# Application of Taguchi Methodology in Selection of Process Parameters For Induction Hardening Of EN8 D Steel

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***ABSTRACT:*** *In this paper, Taguchi method is applied for selection of best working parameters for induction hardening of EN8 D steel. A orthogonal array L9, Signal to Noise ratio, analysis of variance (ANOVA) are applied to study, performance characteristics of induction hardening process. Hardness, case depth , has been considered as performance characteristics. An analysis of variance (ANOVA) of response variables shows a significant influence of process variable power , heating time. The experimental results shows that the predicted regression models suggested could describe the performance characteristics within the limits of the factors being investigated. The results have been verified by confirmation tests.*

***Keywords:*** *Anova , Induction Hardening, Orthogonal array, Regression models, Signal to noise ratio, Taguchi method.*

## I. INTRODUCTION

Economic globalization and rapid and continuous appearing of new technologies, mobilized organizations to obtain the maximum degrees of competitiveness, high quality products in short time in order to ensure their survival and growth in the market. In this scenario, organizations started to look for quality not only in their products but also in its production processes. Many surface hardening (strengthening) treatments are required corresponding variations in physical, chemical and mechanical properties, and re-arrangements of atoms in metals and their alloys . An induction hardening is one of the important treatment among them . Induction hardening process have found ever-increasing applications to improve the performance and life of the parts used in automobile engineering. Thin surface layers i.e 0.25 to 2.3 mm of the work piece made of steel can be hardened by this process. Y.Totic ,R.Sadeler,H.Altum investigated the effects of heating time, feed rate and temperature on wear characteristics of AISI 4140 steel in induction hardening process.[13] Julie.K, Timothy James.[12] studied the effect of feed rate and gap between coil and work piece, quench distance and part temperature by using design of experiment neural network optimization technique on induction hardening process and reported a significant improvement in the process. R Kolleck, R.Veit[7] focused on reduction of processes cycle time, rising energy, costs eco friendly process and need of new heating technologies in hardening process and proposes the inductive heating alternative methodology for boron alloyed steel. Robert Cryderman , Nima Sham Saei, Al Fatemi [9] In this paper study investigates the influences of induction hardened parts produced from steel bars. Resit Unal, Edwin B.Dean[8] In this paper authors were presented the overview of the Taguchi method its steps involved and state that , it is a systematic and efficient approach for determining the optimum experimental configuration of design parameters for performance, quality and cost. Principal benefits include considerable resource savings determination of important factors affecting operation, performance and cost, and quantitative recommendations for design parameters which achieve lowest cost, high quality solutions. In this paper, best working parameters are selected for generation of desired hardness values and pattern in EN8 D steel, by using Taguchi method. Because Taguchi method showed to be a very useful in process improvement provide confident information about influence of factors on a response variable and less number of experiments than traditional method to improve the process while not compromising the desired goals.[3] Taguchi method based design of experiments has been used to study the effects of two process parameters i.e. power and traverse speed.(scanning speed) on important output parameters . Taguchi approach provides a new experimental strategy in which a modified and standardized form of design of experiment (DOE) is used. This technique helps to study effect of many factors (variables) on the desired quality characteristic most economically. By studying the effect of individual factors on the results, the best factor combination can be determined [6] . Taguchi designs experiments using specially constructed tables known as “orthogonal array” (OA). The use of these tables makes the design of experiments very easy and consistent and it requires relatively lesser number of experimental trials to study the entire parameter space. As a result, time, cost, and labour saving can be achieved. The experimental results are then transformed into a signal-to-noise (S/N) ratio. Taguchi recommends the use of the S/N ratio to measure the quality characteristics deviating from the desired values. Usually, there are three categories of quality characteristic in the analysis of the S/N ratio, i.e. The-lower-the-better, the-higher-the-better, and the nominal-the-better. The S/N ratio for each level of process parameters is computed based on the S/N analysis. Regardless of the category of the quality characteristic, a greater S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of the process parameters is the level with the greatest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. With the S/N and ANOVA analyses, the optimal combination of the process parameters can be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design. [10]

## II. EXPERIMENTAL PROCEDURE.

### 2.1 . Experimental apparatus

High frequency induction hardening machine (40 kw, 200khz) make sanket power systems has been used for the performing the experiments . A source of high frequency of electricity is used to drive a large alternating current through a copper coil. The passage of a current through this coil generates a intense and rapidly changing magnetic field in the space within the work coil. The work piece to be heated is placed within this magnetic field where eddy current is generated within the work piece and resistance leads to heating of work piece. The core of the work piece remains unaffected by this process . Induction hardening temperature was above 850 ºC .

### 2.2 Work piece material

Fig. 1a : case study shaft

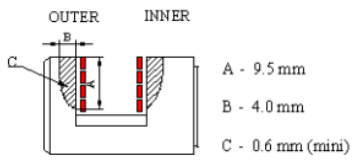


Fig. 1 b :detailed view of slot

The automobile shaft i.e. selector and shifting shaft was selected for study. The work piece material used for present study was EN8 D steel. Its composition was 0.40% Carbon, 0.22% Silicon, 0.71% Manganese , 0.02% Sulphur , and 0.024% Phosphorus . Material conforms to BS 970(1955) for EN8 D steel. This material is suitable for variety of automotive components such as axle, crank shaft, spline shafts and gears etc. The length of work piece is 177 and diameter 19mm respectively. The static induction hardening has been performed on the slot portion of work piece.

### 2.3 Experimental plan.

In this investigation two factors at three levels have been studied. Factors and their levels are shown in table 1 . The
factors and levels are selected on the basis of literature review and their range were finalized after pilot runs.[11]

Table 1 : process parameters and their levels

| Symbol | Process parameters | Level I | Level II | Level III |
|---|---|---|---|---|
| P | Power (kw) | 10 | 12 | 14 |
| T | Heating time (sec) | 02 | 03 | 04 |

The values of factors of induction hardening process were utilized for conducting design of experiments in induction hardening machine for EN8 D steel. The response variables to be investigated were hardness HRc, and its developed pattern i.e. case depth , Based on available in put parameters and their levels an orthogonal array lay out is designed for Taguchi method by using soft ware MINITAB .

Table-2 – Process Parameters and their levels

| Exp. Runs | Power | Heat time | Hardness | Case depth(mm) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Outer | | | Inner | | |
| No | kw | sec | HRc | V | T | C | V | T | C |
| 1 | 10 | 02 | 55 | 8.70 | 2.0 | 0.4 | 8.75 | 2.2 | 0.5 |
| 2 | 10 | 03 | 56 | 8.75 | 2.3 | 0.5 | 8.85 | 2.4 | 0.6 |
| 3 | 10 | 04 | 57 | 9.20 | 2.5 | 0.8 | 9.25 | 2.7 | 0.9 |
| 4 | 12 | 02 | 57 | 9.00 | 2.2 | 0.5 | 9.05 | 2.3 | 0.6 |
| 5 | 12 | 03 | 57 | 9.20 | 2.4 | 0.9 | 9.25 | 2.8 | 0.7 |
| 6 | 12 | 04 | 58 | 9.45 | 3.3 | 1.5 | 9.50 | 3.6 | 1.6 |
| 7 | 14 | 02 | 58 | 9.00 | 3.0 | 1.0 | 9.10 | 3.2 | 1.1 |
| 8 | 14 | 03 | 58 | 9.35 | 3.2 | 1.3 | 9.30 | 3.5 | 1.4 |
| 9 | 14 | 04 | 60 | 9.60 | 4.0 | 1.8 | 9.50 | 3.9 | 1.8 |

V- Vertical , T - Top, C – Centre

### 2.4 Experimental technique

As shown in table 2 nine experiments are conducted. Each experiment is conducted for three times to reduces the errors. Hardness was measured by Rockwell hardness testing machine for C scale at 150 kg load, having diamond indenter at 120 degrees . While automatic Vickers's hardness testing machine is used to measure case depth achieved at various locations.

## III. RESULTS AND DISCUSSIONS

The mean of three experimental values of each run is mentioned in the table 2 further analysis of results were carried by using software MINITAB.

### 3.1 Analysis of variance (ANOVA)

The ANOVA tables has been used to investigate and test for significance of design parameters. It indicates which parameters are significantly affecting the output parameters. In the analysis the sum of squares and variance are calculated . F-test values at 95% confidence level is used to decide the significant factors affecting the process and percentage contribution. Since the p values are less than 0.05 and larger F values indicates that these factors have statically significant effects on the performance . The ANOVA analysis for response are shown in table 3.

Table 3: ANOVA results and percentage contribution for responses.[2][5]

| | | | | | |
|---|---|---|---|---|---|
| | | | | 0 | 9 |
| Heating time | 2 | 0.80222 | 0.401111 | 11.65 | 43.704 |
| Error | 4 | 0.13778 | 0.034444 | | 7.507 |
| Total | 8 | 1.83556 | | | 100 |
| S = 0.1856 R-Sq = 92.49% R-Sq(adj) = 84.99% | | | | | |
| All F-ratios are based on the residual mean square error. | | | | | |

| Source | DF | SS | MS | F | % contribution |
|---|---|---|---|---|---|
| For Hardness | | | | | |
| Power | 2 | 10.6667 | 5.33333 | 32.00 | 66.667 |
| Heating time | 2 | 4.6667 | 2.33333 | 14.00 | 29.167 |
| Error | 4 | 0.6667 | 0.16667 | | 4.166 |
| Total | 8 | 16.0000 | | | 100 |
| S = 0.4082 R-Sq = 95.83% R-Sq(adj) = 91.67% | | | | | |
| For Case depth | | | | | |
| Outer vertical | | | | | |
| Power | 2 | 0.317222 | 0.158611 | 20.39 | 42.171 |
| Heating time | 2 | 0.403889 | 0.201944 | 25.96 | 53.693 |
| Error | 4 | 0.031111 | 0.007778 | | 4.136 |
| Total | 8 | 0.752222 | | | 100 |
| S = 0.08819 R-Sq = 95.86% R-Sq(adj) = 91.73% | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Outer top | | | | | |
| Power | 2 | 2.00667 | 1.00333 | 24.08 | 59.369 |
| Heating time | 2 | 1.20667 | 0.60333 | 14.48 | 35.700 |
| Error | 4 | 0.16667 | 0.04167 | | 4.931 |
| Total | 8 | 3.38000 | | | 100 |
| S = 0.2041 R-Sq = 95.07% R-Sq(adj) = 90.14% | | | | | |
| Outer centre | | | | | |
| Power | 2 | 0.96000 | 0.480000 | 20.57 | 51.064 |
| Heating time | 2 | 0.82667 | 0.413333 | 17.71 | 43.972 |
| Error | 4 | 0.09333 | 0.023333 | | 4.964 |
| Total | 8 | 1.88000 | | | 100 |
| S = 0.1528 R-Sq = 95.04% R-Sq(adj) = 90.07% | | | | | |
| Power | 2 | 0.215000 | 0.107500 | 32.250 | 41.747 |
| Heating time | 2 | 0.286667 | 0.143333 | 43.000 | 55.663 |
| Error | 4 | 0.013333 | 0.003333 | | 2.590 |
| Total | 8 | 0.515000 | | | 100 |
| S = 0.05774 R-Sq = 97.41% R-Sq(adj) = 94.82% | | | | | |
| Inner top | | | | | |
| Power | 2 | 1.82889 | 0.914444 | 20.57 | 59.724 |
| Heating time | 2 | 1.05556 | 0.527778 | 11.87 | 34.470 |
| Error | 4 | 0.17778 | 0.044444 | | 5.806 |
| Total | 8 | 3.06222 | | | 100 |
| S = 0.2108 R-Sq = 94.19% R-Sq(adj) = 88.39% | | | | | |
| Inner centre | | | | | |
| Power | 2 | 0.89556 | 0.447778 | 13.0 | 48.78 |

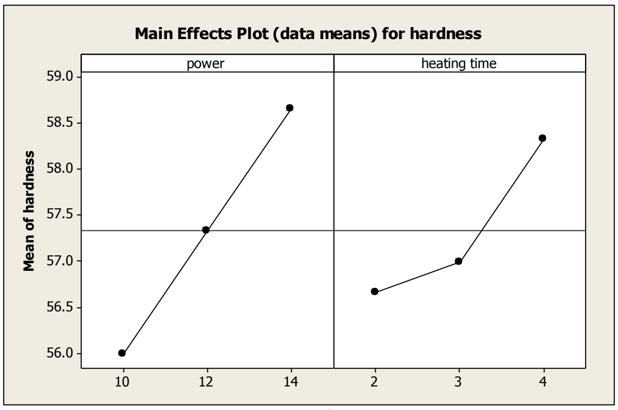

Fig. 2 a : plot for hardness

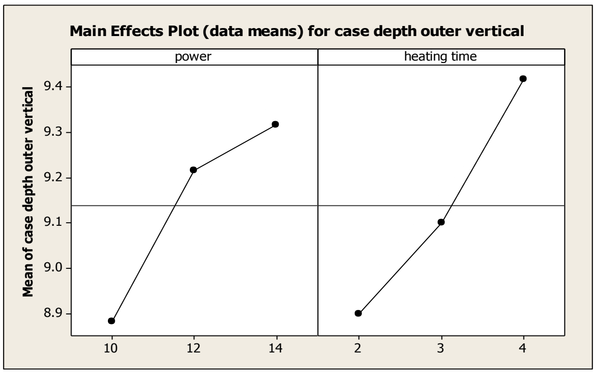

Fig. 2 b: plot for case depth outer vertical

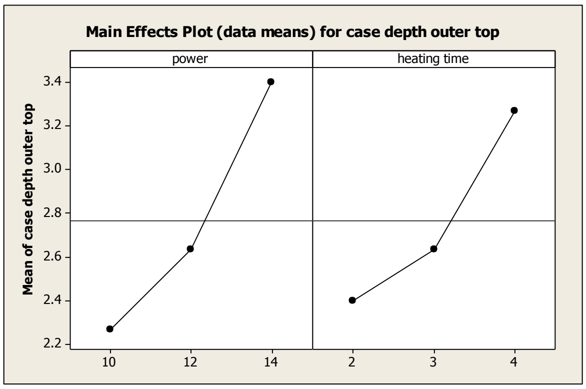

Fig. 2 c : plot for outer top

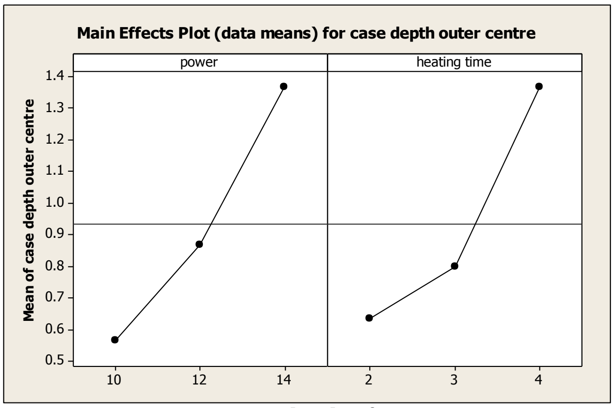


Fig. 2 d : plot for outer centre

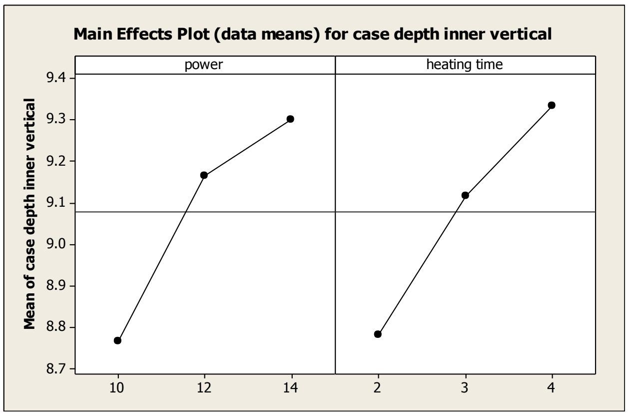


Fig. 2 e : plot for case depth inner vertical

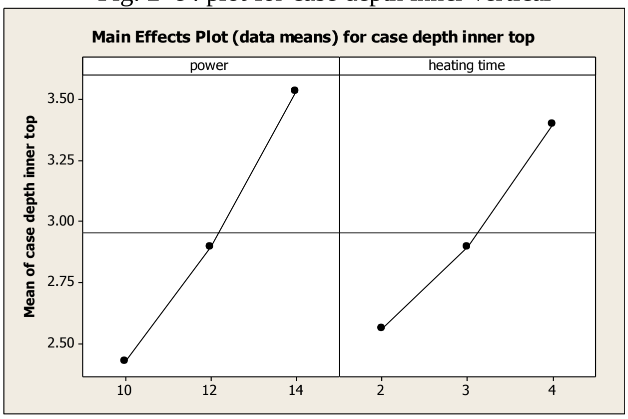


Fig. 2 f: plot for case depth inner top

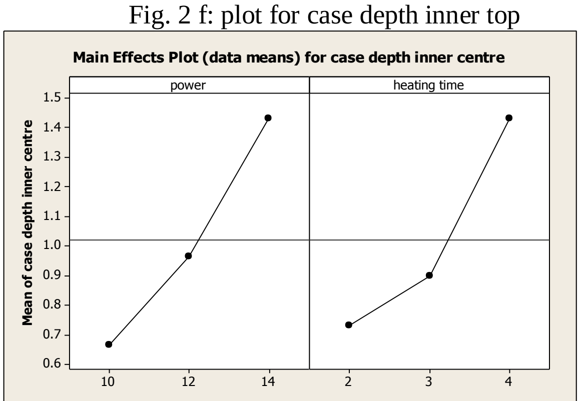


Fig. 2 g: plot for case depth inner centre

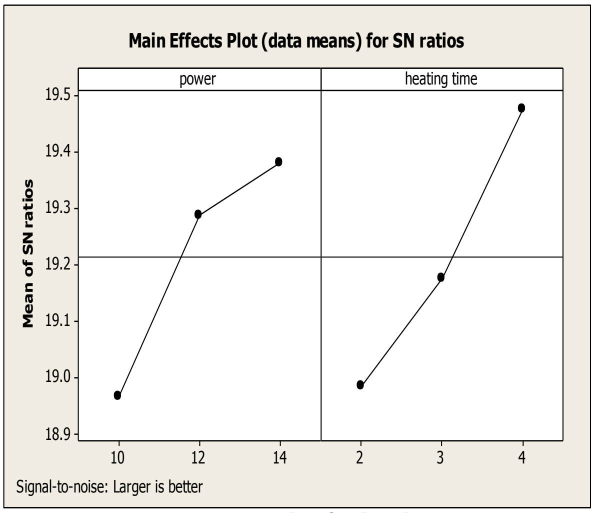


Fig. 3 a : plot for hardness

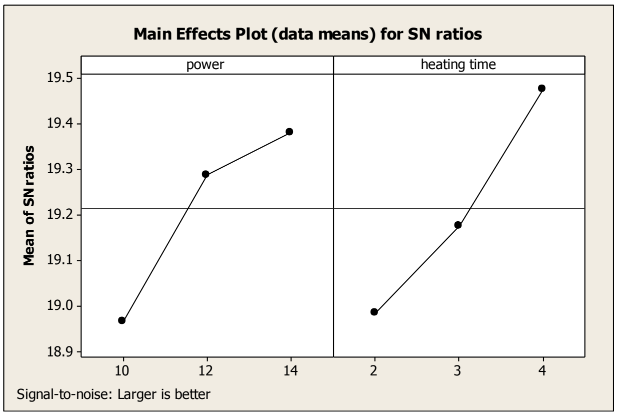


Fig. 3 b: plot for case depth outer vertical

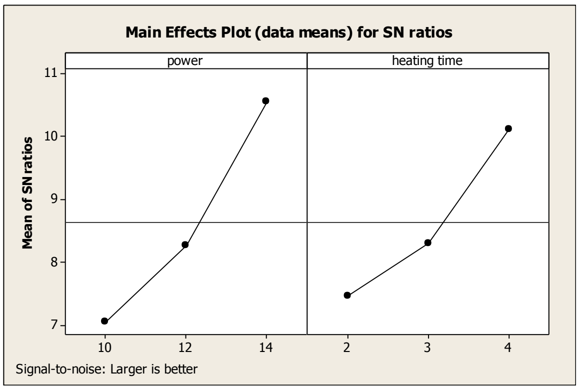


Fig. 3 c : plot for outer top

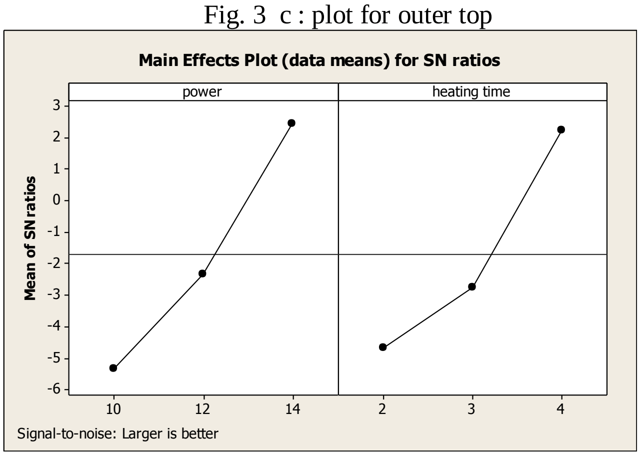

Fig. 3 d : plot for outer centre

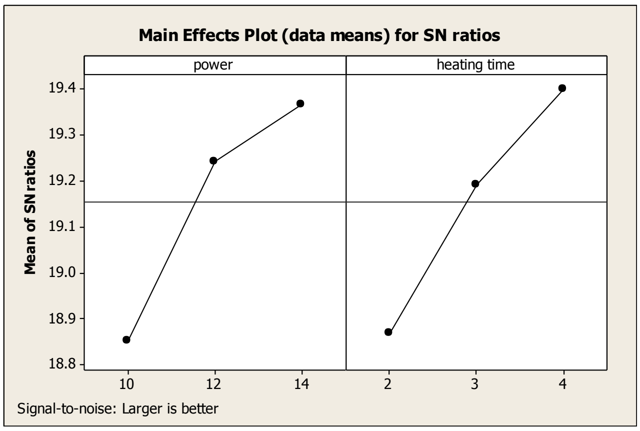


Fig. 3 e : plot for case depth inner vertical

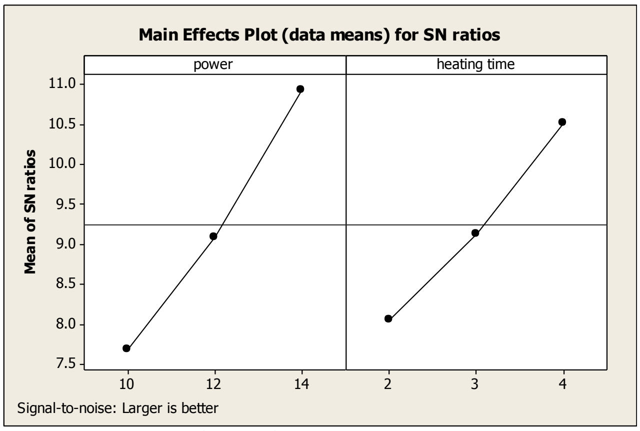


Fig. 3 f: plot for case depth inner top

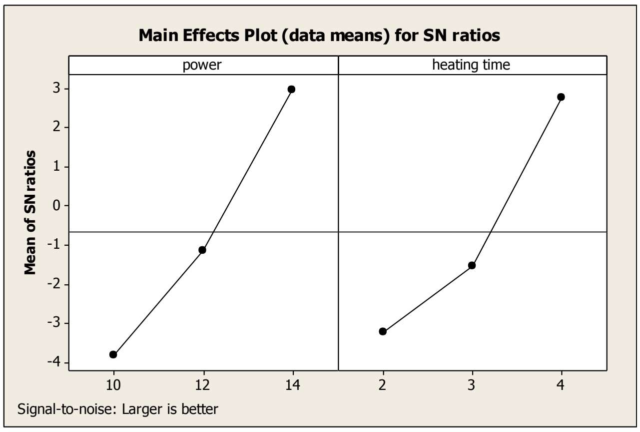


Fig. 3 g: plot for case depth inner centre

Figure 2a and 2b-2g shows main effects plot (data means) of mean for hardness and case depth at various locations i.e. outer vertical , top , centre and inner vertical , top, centre respectively . Figure 3 a – 3g shows S/N ratio graphs for hardness and corresponding case depth. Where the horizontal line is the value of total mean of S/N ratio. Basically larger the S/N ratio better is the quality characteristics for process. As per the S/N ratio analysis from the graphs the levels of parameter to be set getting optimum values of hardness and case depth are P3-T3 i.e. 14kw-4sec According to ANOVA analysis as shown in the table 3 most effective parameter with respect to hardness and case depth is power . It is also observed that in outer vertical and inner vertical case depth pattern achievement heating time plays a important role. The analysis of graphs and ANOVA results clearly indicates that increase in power and heating time increases hardness and corresponding case depth at various locations of work piece . Table 4: Significance of induction hardening parameters for hardness and case depths.

| Process parameter | Mean S/N ratio | | | Significance of induction hardening parameter |
|---|---|---|---|---|
| | Level 1 | Level II | Level III | Max-Min |
| Hardness | | | | |
| P | 34.96 | 35.17 | 35.37 | 0.41 |
| T | 35.06 | 35.12 | 35.32 | 0.25 |
| Case depth | | | | |
| Outer top | | | | |
| P | 7.071 | 8.274 | 10.262 | 3.491 |
| T | 7.470 | 8.310 | 10.123 | 2.653 |
| Outer centre | | | | |
| P | -5.306 | -2.312 | 2.461 | 7.767 |
| T | -4.660 | -2.726 | 2.230 | 6.889 |
| Inner centre | | | | |
| P | -3.791 | -1.151 | 2.952 | 6.743 |
| T | -3.210 | -1.537 | 2.758 | 5.967 |
| Outer vertical | | | | |
| P | 18.97 | 19.31 | 19.38 | 0.41 |
| T | 18.99 | 19.19 | 19.48 | 0.49 |
| Inner vertical | | | | |
| P | 19.03 | 19.34 | 19.37 | 0.33 |
| T | 19.05 | 19.21 | 19.48 | 0.41 |

Significance of induction hardening parameters (difference between max and min values) indicates that power is significantly contributing towards the induction hardening performance as difference gives higher values only in case depth outer vertical and case depth inner vertical time was more influential from above study finds that optimized levels of parameters are P3-T3 i.e. 14 kw-4 sec.

**Confirmation test-**

After identifying the best levels of process parameters, a new experiment was designed and conducted with predicted levels of process parameters optimum parameters found are P-14kw, T-4 sec, comparison between estimated values and confirmation test value shows a small difference between these values. These values correlate each other. This indicates that ANOVA results are closely match with the Taguchi results.[1]

## IV. REGRESSION MODEL.

Multiple linear regression equations were modelled for relationship between process parameters i.e. power and heating time to evaluate hardness and case depths for any combination of factor levels in a range specified model for multiple regression equation is

$$y = \beta_0 + \beta_1 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \text{------} + \beta_p x_p + \varepsilon \quad (1)$$

Where $y$ is dependent parameter, $x_1, x_2, x_3 \ldots x_p$ are independent parameters , β are regression parameters and ε is residue.[3]

The regression coefficients have been obtained by using experimental data. The regression equations for response characteristics as a function of two parameters of the material EN8 D steel considered in this experiment are given below. The insignificant coefficients identified from ANOVA have been omitted from equations for various responses . In this case, regression equations are formulated in terms of parameters i.e. power and heating time by using MINITAB software.

The regression model equations for response in terms of power and heating time are given as below

- Hardness = 46.8 + 0.667 Power + 0.833 Heating time (2)
- Case depth outer vertical = 7.07 + 0.108 Power + 0.258 Heating time (3.1)
- Case depth outer top = -1.93 + 0.283 Power + 0.433 Heating time (3.2)
- Case depth outer centre = -2.53 + 0.200 Power + 0.367 Heating time (3.3)
- Case depth inner vertical = 7.45 + 0.0875 Power + 0.225 Heating time (3.4)
- Case depth inner top = -1.59 + 0.257 Power + 0.417 Heating time (3.5)
- Case depth inner centre = -2.33 + 0.192 Power + 0.350 Heating time (3.6)
-

**Confirmation for regression equations**

Expected values given by models of hardness and case depth at various locations are obtained in any combination of factor levels as specified in table 2 . Percentage variation estimated for this equation 2 for hardness in range of 0.055% to 3.161 %. Where as for the regression equations 3.1 to 3.6 case depth at various locations i.e. outer vertical , top, centre as well as inner vertical , top , centre are calculated as 0.001% to 14.1% . These results obtained by regression equations closely co relate with each other which validated the regression equations developed . Thus the developed equations can be used to predict hardness and case depth values at different locations such as outer vertical , top , centre and inner vertical top and centre respectively for any combination of factor levels in the specified range[2].

## V. CONCLUSION.

Taguchi method of experimental design with L9 orthogonal array has been applied for selection of optimum process parameters of induction hardening of EN8 D steel. The experimental investigation shows the effects of process parameters such as power, heating time on hardness and case depth pattern achieved on work piece. The optimum parameters found are 14 kw power and heating time 4 sec. power is the most influential parameter. Further multiple regression equations are formulated for estimating predicted values of hardness and case depths at various locations such as case depths at outer & inner vertical, top and centre portion of slots for a specified range. The results obtained by regression equations closely co relate each other which validates the regression equation developed.

## VI. ACKNOWLEDGMENT.

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