Simultaneous Dual-Frequency Gear Hardening

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A new approach to induction hardening of automobile transmission gears simultaneously uses medium and high frequencies to achieve the required case characteristics. The process offers many variations of single and combined frequencies to engineer optimum processing parameters for individual gear configurations.

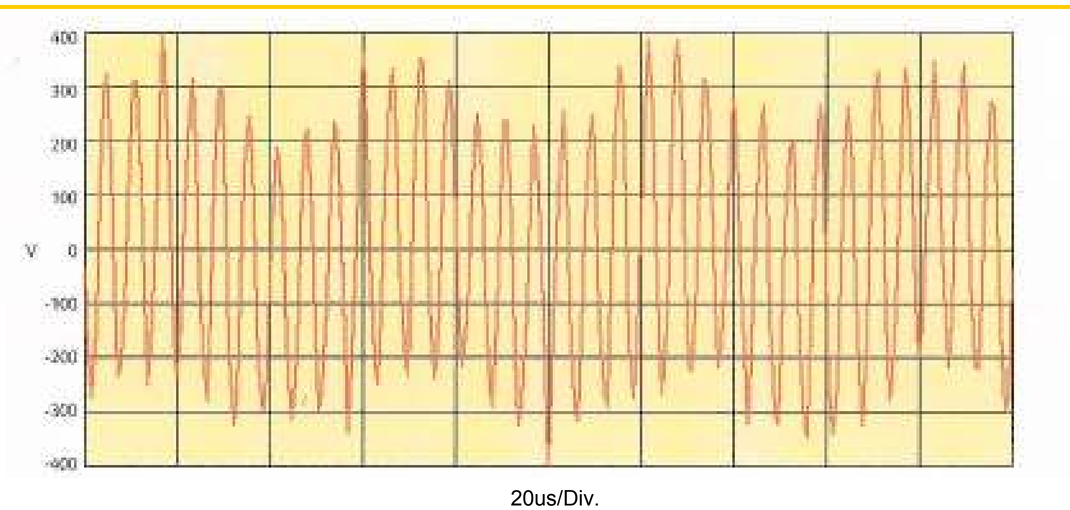
Simultaneous dual-frequency induction heating adds a new dimension to the variables that control the induction heating process. The process requires less energy and space than earlier dual-frequency induction heating systems, as well as atmosphere furnace treating systems. It also can be more easily incorporated into an automotive manufacturing line or flexible work cell. In addition, the process provides a cost benefit by allowing the use of high-carbon steels, which are ideally suited for induction hardening, compared with more expensive high alloy steels used with thermo-chemical processes. The reduced overall heating associated with simultaneous frequency heat-treating technique improves the microstructure of the hardened area, has minimal effect on material core properties and, in most cases, eliminates the need for finish machining to meet dimensional specifications after hardening.

Initial roadblocks

From the very beginning of the industrial application of induction heating to heat treat gears, engineers have attempted to obtain a uniform cast-hardened surface on the tooth profiles of gears. Case hardening increases both the abrasion resistance of the tooth face and the fatigue properties of the root of the tooth without through hardening. However, early induction heating approaches were limited to what could be achieved using a single-frequency power supply, or two power supplies operating independently at different frequencies to sequentially heat the gear plus the mechanics necessary to switch power and move the part. Limitations of a single-frequency power supply and the limited frequency range of early induction equipment only allowed achieving one heat-treating requirement at a time. For example, the strength of the root of the tooth could be achieved (Fig. 1) using a frequency of 10 kHz, the classical medium frequency available using motor-generator sets. However, the abrasion resistance of the tooth face also was increased a the same time at the cost of through hardening the tooth, which made the gear susceptible to fracture.

The tooth face could be hardened without through hardening using high frequency (200 to 450 kHz) generated using vacuum-tube oscillators. However, high frequency was

Simultaneous dual frequency applied to a single inductor. Plot shows coil voltage wave shape of medium frequency with superimposed high frequency and 70% medium frequency. Photo shows uniform heating of gear profile.



INDUCTION HEAT TREATMENTS

Not suitable to harden the root of the tooth because the tooth tip was overheated and the tooth eventually was through hardened as a result of the longer heat time required to reach the root area.

Fig 1 Image of the root of the tooth hardened using a medium frequency (10 kHz). Root-circle diameter: 10mm (0.40in); tooth-tip diameter: 20mm (0.785 in).

Fig 2 Image of the root of the tooth hardened using a high frequency (120 kHz). Root-circle diameter: 10 mm (0.40 in); tooth-tip diameter: 20 mm (0.785 in).

Fig 3 Image of a tooth hardened using the simultaneous dual-frequency (10 kHz and 120 kHz) method. Root circle diameter: 10 mm (0.40 in), tooth tip diameter: 20 mm (0.785 in).

Mechanical approaches

No generators were available to produce a frequency between 10 and 200 kHz, and the available medium and high frequencies were too low too high, respectively, to achieve the ideal case characteristics.

Therefore, induction heating system manufacturers attempted to solve the problem using mechanical methods, leading to development of a dual-frequency process.

In the process, both medium and high frequency ranges are applied separately, one after the other, to the same work-piece. This requires one medium and one high-frequency power supply; each power supply has its own inductor, which is spatially separated from the other. The root of the tooth is austenitized in the first inductor using the medium frequency circuit.

The workpiece then is indexed into the second inductor using the high-frequency circuit to austenitizing the tooth tips and tooth faces. The gear is then quenched. To avoid through heating of the tooth, the final austenitizing operation must be very short (<1 second), which requires very high indexing and power Switching speeds. Therefore, the process never became popular because of very high demand on mechanical component life and accuracy.

Conventional approaches

The development of solid-state, high-frequency generators in the range of 20 to 200 kHz made it possible to improve the dual-frequency induction case hardening process. The workpiece is heated to a temperature below the austenitizing temperature using low frequency, or a low proper density, then the skin is austenitized using a high-frequency pulse, and the parts is quenched.

The hardness contour achieved using this method closely approximates the desired contour (Fig. 2). However, the maximum hardness depth still is achieved at the tooth tip where no hardening is necessary, and the hardness depth at the root is marginal in most instances.

Generally, the gear is overheated at the tooth tip and underheated in the root area. A refinement of the dual-frequency method uses one common inductor, which is first incorporated into a medium-frequency power supply circuit and then switched into a high-frequency circuit. The time required for switching is about 0.5 second. Overall heating time typically is about 10 to 12 seconds. Quench time varies from 10 to 15 seconds depending on material and residual heat in the part. Combines heat and quench cycles range from 20 to 27 seconds. Part transfer time is added to determine total processing time.

Further developments

A further refinement to the dual-frequency method eliminates the need for switching frequencies. In the process, a common inductor is simultaneously supplied with medium and high-frequency energy. The frequency mixture at the inductor consists of a high-frequency oscillation superimposed on a fundamental medium frequency. The amplitude of both oscillations can be controlled separately. In this way the power component of both frequencies, and, therefore the case hardening depth in the root of the tooth and in the tooth face can be adjusted and set separately depending on the requirements for the part.

Simultaneous dual-frequency heating achieves a hardened, uniform case tooth profile without influencing the core in a heating time of less than 0.5 second (Fig. 3). Quench time is reduced to 1 second or less, many gears are self-quenched due to the rapid, shallow heating characteristics of the process.

Automotive transmission gears require not only good abrasion and fatigue properties, but also must have low distortion. The amount of distortion directly relates to the level of noise generated by the transmission; the noise level increases with increasing distortion. There is a direct relationship between the amount of distortion and the volume of material heated; the more material heated, the greater the distortion. Longer heat times at lower frequencies used in the preheating stage of conventional processes results in deep heat penetration, with a greater potential for distortion. The shorter heating time of simultaneous dual-frequency induction hardening at a given case hardening depth requires less thermal dissipation resulting in less distortion.

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