Inductive spin hardening of gears

Easy integration into production flows has made the inductive spin hardening of gears increasingly popular in recent years. Dr. Hansjürg Stiele of EFD Induction explains the basics behind the method.

Induction gear spin hardening can be divided into two main methods: through hardening and contour hardening. With the first method—used primarily for gears exposed to high wear— the tooth perimeter is hardened with a low specific power. However, if the frequency is too low, there is the risk that above the Curie temperature the induced eddy current flows mainly in the root circle, and the temperature lags behind in the teeth. Quenching is either by submersion or spraying, and is usually delayed in order to achieve a uniform temperature between the teeth and the root circle. Tempering after through-hardening is essential for crack prevention.

Contour hardening is divided into single- and dual-frequency processes. With the former, a single generator feeds the inductor. Austenitizing is achieved either in a single heating, or by pre-heating the gear to 550-750^{o}C before heating it to the hardening temperature. The purpose of pre-heating is to reach an adequately high austenitizing temperature in the root circle during final heating, without overheating the teeth tips. Short heating times and a high specific power are usually required to achieve hardening profiles at an irregular distance to the tooth face.

The dual-frequency process uses either separate or simultaneous frequencies. Using separate frequencies achieves hardening profiles similar to case hardening. The process applies two different frequencies one after the other to the gear. The teeth are pre-heated at a low frequency to 550-750^{o}C. The frequency should be such that pre-heating occurs in the root circle area. After a short delay, use of a higher frequency and specific power achieves austenitizing. Accurate monitoring systems are essential, as heating times are measured in tenths of seconds or seconds during this final heating phase.

With the simultaneous dual-frequency method, a lower and a higher frequency feed into the inductor *at the same time*. Hardening is achieved by heating the root circle with the lower frequency, and the tooth tips with the higher (see Fig. 1). Unlike the separate dual-frequency process, pre-heating is not always required when using the simultaneous dual-frequency process. However, the short heating times used with simultaneous frequencies place high demands on the generator and machine engineering. Fig. 2 shows an example of a hardening profile achieved with this method.

Correct quenching is critical for perfect spin hardening results, and should be performed as soon as possible after the final heating. The time gap between heating and quenching can be minimized by using a fast CNC axle to position the spray head, or by integrating a quench circuit into the inductor. During the quenching phase the rotational speed of the gear is decreased to below 50rpm to avoid a ‘shadow effect’ on the flank opposing the direction of rotation.

Many other factors influence spin hardening outcomes. The material to be hardened and its initial structure, for example, have a decisive impact. Due to short austenitizing times, the initial steel structure must be close-grained (ASTM 7 and above). Non-homogenous pearlite-ferrite initial structures are not suitable. The importance of initial structure and carbon content increases as module size decreases. If a somewhat increased quenching distortion is acceptable, inductive pre-quenching and tempering prior to contour hardening can greatly improve the gear’s hardenability.

Module size is another key factor in spin hardening. For the dual frequency method with simultaneous frequencies, the range is $2.2 < m \leq 5$mm. However, for cost reasons the gear diameter should be limited to approximately $d \leq 250$mm. For modules where $m \leq 3.0$mm, the separate dual frequency method is preferred. This is because a final hardening phase with only the higher frequency achieves better hardening at an irregular distance to the face. The single frequency method is almost exclusively used for internal ring gears with a module where $m \leq 1.25$mm, such as those frequently used in automotive automatic transmission systems.

Spin hardening is a versatile and reliable process that can harden spur-toothed, helical spur and internal gears at an irregular distance to the face. However, different gear forms influence hardening results. With helical gearing, an asymmetrical hardening of the tooth flank at a depth of up to 2-3mm from the gear face has to be accepted. This situation is however only pronounced with helix angles of $\beta \geq 28°$. Patented coil solutions are available that limit this effect by enhancing power distribution.

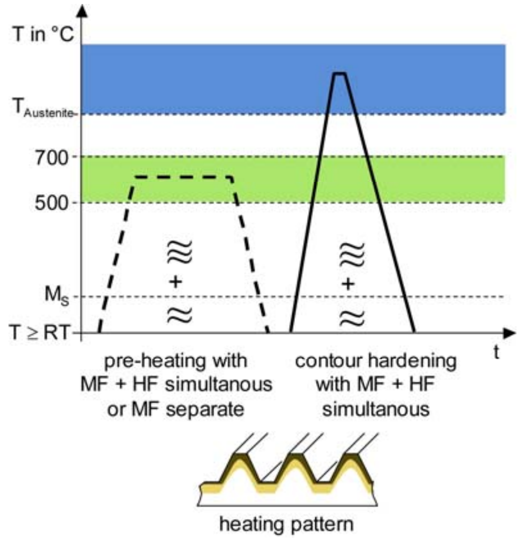

Fig. 1 A schematic time-temperature graph for simultaneous dual-frequency contour hardening (MF = lower frequency, HF = higher frequency).

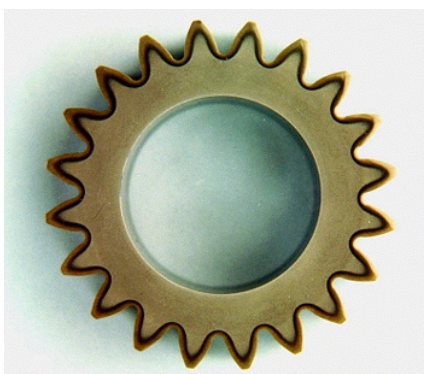

Fig. 2 The end result of simultaneous dual-frequency contour hardening using EFD Induction equipment. The lower frequency hardened the root circle, while the higher frequency hardened the teeth.