

Effect of preheating on fatigue resistance of gears in spin induction coil hardening process

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Abstract. Spin hardening inductors are typically used for fine-sized teeth gear geometry. With the proper selection of several design parameters, only the gear teeth can be case surface hardened without affecting the other surface of gear. Preheating may be done to reach an adapted high austenitizing temperature in the root circle to avoid overheating of the tooth tip during final heating. The effect of preheating of gear on control of compressive residual stresses and case hardening has been experimentally discussed in this paper. Present work is about analysing single frequency mode, preheat hardening treatment and compressive residual stresses field for hardening process of spur gear using spin hardening inductors.

1. Introduction

In spin induction hardening process of spur gear, the gear rotates at high speed within an encircling coil. Selection of coil geometries are important as the relationship between gear surfaces and induction coils, influence the hardening process. It is vital that the gear rotates concentrically as any eccentricities may distort the gear teeth. Special skills are also needed to design and implement the quenching system [1]. The spin induction hardening process is monitored by a control system so that the hardening results can be achieved at the tooth flanks or tooth root or complete tooth by gear hardening using a spin inductor [2]. The microstructure properties can be set to the required depth in carbon-based materials depend upon the frequency, the energy supplied, the quenching method and the coupling distance between gear surface and inductor. Depending on the modulus and geometry, the induction hardening temperatures are slightly higher than with conventional furnace case carburizing hardening technique. It is already established that a decrease in frequency, increases the current penetration depth in the metal [3]. Simultaneous dual frequency induction heating generates a uniform temperature distribution in gear tooth surface [4]. Medium and high frequencies during induction heating provides greater flexibility in controlling temperature in gear profile [5]. Single frequency is suitable for root or tip of the gear. Many researchers worked on controlling fatigue strength by imparting a residual stress in the surface layer of the various material and hence, the nucleation and propagation of fatigue cracks becomes difficult [6,7,8]. It was suggested that a very effective method of improving fatigue performance is through the careful use of residual stress in components. Residual stresses were mainly induced through shot peening and case carburizing process of hardening.

Through a lot of work has been done on spin hardening induction process but its analysis of finding optimum frequency, compressive residual stress and subsequent fatigue resistance is limited. Present



work is about analyzing single frequency mode, effect of preheat hardening treatment and compressive residual stress of induction hardened spur gear.

2. Material and methods

The spur gear material was AISI 5130 with a chemical composition of 0.82% Mn, 0.21% Si, 0.14% Ni, 0.78% Cr, 0.04% Mo, and 0.29% C in weight percentage. An initial microstructure was homogeneous, fine-grain structure, 29 to 31 HRC, consistent induction hardening response with minimum size distortion and minimum grain growth. It is advisable, whenever it is necessary to harden only the tooth tips, a higher frequency and high power density should be applied. To harden only the tooth roots, a lower frequency is preferred. Among the various heating modes for the induction spin hardening of gears, the single-frequency concept is used in the present work.



Figure1. Inductor coil hardening of gear

Low power density provides a deep pattern and a high power density provides a shallow pattern. In this paper, the inductor is fed from a single power supply using a frequency selected as per requirement. Heating (austenitizing) is done with preheating using reduced power to reach a temperature between 550 to 700°C and subsequent final heating at the hardening temperature above critical point (950- 980°C). Preheating was done by pulsed cycles.

Compressive residual stress field (CRSF) was measured by X-Ray diffraction system. The change in lattice spacing in the material is related to compressive residual stress. The relationship between the distance between a given set of lattice planes (d), the wavelength of X-ray radiation (λ), the order of diffraction (n) and the angle θ (diffraction angle) was given by Bragg’s law as follows:

$$2d \sin \theta = n \lambda \quad \text{----- (1)}$$

The diffraction angle was taken as 90° in the present case.

The strain normal to the surface:

$$e = \frac{d_1 - d_0}{d_1} \quad \text{----- (2)}$$

e = normal strain to the surface

d_1 = lattice spacing with induction hardening, A⁰

d_0 = lattice spacing without induction hardening, A⁰

$$\text{Residual compressive stress field} = - E \frac{d_1 - d_0}{d_1} \quad \text{----- (3)}$$

E = 257 kN/mm²

Compressive residual stresses field in hardened spur gear was calculated from equation (3).

3. Results and discussion

Preheating was done to reach an adapted high austenitizing temperature in the root circle during final heating, without overheating of the tooth tip. To achieve hardening profiles at an irregular distance from the tooth face using a single frequency, short heating times are now required. Quenching of small gears (table-1) in spin hardening was done using an integrated spray quench.

Table1. Gear Parameters

S.No.	Description	Symbol	Gear parameters
1	Number of teeth	z	13
2	Module	m	2
3	Addendum	ha	2
4	Dedendum	hf	2.5
5	Face width	w	4
6	Pitch circle diameter	d	26

Tooth geometry and speed of rotation are other important factors that have an effect on gear quenching. It is essential that the eccentricity of the inductor and quench system relative to the gear is negligible. Non-uniform heating, results in distortion of gear shape and size of the gear.

Table 2 shows effect of different factors and process parameters in the final heat treating conditions using single frequency. Frequency was adjusted with variable frequency regulator. At a frequency of 40 kHz, reasonable hardness (more than 55 HRC) was achieved in tooth tip and tooth root circle. However, high frequency of 200 kHz and low frequency of 10 kHz may also be used as per requirement. Cycle time for hardening influences the hardness, saving in energy consumption and distortion in gears.

Table 2. Effect of various parameters on hardness of gear

Frequency	Total heating time(s)	Quenching time(s)	Hardness, HRC	Observation
200kHz	2.2	2.0	58-61	Hardness in tooth tip
40 kHz	2.2	2.0	56-57	Hardness in tooth tip and tooth root
10kHz	2.2	2.0	58-61	Hardness near tooth root

Total heating time includes preheating and final heating time. At an adjusted frequency of 40 kHz, desired hardness (56-57 HRC) was achieved in tooth tip and tooth root. It is seen that selection of parameters such as power density and frequency in induction coil hardening process provides desired hardness in spur gear. The effect of preheating was further investigated for fatigue resistance.

3.1. Fatigue Resistance

The designer wants to avoid cracks in case hardened surface by improving certain mechanical properties in the spur gear case depth. The careful control of compressive stresses in the gear root and flank is required. Phase transformation in the hardening treatment creates an order which results in compressive residual stress state near a tooth surface and acts to impede crack initiation and propagation. Due to rapid heating, the compressive residual stress may not be aligned with the tooth surface and its capability to resist cracks may be limited. Effect of preheating in gear hardening on the compressive residual stress field (CRSF) is studied on reducing the risk of crack initiation in gears and hence improving fatigue resistance. X-ray diffraction method was used to measure compressive residual stress field.

Table 3. CRSF variation with and without preheating gear

Sr. No.	Distance (mm)	CRSF, MPa with preheating	CRSF, MPa without preheating	Hardness HRC
1.	0.0	-630	-300	55-57
2.	0.4	-790	-560	55-57
3.	0.8	-760	-790	55-57
4.	1.2	-760	-430	55-57
5.	1.6	-700	-330	55-57
6.	2.0	-660	-360	55-57

Residual stress measurements were carried out in order to investigate the effect of preheating in gear hardening. Fig. 2 shows the variation of compressive residual stress field (CRSF) with and without preheating.

It was noticed that there is not much variation in CRSF for preheated gear and designer can consider CRSF (-600MPa to -700MPa) for fatigue design (Table 3). However there is abrupt variation in CRSF for without preheated gear and designer can consider CRSF (-300MPa to -400MPa) for fatigue design. It may be established that preheating improves fatigue resistance by uniformity of compressive residual stress field in case hardened gear. Higher value of CRSF opposes tensile loading on gear, making nucleation of cracks difficult and hence increases fatigue of the hardened gear. Abrupt change in residual stress pattern may have chances of micro cracks and distortion in size/shape of the gear teeth. Subsequently, the hardened gear which is not subjected to preheating is expected to have reduced fatigue resistance in long run.

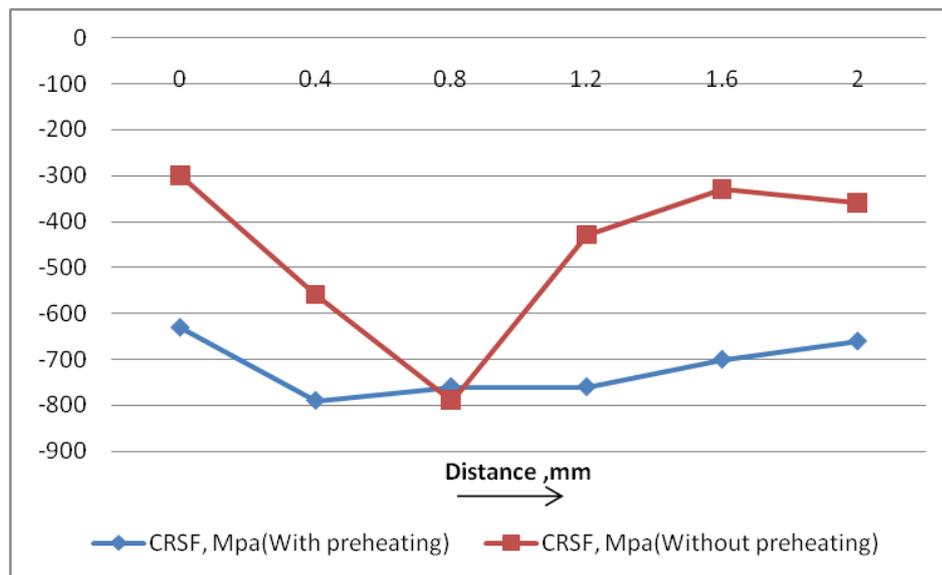


Figure 2. CRSF variation with and without preheating of gear

4. Conclusion

An induction spin hardening process of spur gear was carried out for analyzing single frequency mode, preheat hardening treatment and compressive residual stresses field for hardening process of spur gear . At a adjusted frequency of 40 kHz , desired hardness (55-57 HRC) was achieved in tooth tip and tooth root circle .It is seen that selection of parameters such as power density and frequency in induction coil hardening process provides desired hardness in spur gear.

It was noticed that there is not much variation in CRSF for preheated gear and designer can consider higher CRSF for fatigue design. However there is an abrupt variation in CRSF for without preheated gear and designer can consider lower value for fatigue design. It may be established that preheating improves fatigue resistance by uniformity of compressive residual stress field in case hardened gear. Higher value of CRSF in preheated gear opposes tensile loading on gear and, thereby, increases fatigue resistance of the hardened gear.

5. References

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