International Journal of Modern Science and Technology *Vol. 2, No. 11, 2017. Page 373-376.*
http://www.ijmst.co/ ***ISSN: 2456-0235.***

Research Article

Shot Peening of Induction coil Hardened Spur Gear Tooth to Avoid Failure

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Abstract

Spin hardening inductors uses several design parameters and only the gear teeth can be case surface hardened without affecting the other surface of gear. The induction coil hardened gears are typically tempered for less than a minute time as compared to normal tempering process of one hour at a specified temperature. It is observed that the required surface properties on gear are not achieved and needs improvement by shot peening. Effect of shot peening on surface properties of gear has been discussed in the present work. A hardness model has been worked out using response surface methodology for shot peened gear. Present work is about analyzing various surface properties of hardened and shot peened spur gear using spin hardening inductors and comparing it with non-peened surface.

Keywords: Liquid Induction hardness; Spur gear; Response Surface Methodology; Shot peening.

Introduction

Induction Tempering are widespread use in the automotive and automotive-supply industries. Induction heating and tempering a component only takes around fifteen seconds and Induction tempering can be directly integrated into your production line to improve productivity .The heat can also be controlled precisely. Shot Peening is a method of cold working in which compressive stresses are induced in the exposed surface layers of metallic parts by the impingement of a stream of shots directed at the metal surface at high velocity under controlled conditions. This is due to cyclic plastic deformation of surface layer during shot peening, which implies that the fatigue life would be altered by microstructure .The major applications are related to improvement and restoration of fatigue life and reliability of machine elements by increasing their fatigue strength and enhancement to resistance to stress corrosion cracking and corrosion fatigue. Selection of coil geometries is 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 produce distortion in 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 generally 50-150°C higher than with conventional furnace case carburizing hardening technique. It has already been established that a frequency decrease from 300 kHz to 10 kHz noticeably increases the eddy current penetration depth in the steel from 1 mm to 5.4 mm [3].

Simultaneous dual frequency induction heating applies both medium and high frequencies in a component simultaneously to generate a uniform temperature distribution in gear tooth profile [4]. The energy percentage of medium and high frequencies during induction heating can be adjusted, which provides greater flexibility in controlling temperature distribution in simultaneous dual frequency gear [5]. Single frequency is suitable for root or tip of the gear. Many researchers worked on controlling fatigue strength by imparting a residual stress

Received: 14.11.2017; Received after Revision: 27.11.2017; Accepted: 27.11.2017; Published: 29.11.2017

in the surface layer of the various material, making the nucleation and propagation of fatigue cracks more difficult [6,7,8]. It was suggested that a very effective method of improving fatigue strength is through the careful use of residual stress in components. It is found that conversion of austenite into martensite takes place in shot peening which increases surface hardness, maintaining soft core to have shock stresses and wear resistant surface. This process does not initiate crack nucleation but it repairs cracks [9-10]. In the study of gears [11] the components were shot peened to a 7 to 9A intensity, which increased the compressive residual stress enough to increase the gear surface fatigue life by a factor of 1.6 over that for gears that were not shot peened.

Through a lot of work has been done on spin hardening induction process but its analysis of finding the effect of various shot peening parameters on hardness of gear is limited. Hardness change effect is observed in the process of improving fatigue strength of the gear by shot peening. Present work is about studying the effect of various shot peening variables on hardness of the gear to reduce failure.

Experimental details

The gear material selected in this paper was made of AISI 5130 with a chemical composition of 0.83% Mn, 0.22% Si, 0.15% Ni, 0.80% Cr, 0.04% Mo, and 0.30% C in weight percentage. An initial microstructure was homogeneous, fine-grained structure-promotes a rapid, consistent induction hardening response with minimum shape/size distortion and minimum grain growth. It was induction coil hardened and tempered to an average 460 BHN. Hardness test consists of measuring resistance to plastic deformation of layers of metal near the surface of the gear. In the process of hardness determinations when the metal is indented by a special tip (Steel ball) the tip first overcomes the resistance of metal to elastic deformation and then a small amount of plastic deformation. Brinell hardness test is an indentation hardness test using a verified machine to force a hardened steel ball, called indenter, into the surface of the material specimen under test and thus producing an indentation on it.

Results and discussion

Shot peening improves the fatigue and abrasion resistance of metal parts. But it is eventually realized that though the processing appears simple, the shot peening is really a complicated phenomenon and not only concerned with the original residual stress itself. The mechanical properties of surface layer will be altered by shot peening in such a way that both static and cyclic strength are increased or decreased depending upon the material state before shot peening. The present work concentrates only one mechanical property i.e., the increase in hardness due to shot peening. The design matrix is obtained by the combination of variables. A 20 number of experiments are required when full factorial design is selected in the design expert tool. The various factors that have been selected based on the different research papers, standards and as per the specifications of the gears manufacturer are “A”, “B” and “C”. The level and coded variables as chosen are shown in table 1.

Table 1. Shot peening variables and levels

Variables	Coded levels				
	-(α)	-1	0	+1	+(α)
A (Shot diameter), mm	0.48	0.61	0.74	0.87	1.0
B (Projection pressure), bar	2.1	2.5	2.9	3.3	3.7
C (Peening time), s	2.0	3.5	5.0	6.5	8

The table 2 shows the coded and actual value of the variable at each design point. It shows variables A, B, C as input and hardness as output. Prediction of regression equation for BHN was obtained from response surface technology as given in equation (1).

$$BHN = 398 + 75.0\,A + 7.50\,B + 1.00\,C \quad \ldots(1)$$

The model shows that hardness on surface after shot peening is mainly depends upon shot size, followed by projection pressure and peening time. There is least effect of shot exposure time on hardness. No interaction of various terms was found in the model. Fig. 1 shows the effect of various variables on BHN.

Goodness of fit was evaluated from R^2 (Coefficient of Correlation) = 93.40 % and analysis of variance was done in order to check the reliability and precision of the model (Table

3). The model was linear and possesses 3 degrees of freedom.

Table 2. Various variables and hardness

Input			Output
A	B	C	BHN
0.87	3.3	3.5	494
0.87	2.5	3.5	482
0.87	3.3	6.5	492
0.74	2.9	5.0	478
0.74	2.9	5.0	480
0.87	2.5	6.5	490
0.74	2.9	8.0	482
0.74	2.9	5.0	481
1.00	2.9	5.0	502
0.61	3.3	3.5	470
0.61	2.5	3.5	468
0.74	2.1	5.0	474
0.74	2.9	2.0	474
0.74	2.9	5.0	478
0.74	2.9	5.0	484
0.61	3.3	6.5	472
0.48	2.9	5.0	464
0.74	3.7	5.0	488

0.74	2.9	5.0	480
0.61	2.5	6.5	468

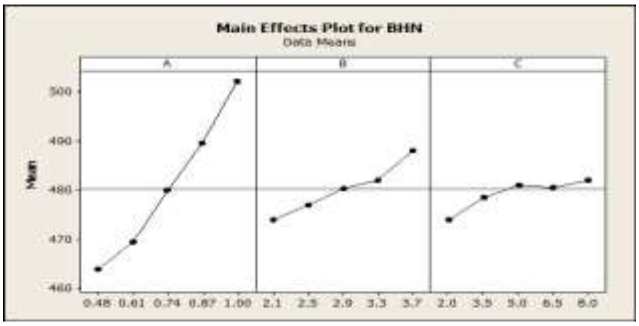

Fig. 1. Main effect of input variable on BHN

Goodness of fit was evaluated from R^2 (Coefficient of Correlation) = 93.40 % and analysis of variance was done in order to check the reliability and precision of the model (Table 3). The model was linear and possesses 3 degrees of freedom. Fig. 2 shows ANNOVA chart for various variables and BHN. The results are in concurrence with data in [9] which verifies the model.

Table 3. ANNOVA for Various variables and hardness

Source	SS	DF	MS	F-value	p-value	R^2	Remarks
Regression	1701	3	567	90.77	0.000	0.934	$F_{0.005,3,16}$=3.24 $F> F_{0.005,3,16}$ Model is adequate
Linear	1701	3	567				
Residual Error	99.65	16	6.25				$F_{(0.005,11,16)}$=2.45 $F< F_{(0.005,11,16)}$ Lack of fit is Insignificant
Lack of fit	75.12	11	6.83	2.87	0.383		
Pure Error	24.83	5	4.97				
Total	1800.95	19					

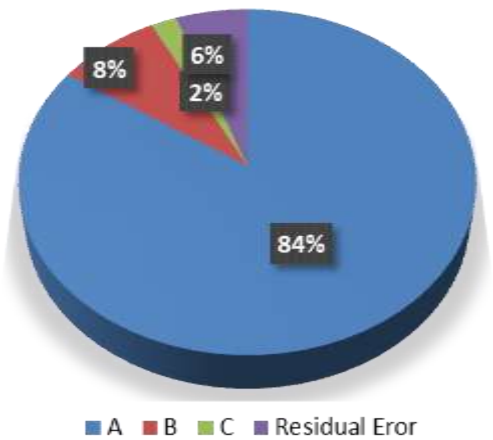

Fig. 2. ANNOVA chart for various variables and BHN

Conclusions

The present work was carried on gear material AISI 5130 with induction hardening and shot peening of the gear. Response surface methodology was used to investigate and analyze the effects of input variables on hardness through shot peening. There is improvement in hardness due to shot peeing of gear. The model shows that hardness on surface after shot peening is mainly depending upon shot size, followed by projection pressure and peening time. There is least effect of shot exposure time on hardness. No interaction of various terms was found in the model.

Conflicts of Interest

Authors declare no conflict of interest

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