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Comparative Analysis of Spin Induction Coil and Gas Carburizing in Case Hardening of Spur Gear

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ABSTRACT

The heat treatment of gears involves gas carburizing in batch or continuous furnaces for longer hours, and then quenching in oil bath. The gears are tempered after hardening in low temperature furnace to impart certain toughness for sufficient time at a specified temperature. Spin hardening inductors are typically used for gears, gear shafts and sprockets. The main aim of spin induction gear hardening is to provide a fine-grained layer of martensitic structure on various teeth of the spur gear. It is always of prime importance to select various design parameters that assist in attaining required hardness patterns in induction coil spin hardening. In the present work, an induction spin hardening process for spur gear is compared with gas carburizing for energy efficient solution, noise resistance and achieving specific surface-hardness properties.

Keywords*: *Induction hardening, noise resistance, spur gear, gas carburizing.

I. INTRODUCTION

Case hardening is often useful to retain full ductility and toughness in the core material of gears for better heat absorption and provides high hardness on the surface/profile in order to attain toughness, reduce wear and increase surface strength. Gears can work better from case hardening process than from thorough hardening, with attaining minimum heat distortion and ductile core can absorb more impact energy. In gas carburizing process of gears, gears are heated to austenitizing temperature for sufficient time and subjected to quenching process and tempering process. A temperature of 190-250^{0}C is sufficient for tempering of low-alloy steels [1]. High fatigue resistance in automobile gears is provided by case hardening. The carburizing temperature ranges 880 to 940ºC and the gas atmosphere is created from liquid or gaseous hydrocarbons [2]. Induction hardening utilizes electric coils to heat quickly the gear teeth, thereafter quenched before the core can become hot. In spin induction hardening process of gear, the gear spins at requisite speed within an induction coil. The spin induction hardening process is monitored by control system to achieve required hardening results [3]. A frequency change from 300 kHz to 10 kHz advisable increases the eddy current penetration depth in the steel from 1.5 mm to 5.4 mm [4]. For modelling the induction hardening process, data regarding phase transformation carbon and carbon steels percentage are required [5,6]. Induction heating can perform localized surface hardening of components [7]. A study regarding microstructure differences between a carburizing treatment and an inductive coil heat treatment of a 50CrMo4 steel was carried [8]. The gradient between surface and core is larger for higher heating rates, since the power intensities have to be higher.

Engineers are always working for noise reduction in gear boxes transmitting power [9]. Heat treatment process in gears can play an important role in reducing the gear noise besides the contribution of other parameters such as the close dimensions, design of the gear tooth profile, material of the gear and structural instability.

Though a lot of work has been done on spin hardening induction process but the analysis of various aspects such as energy efficiency and noise resistance with reference to gear hardening is negligible. Present work is about analysis of these important spin hardening parameters in comparison to gas carburizing of gears.

II. EXPERIMENTATION

The gear material selected in this paper was made of AISI 5130 with a chemical composition of 0.82% Mn, 0.21% Si, 0.16% Ni, 0.79% Cr, 0.04% Mo, and 0.29% C in weight percentage. An initial microstructure was homogeneous, fine-grained structure, 30 to 32 HRC, consistent induction hardening response with minimum gear teeth distortion and least grain growth. This initial microstructure requires a lower-than-usual austenitizing temperature for formation of homogeneous austenite.

When applying induction coils, five major parameters have been selected for hardness pattern requirement. These parameters are power, frequency, cycle time, coil geometry and quenching conditions. Different hardness patterns can be achieved by proper control of these parameters. As a core practice, to harden the tooth tips, a higher frequency and high power density is applied. While to harden only the tooth roots, a lower frequency is applied. There are four conventional heating modes used for the induction spin hardening of gears that utilizes encircling type coils: the conventional single-frequency, pulsing single frequency, simultaneous dual-frequency, and pulsing dual-frequency concepts. In the present work, the simultaneous dual-frequency method, in which a lower and a higher frequency fed into the inductor simultaneously. The simultaneous dual-frequency method uses a lower 10kWh and a higher frequency 200 kWh fed into the inductor simultaneously so that both the tip and root of the gear are hardened.

Low power density provides a deep pattern and a high power density provides a shallow pattern. The uniformity in hardness pattern and repeatability always depends on the position of gear with concentricity of the induction coil. Therefore it is always desirable to maintain the gear concentric with the induction coil. Cycle time is estimated through experimentation so as to optimize the hardness, saving in energy consumption and distortion in gears.

In gas carburizing, carbon monoxide gas reacts with the surface of steel to give a much more rapid absorption of carbon. Spur gears suspended from hooks in the atmosphere controlled gas furnace over a quenching tank and tempered. A required 54-56 HRC was achieved after tempering. The difference in energy meter reading (final energy and initial energy) gives energy consumed during the furnace gas carburizing or spin induction hardening process.

The noise apparatus consists of a pair of spin hardened induction coil gear and gas carurized gear which is rotated by a DC motor. The gear pair is rotated at various speeds with the help of speed change unit.The noise was measured by sound meter and the the rpm of gears was measured by non-contact type tachometer.

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III. RESULTS AND DISCUSSION

3.1. Spin Hardening Parameters

In the present work, the simultaneous dual-frequency method in which a lower and a higher frequency fed into the inductor simultaneously. Hardening is achieved by heating the root circle with the lower frequency, and the tooth tips with the higher frequency (Fig.1). However, the short heating times are used with these simultaneous frequencies need high demands on the electricity/generator.

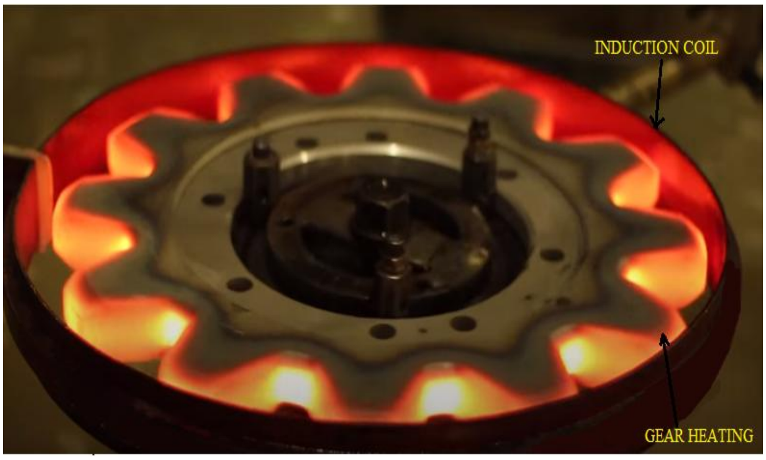

Fig.1.Gear heating by induction coil

For better results in spin hardening, quenching plays a critical role and needs to be performed after final heating. The time gap between heating and quenching was minimized by integrating a quench circuit into the inductor. Quenching of small module gears in spin hardening was done using an integrated spray quench. Tooth geometry and rotational speed are also two major factors considered that have an effect on quench flow and cooling severity during gear quenching. During the quenching phase the rotational speed of the gear is decreased to 50 rpm to avoid a 'shadow effect' on the flank opposing the direction of rotation.

Low frequency and low power density was used for induction tempering. Since the requirement power density is low for induction tempering, it is necessary to heat a gear at slow rate and lower temperature to avoid tooth tip from overheating. It may be noted that tempering was carried out for less than a minute only in hardened area. The advantage of induction tempering lies in system compactness, single part processing, precise control and monitoring of parts. Table 1 shows the effect of different process parameters and time taken during heat treatment. Fig. 2 shows an example of tempering profile achieved with this method.

TABLE 1. Effect of various parameters on hardness of gear

Frequency	Heating time(s)	Quenching time(s)	Hardness HRC	Tempering at low frequency 10Hz for 55s, HRC after tempering	Hardness measurement
200kHz 10kHz	8	6	61-62	54-56	Maximum hardness in tooth tip and tooth root

Fig.2. Tempering of the gear

It is always recommended that concentricity of inductor and proper quenching system relative to the shape and size of gear must be designed to avoid any gear wobbling. Besides non-uniform heating, wobbling can also cause uneven quenching which further leads to distortion in gears. Energy consumption was 0.26 kWh per gear and measured by energy meter. The difference of final energy meter reading and initial energy meter reading gives the energy consumption during the process.

The total time for heat treatment for heating, quenching and tempering is 69s. The final hardness achieved is 54-56 HRC. It may be observed that spin hardening process is much faster as compared with gas carburizing process and provides required hardness value.

3.2 Energy Consumption

The energy calculation refers to the pure energy consumption required for the defined heat-treatment processes like hardening, quenching and tempering. Additional cost and energy such as the acquisition of an induction hardening system, gas carburizing system, loading and unloading time and cost, maintenance, straightening, blasting and the personnel costs are not included for comparison in the hardening process.

3.2.1 Case hardening of AISI 5130

In gas carburizing, the components were heated, quenched directly from the furnace without exposure to atmospheric oxygen. This is accomplished by low temperature tempering, which consists of heating the hardened steel to 225^0C temperature for one hour. This was done to relieve internal stresses and increase toughness. The furnace was operated by electrical energy. The module, number of teeth, face width and other parameters are given in the Table 2.

TABLE 2: Gear Specifications

S.No.	Description	Symbol	Gear Dimensions
1	Number of teeth	Z	13
2	Module	m	6
3	Addendum	ha	6
4	Dedendum	hf	7.5

5	Face width	w	10
6	PCD	df	78

In the present case, gears possess a case-hardening depth of 1.70 mm, a hardness of 54-56 HRC, and it is treated in an electric furnace. The gear dimension are as above and weight per gear is 0.42 kg .The charge size is 120 per batch in furnace or lesser and the total energy consumed is shown in Table 3 and process(consisting of heating, quenching and tempering) took 4.8 hours per batch.

TABLE 3: Number of heat treated gears and energy consumption in carburizing process

S.No.	Number of heat treated gears	Hardness, HRC	Carburizing time, hour	Energy consumption in carburizing process,kWh
1	40	54-56	4.8	29.4
2	80	54-56	4.8	51.2
3	120	54-56	4.8	79.0
4	160	54-56	9.6	108.4
5	200	54-56	9.6	130.2

3.2.2. Induction hardening of quenched and tempered AISI 5130 steel

The case-hardening depth is again 1.70 mm and the hardness is 54-56 HRC by induction hardening, quenching and tempering process. The gear dimensions are same and the workpiece weight was also the same. The energy consumption increases with increase in induction hardening time and number of heat treated gears, Table 4. It is also represented graphically that the energy consumption increases with induction hardening time in spin induction coil hardening process (Fig.3)

TABLE 4. Number of heat treated gears and energy consumption in spin induction hardening

S.N.	No of Gears (Heat treated)	Hardness value, (HRC)	Induction hardening time , (Hours)	Energy consumption in spin induction hardening process (kWh)
1	40	54-56	0.77	10.4
2	80	54-56	1.53	20.8
3	120	54-56	2.3	31.2
4	160	54-56	3.06	41.6
5	200	54-56	3.83	52

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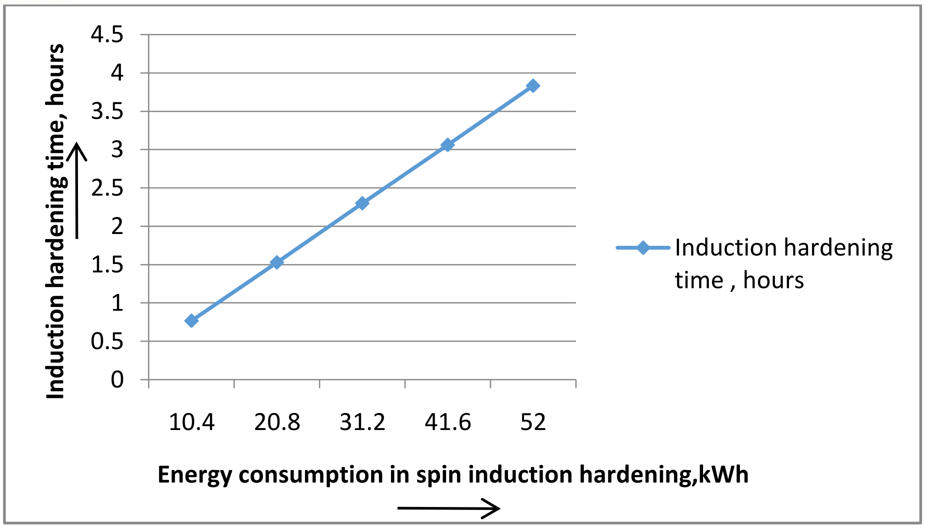

Fig.3.Induction time versus energy consumption

The comparison of the energy consumption alone shows the superiority of the induction process by its direct comparison with gas carburizing for gear hardening .The induction-hardening energy consumption decreases rapidly as compared with case carburizing with increase in number of hardening gears. It is only around one-half or one-third for case hardening (Fig. 4) and time taken for induction hardening is much lesser.

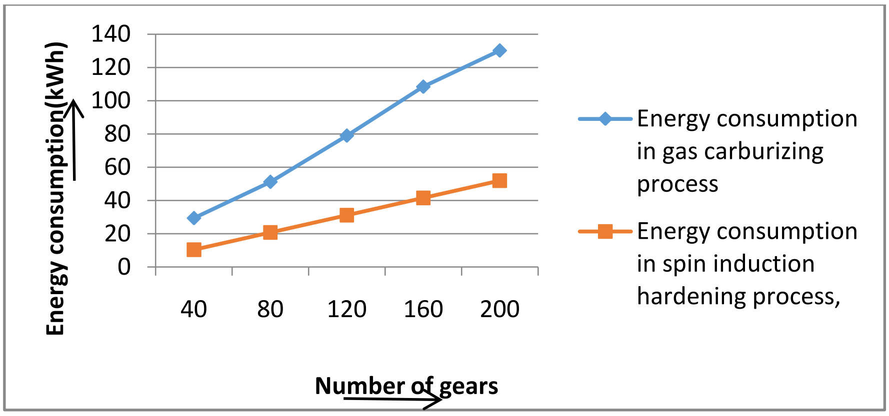

Fig. 4.Number of gears versus energy consumption

3.3 Noise Analysis

The human ear is more sensitive to sound in the frequency range 1 kHz to 4 kHz than to sound at very low or high frequencies. The knowledge about human ear is important in acoustic design and sound measurement. To compensate, sound meters are normally fitted with filters adapting the measured sound response to the human sense of sound. Using the dB(A) filter, the sound level meter is less sensitive to very high and very low frequencies.

Noise is one of the factor that needs to be controlled during operation of gears. With the demands for smaller gear boxes transmitting more power at higher speeds looking for greater efficiency, engineers are always searching for new ways to reduce noise. The apparatus consists of spur gear pair of materials AISI 5130 Steel. The noise was measured by changing the gear pairs for same the same depth of hardened layer 1.7 mm achieved separately by the both the case carburizing and induction hardening process. PCD of 78 mm was used and gears were cut by gear shaper machine. The proposed gear pair was constructed by taking small gear (pinion) with 13 teeth, large gear with 52 teeth and powered by 24 V ,DC motor (Fig.5). The gears were rotated at various speeds and speed of revolution of gear was recorded by non-contact type tachometer.

Fig. 5. Noise measurement set up

Table 5: Effect of gear noise level of gear on dB(A)

S.No.	Parameter	Average dB(A) at 200 rpm	Average dB(A) at 400 rpm	Average dB(A) at 600 rpm	Average dB(A) at 800 rpm
1	Noise level of gear without any surface treatment	54.1	55.6	56.4	58.1
2	Noise level of gear with case carburizing	51.4	52.1	53.1	54.3
3	Noise level of gear with induction hardening	50.9	52.5	53.4	54.5

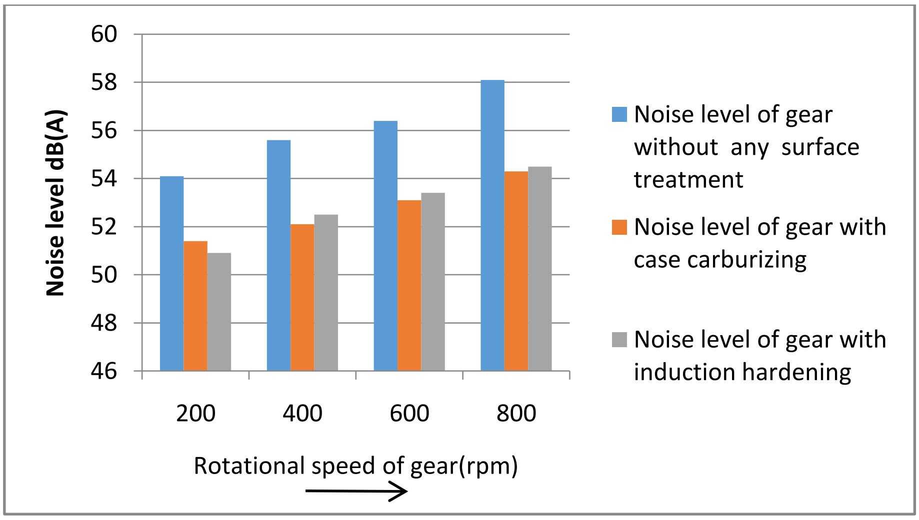

Fig.6. Noise level versus rotational speed of the gear

Noise level decreases with case carburizing or spin induction hardening process (Table 5). It has been found that noise resistance is changed approximately equal in gas carburizing case hardening and induction coil furnace hardening treatment of gears (Fig.6).

V. CONCLUSION

An induction spin hardening process for spur gear is compared with gas carburizing for energy efficient solution, noise resistance and achieving specific surface-hardness of AISI 5130 steel in this paper. The following points have been accomplished from this paper:

1. It may be observed that spin hardening process is much faster as compared with gas carburizing process and provides required hardness value.

2. Noise level decreases in both case carburizing or spin induction hardening process. It has been observed that noise resistance is changed approximately equal in case carburizing and induction furnace hardening treatment of gears.3. The comparison of the energy consumption alone shows the superiority of the induction coil process by direct comparison with case carburizing for gear hardening. The time taken for induction hardening of gears is lesser as comparedwith gas carburizing.4. The induction hardening energy consumption decreases rapidly with increase in number of hardening gears. It is only around one- half or one-third for gas carburizing case hardening of spur gears.

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