An Experimental Investigation on the Effect of Shot Peening on the Tooth Profile, Helix Deviation and Noise Level of Spur Gears

H.Mohassel[1], M.Zehsaz[2], H.Vafadar[1], S.E.Saei[1], H.Zare[1]

1. Applied Researches Unit, R&D Department, Charkheshgar Co., Tabriz, Iran
2. Faculty of Mechanical Engineering, University of Tabriz, Iran

Abstract

This paper investigated the influence of shot peening on the tooth profile, helix deviation and noise level of spur gear. Tooth profile and helix deviation and noise level was obtained by changing the shot size and exposure time. Hence a special CMM apparatus was used for measuring of tooth profile and helix deviation. A special noise and vibration measurement instrument, HARMONIE system, 01dB Metravib, and special gear testing apparatus, HORTH ZP320, were used for the investigation of noise level around an average value of speed of 750 rpm and 100% load condition. The transmission parameters such as backlash, axial clearance, main center distance and run out were controlled during experimental testing. After and before shot peening test gears and counter master gear were engaged each other and sensors including accelerometer and microphone were installed in the sensitive position. The acquired original signals from dBFA software were filtered and processed in MATLAB software. Comparison of experimental results before and after shot peening presented as narrow-band noise level spectrum and as bar graphs of unpeened and the various shot peened state.

Keywords: Shot peening, carburized steel, noise level, tooth profile and helix deviation

Introduction

In an ordinary gearbox the region of tooth contact is a source of vibration and, consequently, noise. [1] sound is generated by excitation in gear teeth meshes and rolling bearings except for sever bearing defects or extreme structure-resonance amplification, gears under loads are the main sources of high-frequency vibration and noise, even in newly built transmission and gearbox system. Gear noise may be divided into two main categories: [2]. The Gear Whine Noise (GWN), as well as the gear rattle noise, is one of the main vibro-acoustic phenomena of gearbox [3].Whine noise that is the purpose of this paper arise from meshing impact; parametrically excited vibration and rolling contact noise arise from gear wheels under loads. These can be reduced by refinement of the gearing parameter design (optimizing the geometry and quality of the toothing) [4]. Gear whine normally manifests itself at gear meshing frequency fg and its harmonics. Gear meshing frequency fg corresponds to the frequency of gear tooth engagement and is given by:

$$fg = \frac{z\Omega}{60} \qquad (1)$$

Where f_g is in Hz, Ω is the shaft rotational speed in rpm and Z is the integer number of gear teeth on the respective gear [2].

Beside, lubrication may be defined as a strategy of controlling friction and wear interposing a solid, liquid and gaseous media between interacting surfaces in relative motion under load. When the contact geometry and operating conditions are such that the load is fully supported by a fluid film, the surface stand completely separated. This is generally referred to as the hydrodynamic lubrication (HL) regime [5]. One considerable advantage of peened surface is that they can induce an element of hydrodynamic lubrication between moving parts [6].The issue of the effect of shot peening on the gear fatigue life is still a subject of interest of many researchers and many works have been published. But few studies have been made, however, on the effect of shot peening on the gears manufacturing accuracy and gear noise level. The present research work has been carried out, by controlled testing, to find out the influence of shot peening on the accuracy of gears according to elemental specifying and measuring system that was performed by computer-controlled inspection equipment and gear noise level.

Experimental Data

Chemical composition (w, %) of this steel is: C: 0.201, Si: 0.244, Mn: 1.170, P: <0.001, S: 0.012, Mo: 0.040, Ni: 0.076, Cr: 1.070. Test gears were spur gear of d_a=235mm, d_f =213.8mm in diameter with involute tooth form. The technical specification of the test gear and counter master gear listed in Table1. At least the experiment was conducted for three times.

Table 1: Technical Specification for the test gears and counter master gear

		Gear	Counter master gear
Module (m_n)		4.75	4.75
Pressure Angle (α_n)		20	20
Number of Teeth (Z)		47	20
Addendum Modification Coefficient (x)	mm	0.39054	0.73258
Center Distance	mm	164	164
Length of path of contact (g_α)		18.07	18.32
Tooth surface finishing		shaving	grounding
Face width	mm	34.70	51
Gear quality		8	9
Hardness	HRC	63	63

After machining, test gears were heat treated in a furnace, RICHELIN (Austria), containing a carbon monoxide atmosphere under the industrial condition. Impeller ejection type of shot peening machine called GUTTMAN (Germany), was used for peening the test gears. Shot peening of test gears was performed by using three shot size of S230, 460 and 660. Experimental conditions on shot peening are shown in Table 2 and 3.

Table 2: Shot Peening condition

Shot Peening Parameters		Condition
Shot type		Cast Steel Shot
r.p.m		1450 r.p.m
Peening angle	deg.	90°
Temperature	°C	30
Coverage	%	98
Projection Velocity	m/s	72

Table 3: Shot peening beads properties

Shot size	Type of beads	Hardness of shot (HV)	Average size (mm)
S230	Shot Steel	Approx. 510	0.6
S460	Shot Steel	Approx. 500	1.18
S660	Shot Steel	Approx. 500	2.0

Result and Discussion:

Table 4 shows the Almen intensity and roughness of peened surface with different shot size and peening time. Prior to shot peening, following standardized procedures and by using type 'A' Almen test strips the saturation curve for shot size (S230, S460) were constructed and based on these curve the peening time selected 100 and 150 sec. Almen intensity at two peening time for three shot size is shown in Figure1. As illustrated, at 150 seconds using the greater size of shots leads to a higher Almen intensity.

Table 4: Peened surface properties

specimen	Shot size	exposure time(sec)	Almen Intensity (A), mm	(R_a)Surface Roughness(μm)
G1	S230	100	0.42	0.91
G2	S460	100	0.74	1.01
G3	S660	100	1.08	1.10
G4	S230	150	0.43	1.00
G5	S460	150	0.85	1.07
G6	S660	150	1.15	1.25
unpeened				0.8

The mean arithmetic deviation of surface (R_a) and mean asperity height (R_z) of tooth flank were measured using a Mitutoyo, Sj.301, roughness tester. The effect of shot peening with different shot size and exposure time on the surface roughness are shown in figure2. The surface roughness data for test gears in figure 2 revealed that surface roughness of shot peened test gears are mostly influenced by the size of shots and peening time. As illustrated, the most significant change was obtained by shot peening with shot size of S660 and exposure time of 150sec. while S230 with the smallest size and exposure time of 100sec exhibits the lower value of increasing at the surface roughness. The test gear G6 exhibits the highest amount of surface roughness while G1 possess the lowest value of surface roughness.

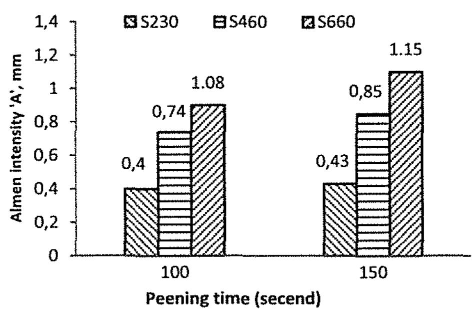

Fig 1: Almen intensity versus peening time for various beads

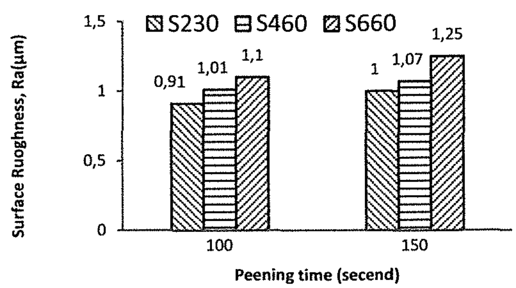

Fig 2: Surface roughness versus peening time for various beads

The tests were performed using a special CMM apparatus, Hofler EMZ420, according to elemental specifying and DIN3961, 3962 part1 and 2. For instance, one of the chosen tooth profile and helix deviation graphs before and after shot peening is presented in figure 3. There are two graphs of the accuracy; one of them (marked with square) is for unpeened test gears (G6). Then the same gears were shot peened and the other gear accuracy graphs (marked with circle) were obtained. Comparison of the two graphs before and after shot peening revealed that these graphs is inside of the tolerances and shot peening has very low impact on tooth alignment.

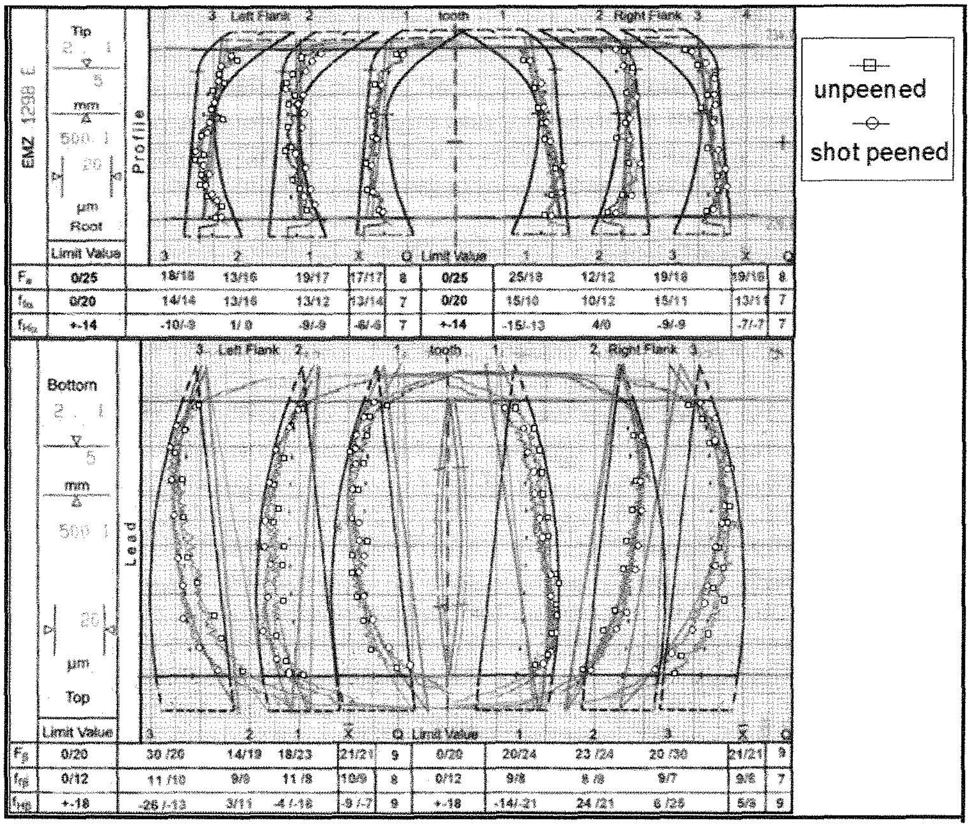

Fig 3: example of the tooth profile and helix deviation graph of G6 test gear. Square mark: un-peened tooth flank, circle mark: shot peened tooth flank

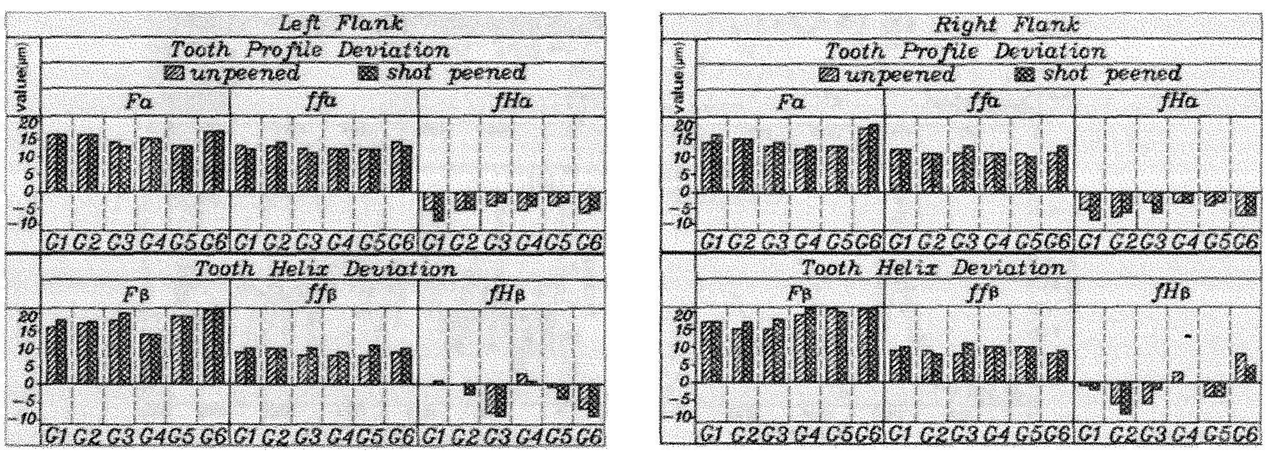

Fig 4: summary of the tooth profile and helix deviation for each of the test gears

Summary of the tooth profile and helix deviation for each of the test gears are presented in figure 4. The analysis and comparison deal with the carburized test gears with profile and helix deviation before and after shot peening were performed. As you can see, the investigation revealed that the influence of shot peening with different shot size on the accuracy of gears were considered negligibly small. This was probably caused by the high hardness of the test gears.

The test gears were clamped between centers and run in mesh with a master gear on time tested machine for noise checks called HÜRTH ZP320. During experimental testing, the transmission parameters such as backlash, axial clearance, main center distance and run out were controlled. For the purpose of determining the effects of shot peening on the noise and vibration level of test gears, measuring has been performed by the application of the HARMONI system, 01dB Metravib at the same point of the same test gears before and after shot peening by constant speed around an average value of 750 revolutions per minutes (rpm). The original signals were acquired in the sensitive position by using a microphone and accelerometer. During the measurement, master gear is driving gear while the test gears are driven and slightly broken in order to ensure constant contact between the cooperating sides of the gears. Some of the chosen results of the analysis of narrow band noise and vibration spectrum (Flattop window with 50% overlap frequency) in Matlab software during the steady state test under 100% load are presented in figure 5. The instrument mode is FFT analysis in the frequency domain. The frequency span is 3KHZ. As illustrated, there are two waves of noise and vibration; one of them (marked with circle) is for un-peened test gears. The same test gears were shot peened with different shot size of S230, 460 and 660 with peening time of 100 and 150 sec. the test were done again and the other waves (marked with x) were recorded. The summary of the noise and vibration level for each of the test gears are presented in figure 6. As can be seen, the amplitude of vibration and also the intensity of noise are decreased after shot peening. One considerable advantage of peened surface is that they can induce an element of hydrodynamic lubrication between moving parts [6], it means that topography of surface obtained by shot peening has characteristic peak and valleys [9]. On the other hand, with due attention to detention of air and lubricant between the teeth is the factor influence the vibro-accoustic emission [10]. For the test gears with the largest amount of valleys on their surface (Table.4), it is expected the detention of air and lubricant to be the highest value between the meshing gears, which reflect the important effect on the noise and vibration level.

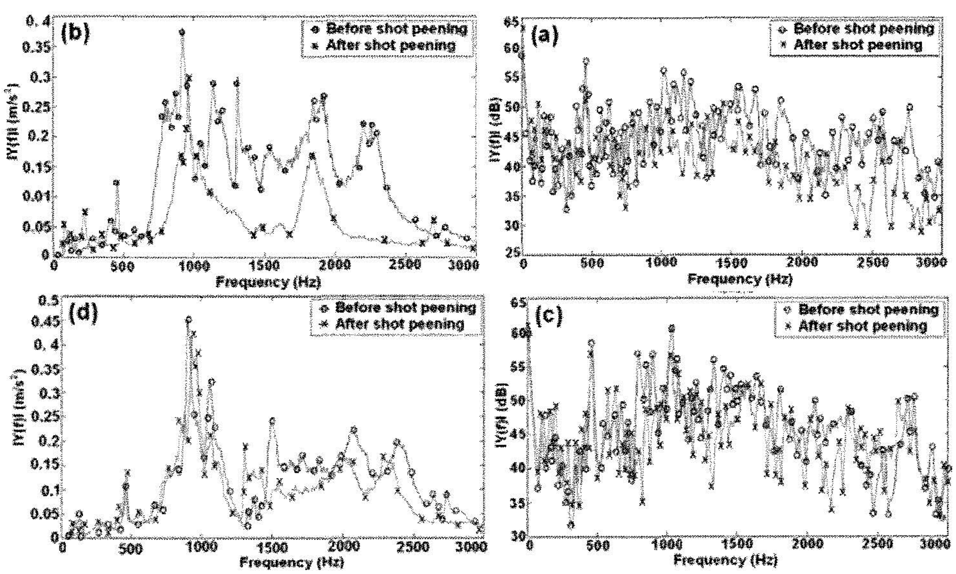

Fig 5: Spectrums of the meshing gears noise and vibrations before and after shot peening for G2 noise b) G2 vibration c) G4 noise and d) G4 vibration spectrum

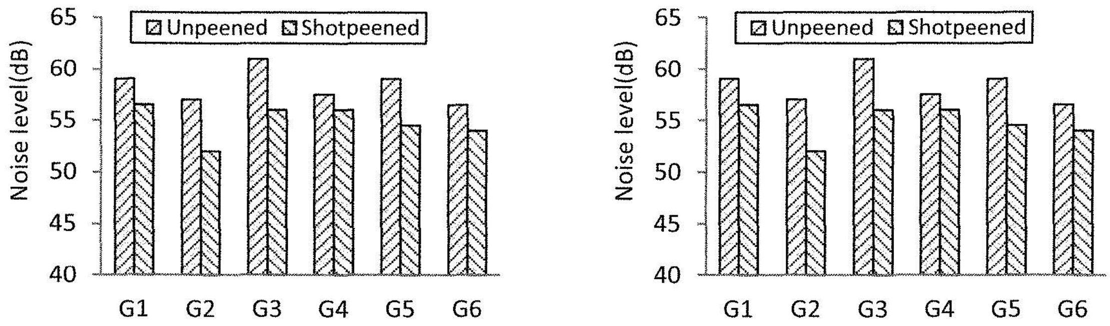

Fig 6: The summary of the noise and vibration level for each of the test gears

Conclusion

From the results obtained it can be concluded that:

1) the amount of surface roughness is increased with the increase of shot size and peening time , for these six test gears, the effect of shot peening on the surface roughness for G6 is at the highest value while for G1 is at the lowest value.
2) Noise level of shot peened test gears G3 and G6, due to the high value of valleys are lower than the other test gears
3) The effect of shot peening with different shot size on the carburized tooth profile and helix deviation is negligible small.

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