Investigating the Effect of Induction Parameters for Optimizing the Heat Treatment of 4620 AISI Steel in the Steering Wheel Pinion

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***Abstract*-This paper presents a new method for optimizing the heat treatment of 4620 AISI steel in the steering wheel pinion. In the first place, the pinion was carburized and quenched in oil at 120 ℃. The second step was stress-relief and temper by induction. Finally, a machining operation was carried out to make thread and spline. According to the standard, the surface hardness of spline should be 37-45 HRC. Meanwhile, the pinion should machine easily to prevent fast-failing of the machining tools. As a result, the mentioned procedure was repeated with different induction parameters. The most important induction parameters for this research were the power of induction and the coil motion speed. The diameter of the thick part of the pinion has a major role in the hardness of spline because of the thickness of the carburized layer after the machining process. Thus, this parameter was included in the experiments too. According to the results, it was found out that by increasing the induction power, the spline surface hardness decreased. In addition, the effect of high speed of coil motion was more than its lower one. This effect increases the hardness of spline surface intensely. Based on these findings, it was concluded that using low power induction, high coil speed and small diameter lead to lower costs, increased speed of the process and good machining ability. This study demonstrated that the proposed technique can be considered more suitable than the existing procedure.**

Keywords- Induction; Pinion; Hardness

I. INTRODUCTION

Extensive production experience has demonstrated the commercial success of induction tempering for many metallurgical applications. The success of induction tempering has been related fundamentally to the possibility of compensating for short tempering times with higher tempering temperatures. Economically, induction tempering has been proven particularly compatible to automation in production lines. Because tempering is performed below the lower transformation temperature 725 ℃, lower-frequency induction tempering installations are used generally. Such installations are necessary for tempering large sections to minimize any temperature gradient from the surface to the interior. Frequency selection is basically related to the required depth of heating. It should be noted that line frequencies (60 Hz) may be used for tempering parts 25 to 50 mm in diameter or larger, because the usual objective of induction tempering is to produce uniform hardness throughout the cross section, rather than to heat the surface. The power density within the inductor is generally low (0.08 to 0.8 W/mm^2). Power densities may be selected on the basis of experience, tests or data. Furthermore, the heating time is comparatively long to help provide uniform heating throughout the part. To meet production requirements, length of the inductor can be increased or more than one bar can be processed at a time. In general, the control of induction tempering is achieved by the selection of the power density and the rate of feed through the coil on the basis of tempered product's hardness tests. Automatic control may be obtained at tempering temperatures above 425 ℃ by the use of a special radiation pyrometer and high-speed controller. This arrangement may be used to vary the speed of the scanning operation continuously or to control the power [1-4].

In this research, induction tempering was done for pinion used in the steering wheel. With movement of the steering wheel by a driver, the torque made by the steering wheel shaft is transferred to the spiral at the end of the shaft. With this movement, the bicorn of the pinion make a revolving movement around its stalk and that movement goes to other parts. The most important parts of the pinion are thread and spline, which are located in the end of the pinion. In the old method, the pinion is carburized and cooled in the furnace. After carburizing, machining operation is done to make thread and spline. Then, the pinion is austenitized and quenched in oil at 120 ℃ .The hardened pinion is stress-relieved at 230 ℃ and tempered by induction to increase toughness of thread and spline. The deficiencies of this method are that it is time-consuming and costly, because there are two austenitizing steps. This method was used in a company to produce pinion. To solve this problem, a new procedure was used in this research. In the suggested technique, one austenitizing step was omitted. In other words, after carburizing, the pinion was quenched in oil at 120 ℃. Then, the pinion was stress-relieved and tempered by induction. After that, a machining operation was done to make the thread and spline. The benefit of this strategy is the decreased time cost of the process. As a result, more pinions can be produced in comparison with the previous tactic during the same time, and with this new method, energy also can be saved by omitting one austenitizing step.

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II. EXPERIMENTAL PROCEDURE

The pinion was made of AISI 4620 steel. The chemical composition of AISI 4620 steel is given in Table 1.

TABLE 1 CHEMICAL COMPOSITION OF AISI 4620 STEEL, IN WT. % [2]

Elements	%C	%Si	%Mn	%Cr	%Mo	%Cu	%Ni	%P & %S
Wt.%	0.17-0.23	0.15-0.35	0.55-0.90	0.85-1.25	0.15-0.35	0.30	0.25	<0.03

The raw pinion was prepared by forging. It is shown in Fig. 1.

Fig. 1 The raw pinion

The end of the raw pinion was machined in two ways, cylindrical and conical. This part would be heat treated. These two models are shown in Fig. 2.

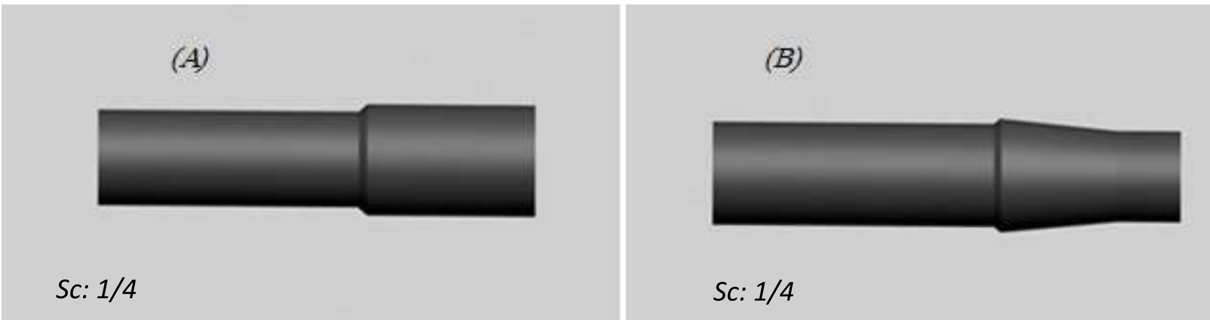

Fig. 2 Two machining ways (A) cylindrical (B) conical

Then, the raw pinion was carburized at 900 ℃ and quenched in oil at 120 ℃. Next, the pinion was stress-relieved and tempered by induction. Only the end parts of the pinion were induced. The pinion was firm and the coil was moved from upper position to the end of it. There are two parameters affecting the induction. One is the power of induction and the other is the speed of coil motion. After that, a machining operation was done to make the thread and spline. The surface hardness of spline should be 37-45 HRC. Meanwhile, it should have good machine ability. Thus, the mentioned process was repeated with different induction parameters. Another important parameter was the diameter of the pinion's thick part. That was the part that would be machined. This item was varied in the tests. The details of the tests are shown in Table 2.

TABLE 2 DETAILS OF TESTS

Numbers	Speed of coil(mm/sec)	Power	Maximum diameter of the thin part of pinion	Machining way
1	11	15%	24.5	cylindrical
2	11	15%	24.85	cylindrical
3	11	15%	25.2	cylindrical
4	11	20%	24.5	cylindrical
5	11	12%	24.5	cylindrical
6	11	15%	24.5	cylindrical

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7	15	20%	24.5	cylindrical
8	14	15%	24.5	cylindrical
9	11	15%	23	conical
10	11	15%	23.5	conical
11	11	15%	24	conical
12	11	17%	23	conical
13	11	17%	23.5	conical
14	11	17%	24	conical

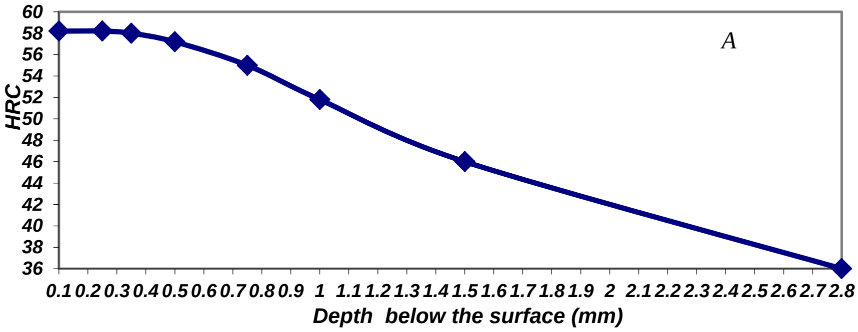
Then, the surface hardness of pinions was measured by universal surface hardness instrument (UV1).

III. RESULTS AND DISCUSSION

In order to check the characteristics of the new pinions, the mentioned parameters were investigated:

A. Surface Hardness of the Stalk of Pinions

In comparison with the pinions produced with old method, the stalk of the new pinions should have the hardness between 58 and 62 HRC. Fig. 3 shows the hardness diagrams of the stalks of new and old pinions.



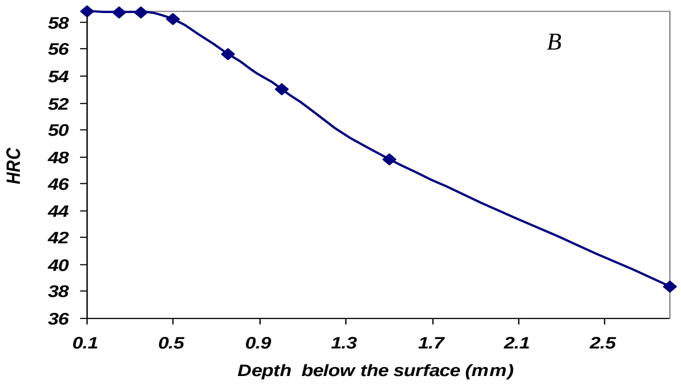


Fig. 3 A) Hardness diagram of stalk produced with old method. B) Hardness diagram of stalk produced with new method

As the diagrams show, this new method provides efficient hardness of the stalk of pinion.

In the old procedure, the pinion is only cylindrically machined. In this study, the pinions were first heat treated by the new method and the induction parameters were investigated. The first item was the power of induction. For tempering the pinion, the part was immobile and the coil was moving longitudinally. Thus, the speed of coil motion was another important parameter. After induction, the pinions were machined. Therefore, another important thing was the diameter of the part to be machined. The pinion should have good machining ability. Thus, this parameter was investigated for this way of machining too.

B. The Effect of the Diameter of the Thin Part of Pinion on the Surface Hardness of Cylindrically Machined Spline

To investigate this effect, tests No. 1, 2 and 3 were carried out. Fig. 4 shows the average surface hardness of spline as a function of diameter.

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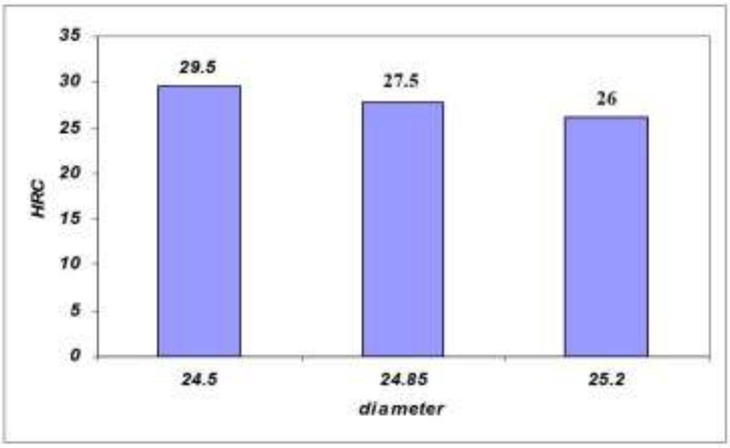

Fig. 4 Surface hardness of spline as a function of diameter for tests No. 1, 2 and 3

As seen in Fig. 4, with increasing diameter of the pinion's thick part, the surface hardness of the spline decreases. The reason was that when the diameter was bigger, more machining operations should be done to reach the suitable diameter. Thus, the carburized area was omitted and the hardness was decreased. So the pinions with smaller diameter were more appropriate.

C. Effect of the Power of Induction on the Surface Hardness of Cylindrically Machined Pinions

The tests No. 4, 5 and 6 were chosen to investigate this effect. Fig. 5 shows the average surface hardness of spline as a function of power of induction.

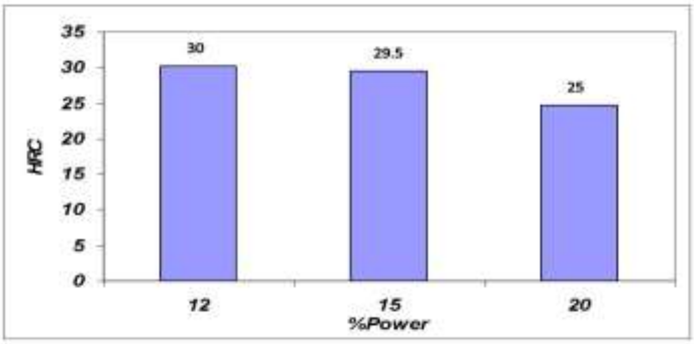

Fig. 5 Surface hardness of spline as a function of %power for tests No. 4, 5 and 6

It is obvious that when the power of induction increases, the induction temperature of the pinion would become higher. Tempering of hardened steel structures involves diffusion of carbon atoms to form iron carbide (Fe_3C or cementite) [5]. The extent of diffusion increases with both increasing temperatures and time. Thus high-temperature treatment leads to lower hardness. Fig. 5 demonstrates this phenomenon.

D. Effect of Coil Motion Speed on the Surface Hardness of Cylindrically Machined Pinions

With tests No. 4, 6, 7 and 8, this effect was explored. Fig. 6 and Fig. 7 show the average surface hardness of spline as a function of velocity. It is shown in Fig. 6 that increasing coil motion speed increases the surface hardness of spline. It is because of the decrease of the time of induction. As a result, the heat decreases and the part could not reach the appropriate hardness.

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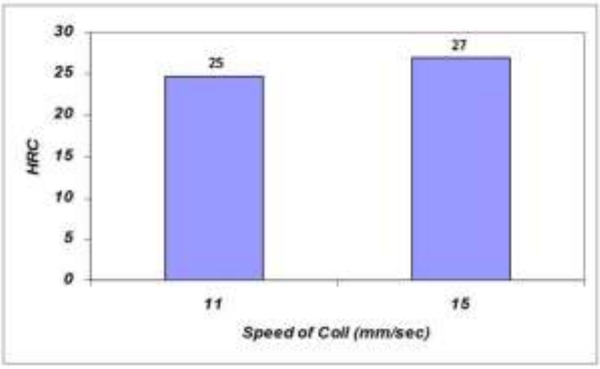

Fig. 6 Surface hardness of spline as a function of coil motion speed for tests No. 4 and 7

Another issue investigated was the influence of power on hardness changes of pinion surface. Comparison between Fig. 6 and Fig. 7 shows that the effect of changing coil motion speed on surface hardness of spline is more obvious at 20% of induction power.

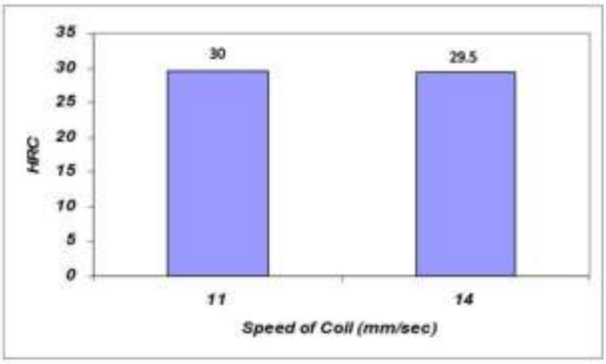

Fig. 7 Surface hardness of spline as a function of coil speed for tests No. 6 and 8

The surface hardness of spline should be between 35 HRC and 45 HRC. However, in cylindrical way this hardness is impracticable. It is because of the elimination of most part of the hardened layer in machining. To solve this problem the conical way of machining was chosen. Thus, the elimination of the hardened layer was minor. This phenomenon is shown in Figs. 8 and 9.

Fig. 8 the omitting of the carburized layer in cylindrically machining A) after machining, B) before machining

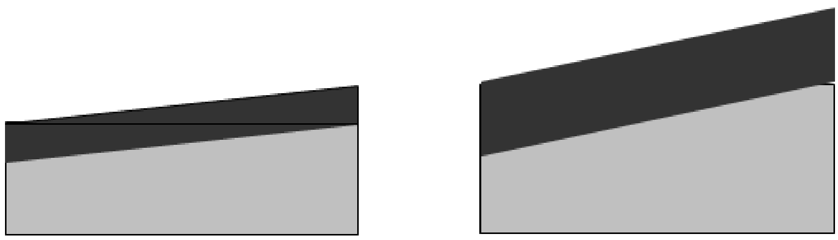

Fig. 9 the minor omitting of the carburized layer in conically machining A) after machining, B) before machining

Therefore, the parameters were investigated in this way of machining.

E. The Effect of the Diameter of the Thin Part of Pinion on the Surface Hardness of Conically Machined Pinions

Fig. 10 shows the average surface hardness of spline as a function of diameter.

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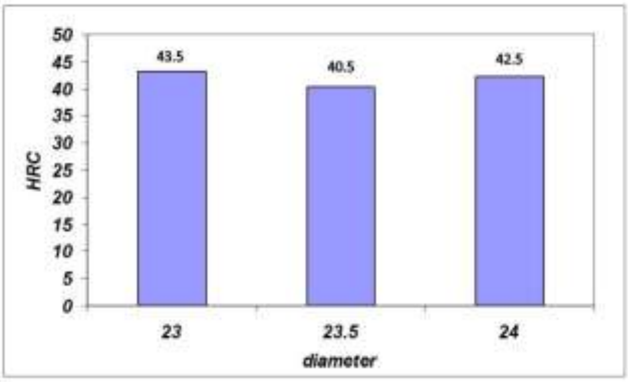

Fig. 10 Surface hardness of spline as a function of diameter for tests No. 9, 10 and 11

As seen in Fig. 10, the surface hardness does not show a uniform increasing or decreasing behavior. However, the hardness is within the standard range and it is close to the upper limit. Thus, the machining operation was becoming hard. To solve this problem these tests were repeated with 17% induction power. Fig. 11 shows these results.

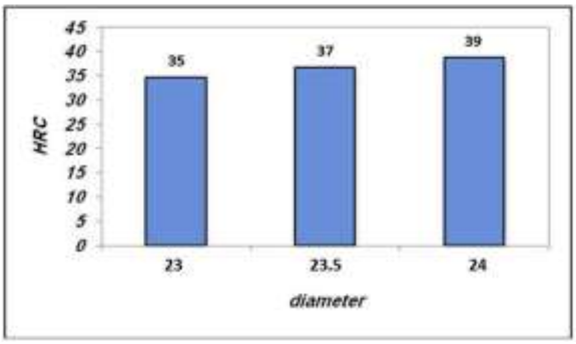

Fig. 11 Surface hardness of spline as a function of diameter for tests No. 12, 13 and 14

It is obvious that the surface hardness was in the standard range and was close to the lower limit. Thus, these pinions had better machining ability.

F. Microstructural Analyzes

The microstructures of the pinions produced with the old and new methods were almost the same. In the old method, the pinion is carburized at 880 ˚C and cooled in the furnace. After that, machining operation is done to make the thread and spline. Then, the pinion is austenitized at 880 ˚C and quenched in oil at 120 ℃ .The hardened pinion is stress-relieved at 230 ℃ and tempered by induction to increase toughness of thread and spline. However, in new procedure, after carburizing at the same temperature, the pinion is quenched in oil at 120 ℃. Then, the pinion is stress-relieved and tempered by induction. After that, a machining operation is done to make the thread and spline. As shown in Fig. 12, both microstructures are tempered martensite.

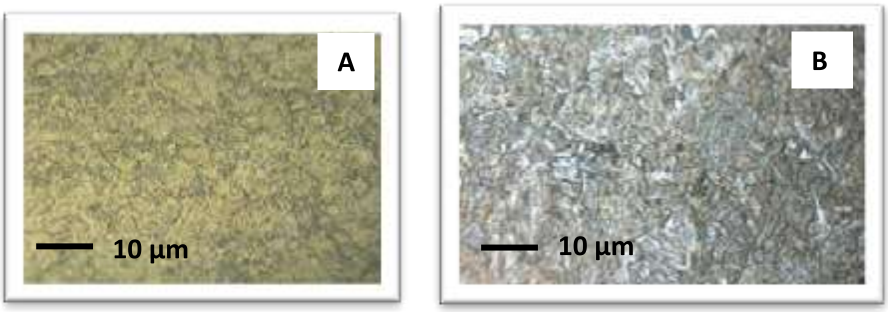

Fig. 12 A) Microstructure of the pinion produced with old method B) Microstructure of the pinion produced with new method

IV. CONCLUSIONS

In this study, a new method for optimizing the heat treatment of 4620 AISI steel in the steering wheel pinion was investigated. In this new technique, the pinion is carburized and quenched in oil at 120 ℃. Then, it is stress-relieved and tempered by induction. After that, a machining operation to make the thread and spline is performed. The following results were obtained from the tests:

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1) Increasing the power of induction led to increasing heat and decreasing hardness of spline surface.
2) High speed of the coil motion increased the hardness of spline surface.
3) Using low power induction, coil high speed, and low diameter of the pinion's thick part resulted in decreasing costs, increasing speed of process, and good machine ability.
4) The pinions cylindrically machined have low hardness because of the elimination of the most carburized layer after induction. Thus, the conical way was chosen to machine the pinions and the problem was solved.
5) 23.5 mm was the suitable diameter of the thin part for conically machined pinions.
6) 11 $^{mm}/_{s}$ coil speed and 17% power of induction system were optimized parameters for this new method.

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