Minimal distortion induction hardening of crankshafts

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During induction hardening of crankshafts, undesirable distortion occurs in the component, in particular in case of fillet hardening. The procedure patented by SMS Elotherm solves this problem by means of a combination of distortion simulation, an appropriate hardening sequence, specific power control, and a special mechanical workpiece handling system. This paper sets out the principles and the current techniques for minimal distortion induction hardening.

The greatly increased cost of fuel and the global requirement to reduce CO_2 emissions have created a trend within the combustion engine manufacturing industry to develop lighter, smaller, and at the same time, more efficient units. This "downsizing" makes high demands the material and the mechanical properties of engine components - especially on the crankshaft. The demands made on the bending fatigue strength and on the wear resistance properties in these precision components therefore also increase greatly. For this reason the special stress zones of crankshafts are hardened specifically to meet such requirements by means of induction technology. However, due to the process and materials used this results in an expansion in volume and thus to undesirable distortion. The solution is the process developed and patented by SMS Elotherm for minimal distortion induction hardening for every type and size of crankshaft.

The induction hardening technology

Hardening as a procedure for setting certain properties of the case is based on metallurgic conversions as the result of heat treatment specific to the materials. The hardening process is divided into four phases:

1. Heating (**Figure 1**)
2. Holding
3. Quenching (**Figure 2**)
4. If necessary, annealing

An essential advantage of induction heat treatment lies in the fact that high power densities (typically 500 - 2000 W/cm²) are achieved within a short period of time ready to heat the case layer close to the surface.

The actual formation of the tempered martensitic structure takes place once the heating phase has ended. To this end the austenite in the area to be hardened must be selectively quenched. The result of this process is the considerable increase of hardness of the surface of the material compared with its initial condition. Based on the structural changes of the lattice at the required cooling rates, the formation of martensite is an extremely demanding process which, in order to be mastered reliably, requires equally high measures of process and engineering expertise.

Depending on the application, compressible and non-compressible fluids are used as quenching media (gases, water, oils etc.). The various media are distinct from one another by their different quenching effects. If quenching is too slow the result is a bainitic final

Fig. 1: Inductor during heating

Fig. 2: Quenching procedure

Fig. 3: Hardening machine for large crankshafts up to 5000mm in size

structure, while quenching that is too fast can result in the appearance of unacceptable distortion and the formation of cracks. It is therefore a matter of finding the balance between the required final hardness, structural quality of the lattice and the condition of the component after hardening.

The formation of martensite results in a massive increase in strength. However at the same time brittleness and mechanical stress also increase. In order to reduce undesirable mechanical stress on a component to an acceptable level, the workpiece concerned is often tempered immediately after the hardening process. This usually occurs at temperatures between 180 and 300°C. Indeed this procedure is accompanied by a reduction of hardness, but it does considerably increase bending fatigue strength.

The machine technology used for hardening crankshafts

There are various machine technology concepts available for hardening crankshafts. Important criteria for the design of a machine are as follows:

- The geometry of the crankshaft
- The hardness specifications
- Annealing
- The cycle time
- The production program
- Logistics

The hardening process requires perfect interplay between the mechanical movements monitored by control technology, the provision of electrical induction power, and the quenching medium. This results in various induction hardening solutions.

A significant feature of crankshaft hardening machines is the parallel oscillating circuit used to generate the necessary induction power. The advantage of the parallel oscillating circuit is the process control system which is dependent on the voltage. It prevents the material from overheating when the hardness temperature is reached; such overheating would cause the surface to melt.

Essential conditions for all machine types are reproducibility of results and availability. Due to many years of experience at SMS Elotherm in the field of induction technology - in particular its expertise in handling high currents; the requirements of advanced engine manufacturers are met:

- Constant operating parameters during operation
- Long-term stability of induction tools
- High wear resistance and rigidity of the mechanical machine part
- Monitoring of the energy induced in the workpiece by means of a patented process [1]
- Angle control option (power pulsing)

The range of crankshaft hardening machines from SMS Elotherm includes machines for small series production, for large crankshafts (**Figure 3**) and fully automatic machining centers (**Figure 4**) with hourly capacities of up to 120 crankshafts.

Fig. 4: Flexible hardening machine for crankshafts

Component distortion and internal stress

Depending on the material, the induction process generates a growth in volume during the micro-structural change. This is an undesired reaction, because the stress generated distort the crankshaft. The type of expansion has several causes which are mainly due to the uneven distribution of mass along the crankshaft. In cases where only the bearing surfaces are hardened, this is fairly minor and almost always causes axial expansion. It can be easily compensated by pre-calculating length allowances.

It is more difficult in the case of fillet hardening. In this case, in addition to axial expansion, there is also volume growth in the area of the side walls. Due to the structure of the shaft, this can distort neighboring bearings. This distortion can only be compensated by specific counter-hardening.

However, the residual compressive stress close to the surface caused by the hardening process is not the only reason for the component's distortion.

There is usually certain internal stress caused by former manufacturing steps. Internal stress of the crankshaft is created during the cast or forging process [2]. The internal stress is partially released during the heating phase of the hardening process, but later on overlaid with the stress caused by the microstructural changes. The consequence is that undesirable distortion can occur in the component. Nowadays, manufacturers are using the distortion control option offered by the modern induction systems from SMS Elotherm. To do this it is necessary to adjust the upstream processes in such a way that they guarantee reproducible and constant internal stress behavior of the components.

The geometry of the crankshaft also causes further distortion during the case hardening process. The major influencing variables are:

- the orientation of the bearings
- the overlap of main and pin bearings
- the thickness of the counter weights

Furthermore, the required hardness zone is an important influencing variable. Here the hardness distortion is defined in particular by the hardening depth, especially in the radius, and the height of the hardness zone at the side walls of the counter weights.

Minimal distortion induction hardening

The problems of hardness distortion can be solved by making use of the appropriate hardening sequence and with the correct power control system. The process patented by SMS Elotherm has proved in practice that the desired results are obtained despite a very wide variety of crankshaft shapes.

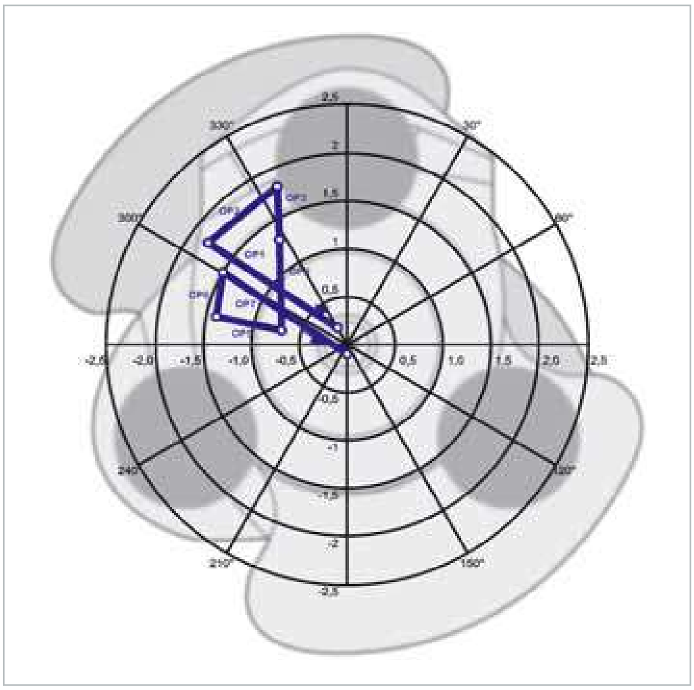

Fig. 5: Hardening sequence for a six-cylinder in-line crankshaft

Hardening sequence

The term 'hardening sequence' is understood to mean a sequence of hardening steps on single bearings or groups of bearings. Having analyzed the hardness specification, the material expansion properties and the geometric dependences, the sequence of hardening operations is verified on the component. An optimized hardening sequence is illustrated here in the example of a six-cylinder in-line crankshaft (**Figure 5**).

Power control system

The power control system enables the induction hardening process to react to variable mass distributions on the perimeter of a bearing. The angular position of the workpiece is recorded continuously during the hardening process. By presetting the heating power according to the angle in the preset angle range, it is possible to control the run out. For pin bearings the power control is used to prevent overheating in the area of the upper dead point (**Figure 6**). In the case of main bearings it is mostly used to control distortion. There, within the range of the angular overlap with the neighboring pin bearing, it is possible to effect the distortion positively.

Distortion simulation

For both, engine manufacturers and machine builders, the optimum hardening sequence and the correct use of the power control system are fundamental. It requires a great deal of experience of the materials and of the workpiece itself, combined with comprehensive process expertise. In recent times numeric distortion calculation systems offer excellent support - especially for complex workpieces. The direction of hardness distortion is determined on the basis of 3D modelling and a suitable hardening sequence and power control is selected. In **Figure 7** at the top it is possible to see the distortion in the shaft

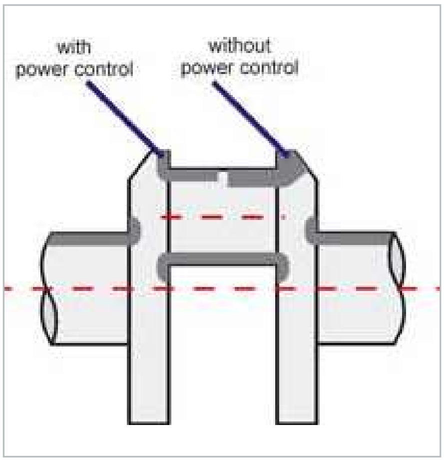

Fig. 6: Power control system

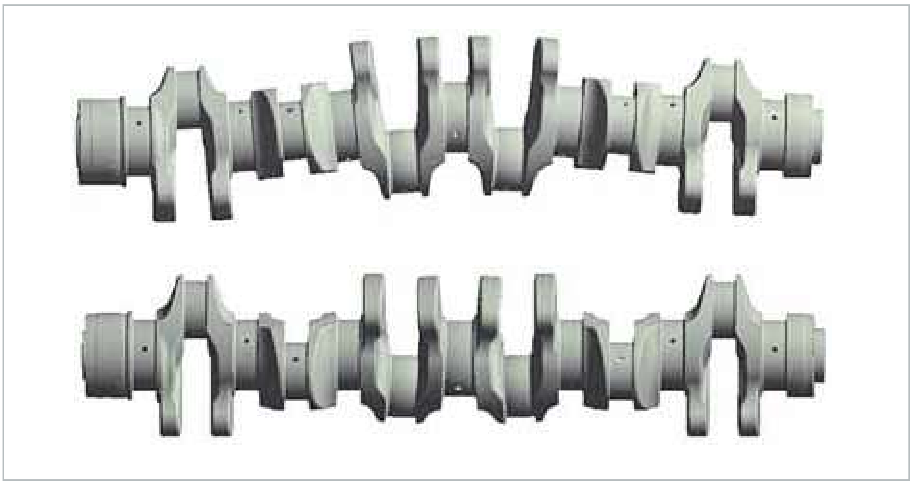

Fig. 7: Distortion control in a six-cylinder in-line crankshaft (distortion raised)

caused by simultaneous hardening of the pin bearings. The shaft clearly shows run out beginning at the central main bearing. The following hardening process with power control makes it possible to push it back, thus achieving a distinct reduction in distortion (figure 7 bottom).

Chuck clamping configuration

It is possible to achieve a clear reduction in distortion by using special design fixtures on the hardening machines. The clamping chucks [3], patented by SMS Elotherm, allow the crankshaft to expand lengthwise. One of the clamping chucks works as a rotary drive, while the second clamping chuck monitors the rotation with a floating bearing. This means that no axial forces that could result in distortion will affect the crankshaft.

Steady rests

In particularly distortion-critical crankshafts, patented supporting rollers, known as three-point steady rests [4] are used. This means that even crankshafts with a very complex geometry can be processed creating a deep hardening depth. The steady rests can be used for example during the entire hardening process or only in the further quenching phase.

Conclusion

The proven SMS Elotherm processes for minimal distortion hardening are convincing by its clear advantages over comparable, conventional methods. They significantly reduce distortion in the shaft during the hardening process, minimizing the following grinding operation with its high tool cost. Altogether, less processing time is required and overall production efficiency increases.

Literature

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[4] Patent DE 199 34 534 C1, Method and apparatus for case hardening of crankshafts

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