFESSIONAL MAINTENANCE

So far the focus was on the process and media monitoring, which has a great influence on the product quality and productivity of the machine. An additional and significant topic is the maintenance of the inductors. As described in the first part, inductor wear will contribute to an unwanted hardening result. The dimensional requirements for the inductors are very high here and, even though they are subject to thermal stress in a rough environment, they are supposed to have several 10,000 heating cycles. For a user-friendly maintenance RFID chips are used, which offer several benefits for local data storage and are a prerequisite for the system EloMind.

The mechanical inductor cleaning, which removes the residue on the housing and the heating coil needs to be carried out as first step of a proper maintenance.

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With a specially developed maintenance unit (**Fig. 10**) the inductor maintenance is not run arbitrarily any more, but programme supported and documented.

All geometrical test dimensions are checked and stored in the chip. The operator is guided through a step-by-step process, including sample pictures and gets a quick overview of the status of each inductor set. Using electronic pressure sensors and a flow sensor, the cooling rate is measured. All data generated including the maintenance log will be written to the inductor chip and can also be sent to the company network to be managed there in the form of a tool database.

The inductor chip also allows near field communication (NFC) and can be read directly by means of a mobile phone app. Thus, it is already possible to check the status of the inductor during the removal of the inductor from the inductor magazine.

Each inductor shows signs of ageing in the course of his lifetime, which lead to the need of parameter adjustments. Typically not the process times will be adapted for cycle time restrictions, but rather the voltage/power. These offset values are also stored on the RFID chip and used in the induction hardening machine for process correction.

The read and write functionality also allows to display the frequency distribution of performance data run since the last maintenance. The new maintenance concept achieves a great transparency in the use of inductors.

CONCLUSION

Inductors and cooling media are the tools in induction hardening. Their maintenance and monitoring is the basis for quality with the focus on a detailed process analysis. Preventive systems such as EloFresh and user-guided maintenance such as EloMind reduce the risk of violating the tolerance limits. Quality and productivity in induction hardening are stabilized at a high level using this new developed system technology, EloConnect by SMS Elotherm.

LITERATURE

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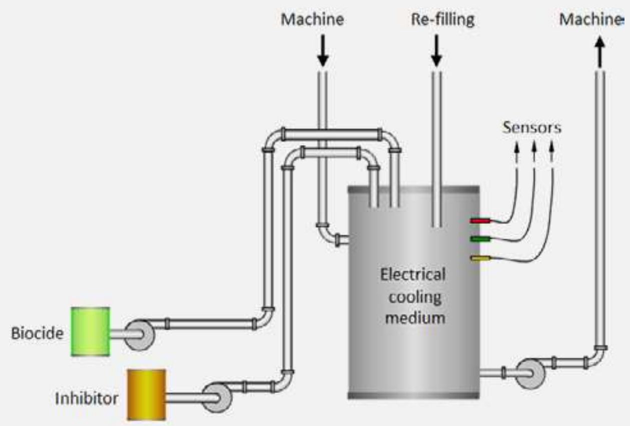

Fig. 8: EloFresh schematic for cooling medium

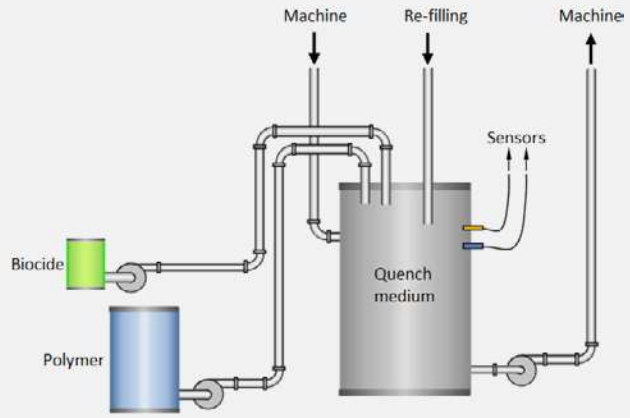

Fig. 9: EloFresh schematic for quench medium

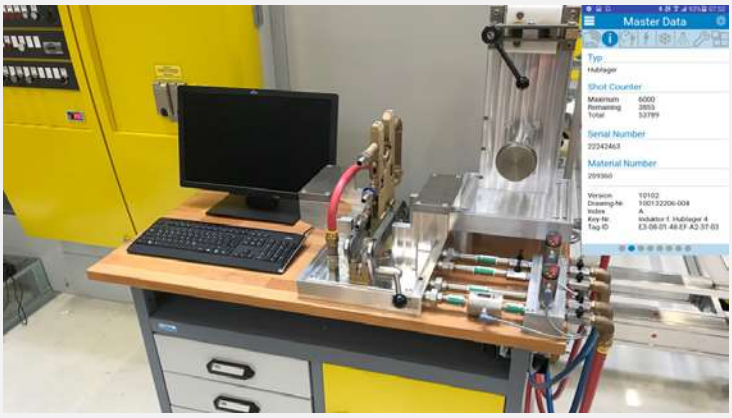

Fig. 10: Maintenance unit with flow control and PC-guided maintenance, upper right corner: screen shot of mobile phone app

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