Induction hardening – A quick guide to methods and coils

There are two alternative methods of induction hardening: conventional "scanning hardening" and the less common "single-shot hardening". This article looks at the induction hardening process and discusses these options.

It is sometimes the case that workpiece characteristics determine which method must be used. A long, large-diameter shaft, for instance, requires scanning, as the power needed for single-shot hardening would simply be excessive. Then there are workpieces whose irregular shapes or complex geometries makes single-shot hardening the only viable alternative.

SCANNING HARDENING

Scanning hardening involves relative movement between the workpiece and the induction coil. Scanning is divided into vertical and horizontal hardening. In the former, the workpiece is held stationary in a vertical position and a coil moves across its length (sometimes the coil is stationary and the workpiece moves), The coil moves at various speeds, but it is typically in the range of 5-25 mm/second. A major advantage with vertical scanning is that the induction coil is relatively easy to make, as it is normally a single-turn, round ring. Another advantage with vertical scanning is that the quench assembly is placed below the induction coil. This means the quench medium flows downward without interfering with the heating. It is possible to control the depth of hardening in different zones of the workpiece by adjusting the coil's speed and the power fed into it.

With horizontal scanning hardening (**Fig. 1**), a horizontally held workpiece is fed through a coil and quench. One benefit of horizontal scanning is that it can reduce distortion. This is achieved by maintaining the workpiece in a concentric position in the coil and quench, as this results in symmetrical heating and quenching. Another benefit of horizontal scanning is that it facilitates the hardening of large workpieces. It is, for example, possible to harden tubes up to 6 m long with this method.

SINGLE-SHOT HARDENING

Single-shot hardening means the complete hardening zone is first heated and then quenched. Such hardening can be achieved with a multi-turn coil that encircles the entire hardening zone. But for workpieces with rotational symmetry, a coil is typically used that follows the workpiece's contour, combined with rotation. Coils can be designed to "push extra heat" into areas such as fillets on flanged shafts, where it is often difficult to obtain sufficient hardening depth.

The benefits of single-shot hardening include minimized distortion and optimal results for workpieces with complex geometries and/or large diameter changes. The method's relatively long heating times (compared to scanning) also benefit the workpiece microstructure and residual stresses. But even if single-shot's heating time for each grain is longer compared to scanning, the total heating time is shorter since the entire heating zone is heated at the same time.

Single-shot hardening typically requires more power than scanning. This extra power is needed to achieve the required temperature increase in the complete hardening zone. Moreover, the coils used in single-shot hardening are more complicated and expensive than those used in scanning. And if the power demand changes somewhere on the workpiece, it will be necessary to physically modify the single-shot coil. With scanning, such changes can usually be handled by adjusting the control program.

NO TOIL, NO COIL

Regardless of the induction hardening method used, the inductor (coil) is a critical component. In fact, designing and testing coils is often the process with the longest lead time when devising an induction heating solution. A key reason for this is the

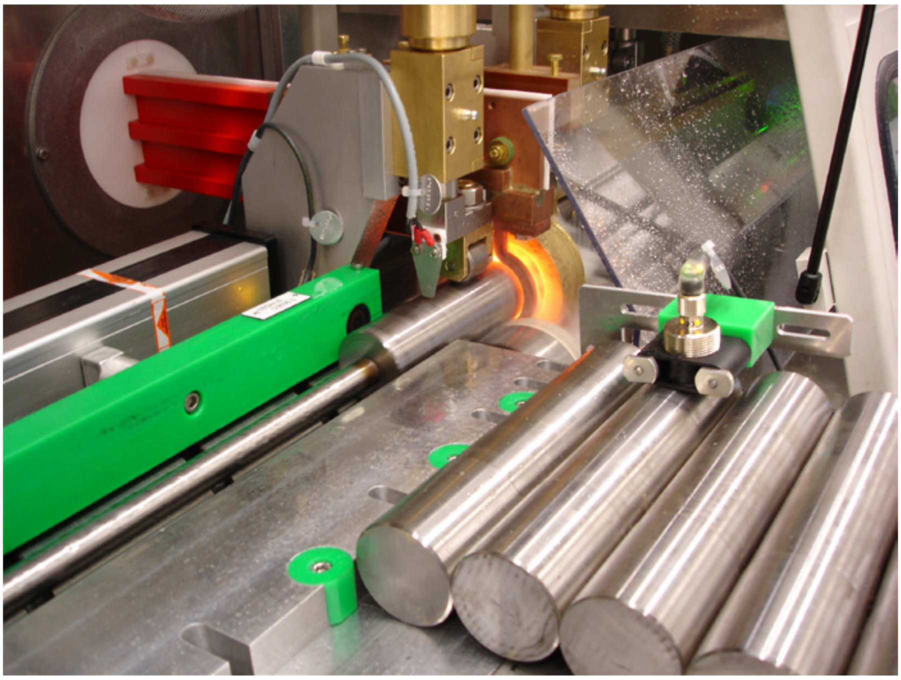

Fig. 1: Example of high-volume horizontal scanning hardening

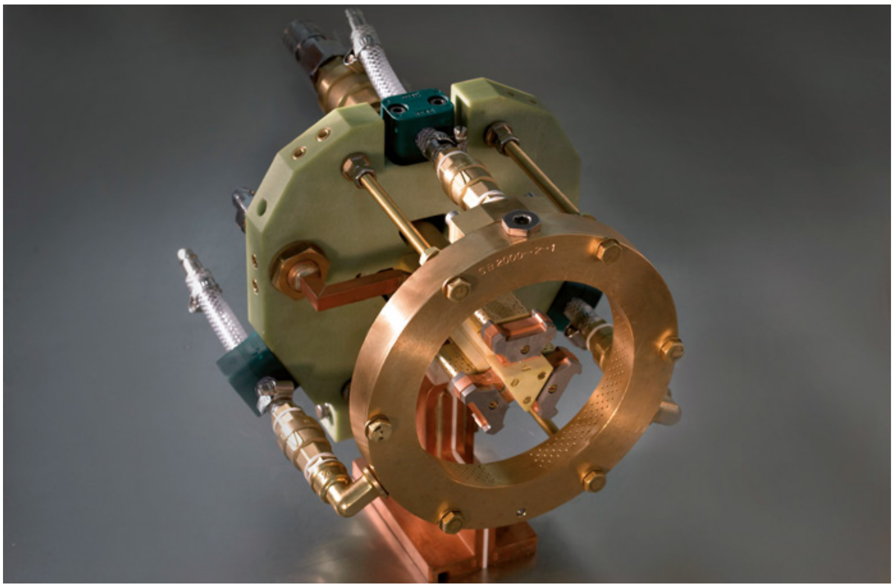

Fig. 2: Example of a specialized induction coil designed and built for the specific task of hardening CV (constant-velocity) joints

fact that coils are task-specific. They must be designed to achieve specific results on specific materials under specific conditions. There are no (or at least there shouldn't be) off-the-shelf coil designs.

Rigorous testing of a coil's design and construction is essential (**Fig. 2**). Too few people realize that coils are often the part most exposed to harsh operating conditions. Therefore, testing and computer-aided simulation are sometimes needed to arrive at a design that is both safe and fatigue-resistant. And, of course, it takes repeated testing to achieve optimal part heating patterns. Nothing can be taken for granted when designing induction coils. With very high power-density coils, for example, one even needs to determine the correct speed at which cooling water should flow through the coil. Too low a speed will result in insufficient thermal transference. But even when the correct speed has been found, the coil designer must decide whether a booster pump is necessary in order to achieve and maintain the desired water through-flow rate. A competent coil designer will also specify a purity level for the cooling water in order to minimize corrosion on the inside of the coil. So, something as apparently straightforward as the coil's water is in fact a complex matter demanding technical competence and specialized equipment.

MAGNETIC-FLUX CONCENTRATORS

Magnetic-flux concentrators are another aspect of an overall induction solution that at first glance seems relatively straightforward. As the name suggests, the main function of such concentrators is to concentrate the coil's current in the area of the coil facing the workpiece. Without a concentrator, the magnetic flux propagates around the coil in air – a medium with low magnetic permeability – setting up a magnetic field that draws part of the current away from the active zone facing the part. But when the return flux is conducted by a concentrator, the magnetic field can be restricted to precisely defined areas of the workpiece, resulting in the localized hardening zones characteristic of induction heating.

Many variables must be considered when making flux concentrators: the workpiece material, the coil's shape and the application. Each influences the concentrator's final design. Even deciding what material to use for the concentrator can be a complicated task. Basically, concentrators are made from laminates or from pure ferrites and ferrite- or iron-based powders. Each concentrator material has its own drawbacks and advantages. Laminates have the highest flux densities and magnetic permeability, and they are also less expensive as parts than iron- and ferrite-based powders. Laminates must, however, be stamped to a few standardized sizes and are therefore less flexible. They are also labor-intensive to mount. Pure ferrites can also offer outstanding magnetic permeability. They suffer from low-saturation flux density, however, and their brittleness makes them difficult to machine (diamond-tipped cutters must be used). Iron powders are easy to shape and offer high flux densities. But great care must be taken to provide against overheating because internal losses, together with heat transfer from the heated part by radiation, may harm the binder of such powders due to the relatively low working temperature.

CONCLUSION

Of course, many other factors need to be considered when designing induction coils, not the least of which being its efficiency. Correct impedance matching between the coil and the power source, for instance, is crucial in order to use the full power from the power source. Its reactive power need, which is normally several times that of the requirement for active power, influences the frequency. It is also vital to select the correct form of electrical insulation for the coil. Again, these are complicated decisions influenced by several variables. As we have seen, a professionally designed and fabricated induction coil is an advanced, complex component. Unfortunately, too many induction users persist in viewing coils as low-tech copper tubes. The results of this misconception are incorrect and even dangerous coil designs; amateurish repairs; insufficient or incorrect maintenance; and, ultimately, process and equipment failures.

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