Sleeve synchronizer induction hardening process parameter optimization For better hardness and case depth using Taguchi, Grey Relational Analysis and RABAL Algorithm – a Practical Investigation

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Abstract- In the global competitive environment it is mandatory to operate all the manufacturing process optimally to stay competitive. Auto industries random growth, in particular, calls for lots of intricate special processes with higher quality requirement. Selection of optimization technique is also crucial, as trials are consuming cost and time and selection of process parameters, levels and experimentation methods are crucial to achieve results right first time. Sleeve synchronizer, a critical part used in manual transmissions for power shifting of first second gear. Induction hardening is one of the critical special processes involved in sleeve synchroniser manufacturing, where hardness and effective case depth are the important parameters need to be optimized simultaneously. Optimization of Sleeve synchronizer induction hardening is critical, as hardness and effective case depth cannot be checked 100% in real time environment, as effective case depth checking involves destructive testing. This research uses Taguchi parameter design coupled with grey relational analysis for simultaneous optimization of parameters for better hardness and effective case depth and it uses RABAL Algorithm to achieve results right first time. Experiments are conducted based on Taguchi $L_{27}2^{13}$ Orthogonal array, which reduces the number of trial runs from 1594323 to 27. Grey relational analysis in this research is used to convert multi objectives, hardness and effective case depth in to single grey relational grade, which is further optimized using Taguchi parameter Design. Essential care through RABAL algorithm is taken and required optimization is achieved right first time.

Keywords: Orthogonal Array, Sleeve synchronizer, Induction Hardening, Grey relational Analysis, Taguchi Parameter Design, RABAL Algorithm.

I.INTRODUCTION

Nowadays, some of the steel parts have been applied induction hardening for better mechanical properties in the automotive and aerospace industry sectors. Induction hardening is commonly used in steels, are high magnetic permeability.

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Martensite formation was observed application as a result of non-diffusion transformation after induction hardening. [1]. The Sleeve Synchronizer is a part used in Automobile manual transmissions, having critical manufacturing operations such as forging, Broaching, Spline rolling, V-chamfering, Key way milling, Hobbing, Deburring, Shaving, Carburizing, Induction hardening and Groove hard turning.

Main purpose of Sleeve synchronizer is to power shifting of second gear and first gear in Manual transmissions. If the Sleeve synchronizer is shifted backward by shift lever and fork, the first gear is engaged to the output shaft through the Hub. When the Sleeve synchronizer is shifted forward by shift lever and fork, the second gear is engaged to the output shaft through the hub [2]. Induction hardening is one of the critical operations in sleeve synchronizer manufacturing, as the hardness and effective case depth are related with functionality and durability of the product.

Many researchers have done extensive study in induction hardening. Kochure and Nabdukar applied Taguchi method 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 [3]. Sergeant et al. presents a method for designing optimal passive and active shields for axisymmetric induction heaters. Such shields are needed to protect human operators and external electronic equipment from stray magnetic fields. The method uses a genetic algorithm (GA) to minimize an objective function [4]. Phuong Xuan Dang used process parameter optimization method for energy efficiency in induction heating process [5]. Lynn Ferguson et al. studied the stress and deformation of tubular products during induction hardening [6]. Most of The research are not considered real time factors and not done at real time environment. It is essential for a research to either replicate the real time environment or the research has to be carried out at real time environment. In this sleeve synchronizer induction hardening, simultaneous optimization of parameters for better hardness and case depth is carried out in real time environment using Taguchi and grey relational analysis (TGRA). TGRA is successfully used by many researchers for simultaneous optimization [7, 8, 9, 10, 11 & 12]. Most of the research uses only lesser number of process parameters in optimization problems [13, 14, 15, 16 & 17], where as real time problems involve more number of factors with quadratic relationship between the factors and

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response variable. Factor allocation in the problems involving more number of process parameters is crucial in Taguchi parameter design, as confounding problem may happen. It is better to use RABAL Algorithm for better factor allocation and achieve results of Taguchi Parameter design in right first time.

Experimental conditions

Sleeve synchronizer Induction hardening in carried out in HFI (HFT-01) induction hardening machine with specification of 100 KW 50 KHz - 50KW 10KHz.

Figure 1 Induction Hardening Machine

Figure 1 shows the induction hardening machine used for induction hardening of Sleeve synchronizer where heating is done at two stages followed by quenching, plug insertion, quenching during plug insertion, quenching during plug insertion and finally washing. After induction hardening it is essential to maintain major diameter, minor diameter and Inner ball diameter with in specification that will be ensured during plug insertion and plug quenching. As no deformation is ensured in sleeve synchronizer, Hardness and its case depth are the important response variables need to be optimized simultaneously.

Induction Hardening Factors and Level selection

Based on brain storming and machine manufacturer data, thirteen factors are selected with three levels for the research to identify the quadratic relationship between factors and response variable. Table 1 represents the factors and its levels

Table 1 Induction Hardening Factors and its levels

Process parameters	Unit	L 1	L 2	L 3
1st Heat Delay time (A)	Seconds	0.4	0.5	0.6
1st Heating Time (B)	Seconds	7.8	8	8.2
1st Heating Voltage (C)	Volts	333	335	337
2nd Heat Delay time (D)	Seconds	2.8	3	3.2
2nd Heating Time (E)	Seconds	6.8	7	7.2
2nd Heating Voltage (F)	Volts	258	260	262
Quenching Flow (G)	Seconds	90	95	100
Quenching time (H)	Seconds	11	12	13
Plug Time (J)	Seconds	2.5	3	3.5
Plug Quench time (K)	Seconds	2.5	3	3.5
Quench Air time (L)	Seconds	4	5	6
Washing time (M)	Seconds	4	5	6
Washing Air time (N)	Seconds	3	4	5

Based on thirteen factors at three levels, $L_{27}3^{13}$ orthogonal array is selected for the study. Instead of conducting 3^{13} experiments, it is sufficient to conduct only 27 experiments by L27 orthogonal array in Taguchi method to derive the results. As Taguchi method uses very minimal number of experiments it is mandatory to ensure basic principles of experimentation such as randomization, replication and local control throughout the experimentation. Table 2 shown below indicates the specification values for the identified response variables and measurement method

Table 2 Induction hardening response variables

Response variables	Specification		
	Max	Min	Range
Hardness	65 HRC	58 HRC	7 HRC
Case Depth	0.6	0.4	0.20 (550 HV min)

Hardness values are checked using Rockwell Hardness tester Digital of mitutoya make. Both the quality characteristics are of nominal the best type. Basic principles of experimentation replication is followed, for both the cases of hardness and case depth two replicates are used to identify the variability within the process. Experiments are randomized throughout the experimentation and total 54 experiments are carried out in completely randomized manner. Polymer concentration, type of coil used, distance between the coil & work and type of plug used (type and dimensions of plug is important to ensure no deformation on inner major and minor diameters as shown in Figure 2) are maintained as constant as a local control measure in the experimentation.

Figure 2 – Sleeve synchronizer Inner diameter

Figure 3 – Sleeve synchronizer Outer diameter

Figure 3 shows the clear outer view of sleeve synchronizer induction hardening of teeth area is important to increase the strength and improve the life of the sleeve synchronizer.

Table 3 – Sleeve Synchronizer Induction Hardening Experimental Results

Trial No	A	B	C	D	E	F	G	H	J	K	L	M	N	Hardness		ECD	
														S 1	S 2	S 1	S 2
1	0.4	7.8	333	2.8	6.8	258	90	11	2.5	2.5	4	4	3	64	63.7	0.54	0.53
2	0.4	7.8	333	2.8	7	260	95	12	3	3	5	5	4	63	62.9	0.51	0.51
3	0.4	7.8	333	2.8	7.2	262	100	13	3.5	3.5	6	6	5	63.4	64.3	0.54	0.53
4	0.4	8	335	3	6.8	258	90	12	3	3	6	6	5	64	63.6	0.51	0.51
5	0.4	8	335	3	7	260	95	13	3.5	3.5	4	4	3	65.7	63.8	0.54	0.53
6	0.4	8	335	3	7.2	262	100	11	2.5	2.5	5	5	4	66.4	66.2	0.5	0.51
7	0.4	8.2	337	3.2	6.8	258	90	13	3.5	3.5	5	5	4	64.7	64.6	0.57	0.573
8	0.4	8.2	337	3.2	7	260	95	11	2.5	2.5	6	6	5	66.2	66.3	0.52	0.53
9	0.4	8.2	337	3.2	7.2	262	100	12	3	3	4	4	3	66.4	65.3	0.6	0.61
10	0.5	7.8	335	3.2	6.8	260	100	11	3	3.5	4	5	5	64.8	62.1	0.47	0.476
11	0.5	7.8	335	3.2	7	262	90	12	3.5	2.5	5	6	3	64	64.7	0.49	0.5
12	0.5	7.8	335	3.2	7.2	258	95	13	2.5	3	6	4	4	63.9	64	0.49	0.48
13	0.5	8	337	2.8	6.8	260	100	12	3.5	2.5	6	4	4	63.8	64	0.49	0.49
14	0.5	8	337	2.8	7	262	90	13	2.5	3	4	5	5	63.4	64.7	0.5	0.503
15	0.5	8	337	2.8	7.2	258	95	11	3	3.5	5	6	3	63.9	64.9	0.47	0.47
16	0.5	8.2	333	3	6.8	260	100	13	2.5	3	5	6	3	63.4	65	0.57	0.57
17	0.5	8.2	333	3	7	262	90	11	3	3.5	6	4	4	64	64.3	0.47	0.47
18	0.5	8.2	333	3	7.2	258	95	12	3.5	2.5	4	5	5	62.9	62.2	0.5	0.51
19	0.6	7.8	337	3	6.8	262	95	11	3.5	3	4	6	4	65.2	64.7	0.49	0.5
20	0.6	7.8	337	3	7	258	100	12	2.5	3.5	5	4	5	63.6	65.2	0.49	0.49
21	0.6	7.8	337	3	7.2	260	90	13	3	2.5	6	5	3	65.2	65.8	0.5	0.51
22	0.6	8	333	3.2	6.8	262	95	12	2.5	3.5	6	5	3	64.5	64.8	0.52	0.53
23	0.6	8	333	3.2	7	258	100	13	3	2.5	4	6	4	63.4	63.2	0.51	0.51
24	0.6	8	333	3.2	7.2	260	90	11	3.5	3	5	4	5	64.4	62.8	0.53	0.53
25	0.6	8.2	335	2.8	6.8	262	95	13	3	2.5	5	4	5	64	63.6	0.54	0.53
26	0.6	8.2	335	2.8	7	258	100	11	3.5	3	6	5	3	63.3	62.9	0.51	0.51
27	0.6	8.2	335	2.8	7.2	260	90	12	2.5	3.5	4	6	4	63.6	62.3	0.49	0.5

27 trials are conducted with two replicates (Actually 54 numbers of trials) and Hardness in HRC and case depth in mm values are tabulated. It is essential to do simultaneous optimization for both hardness and case depth as both the parameters are equally important. But hardness values are in the range of 62.2 HRC to 66.6 HRC but case depth values will be in the range of 0.47mm to 0.574mm. it is important to commonise the range of hardness and case depth to a common value and further weighted average can be taken as a single value so that simultaneous optimization can be proceeded easily. Grey relational analysis is a 5 step methodology which converts multi objective function problems in to single objective function problems in a similar fashion.

In Grey relational analysis, Loss function of individual responses is normalized to a same measurement unit to form grey relational coefficients. After assigning weight to individual grey relational coefficients, Weighted grey relational grade is identified, which is a single value can be optimized easily as single objective function problem using Taguchi design it.

Step 1: Normalization of Loss Function

Step 2: Determination of Deviation sequences

Step 3: Calculate Grey relational coefficient

Step 4: Determination of weighted Grey relational grade

Step 5: Determination of optimum parameters

The weighted grey relational grade calculated for each sequence is taken as a single response optimization problem for further analysis which can be easily carried out using Taguchi method. TGRA is successfully utilized and proved by researchers in processes such as EDM [18], milling of Aluminium [19], Metal inert gas welding [20], flat plate heat sink [21] and micro EDM [22]. Hardness and Effective case depth values are changed to the range of 0.33 to 0.1 (a common range) as indicated in the table 4. For hardness 75% weightage is given and 25% weightage is given for effective case depth due to less variability observed in effective case depth.

Table 4 – Sleeve synchronizer induction hardening – Grey relational analysis results

Trial No	Hardness		Loss fn	Max - Xi	1-N	Min+ZMax	ECD		Loss fn	Max - Xi	1-N	Min+ZMax	Weighted Grey rel Grade
	S 1	S 2		Range		Xi+Zmax	S 1	S 2		Range		Xi+Zmax	
1	64	63.7	11.09	0.802	0.198	0.716	0.54	0.53	0.00250	0.8873	0.1127	0.816	0.74
2	63	62.9	4.21	0.960	0.040	0.925	0.51	0.51	0.00020	0.9914	0.0086	0.983	0.94
3	63.4	64.3	11.45	0.794	0.206	0.708	0.54	0.53	0.00250	0.8873	0.1127	0.816	0.74
4	64	63.6	10.66	0.812	0.188	0.727	0.51	0.51	0.00020	0.9914	0.0086	0.983	0.79
5	65.7	63.8	22.93	0.531	0.469	0.516	0.54	0.53	0.00250	0.8873	0.1127	0.816	0.59
6	66.4	66.2	46.1	0.000	1.000	0.333	0.5	0.51	0.00010	0.9959	0.0041	0.992	0.50
7	64.7	64.6	19.85	0.601	0.399	0.556	0.57	0.573	0.01023	0.5374	0.4626	0.519	0.55
8	66.2	66.3	45.13	0.022	0.978	0.338	0.52	0.53	0.00130	0.9416	0.0584	0.895	0.48
9	66.4	65.3	38.45	0.175	0.825	0.377	0.6	0.61	0.02210	0.0000	1.0000	0.333	0.37
10	64.8	62.1	11.25	0.798	0.202	0.713	0.47	0.476	0.00148	0.9336	0.0664	0.883	0.76
11	64	64.7	16.49	0.678	0.322	0.609	0.49	0.5	0.00010	0.9959	0.0041	0.992	0.70
12	63.9	64	12.01	0.781	0.219	0.695	0.49	0.48	0.00050	0.9778	0.0222	0.958	0.76
13	63.8	64	11.54	0.792	0.208	0.706	0.49	0.49	0.00020	0.9914	0.0086	0.983	0.78
14	63.4	64.7	13.85	0.739	0.261	0.657	0.5	0.503	0.00001	1.0000	0.0000	1.000	0.74
15	63.9	64.9	17.32	0.659	0.341	0.595	0.47	0.47	0.00180	0.9190	0.0810	0.861	0.66
16	63.4	65	15.86	0.693	0.307	0.619	0.57	0.57	0.00980	0.5568	0.4432	0.530	0.60
17	64	64.3	14.09	0.733	0.267	0.652	0.47	0.47	0.00180	0.9190	0.0810	0.861	0.70
18	62.9	62.2	2.45	1.000	0.000	1.000	0.5	0.51	0.00010	0.9959	0.0041	0.992	1.00
19	65.2	64.7	23.93	0.508	0.492	0.504	0.49	0.5	0.00010	0.9959	0.0041	0.992	0.63
20	63.6	65.2	18.1	0.641	0.359	0.582	0.49	0.49	0.00020	0.9914	0.0086	0.983	0.68
21	65.2	65.8	32.18	0.319	0.681	0.423	0.5	0.51	0.00010	0.9959	0.0041	0.992	0.57
22	64.5	64.8	19.89	0.600	0.400	0.556	0.52	0.53	0.00130	0.9416	0.0584	0.895	0.64
23	63.4	63.2	6.5	0.907	0.093	0.843	0.51	0.51	0.00020	0.9914	0.0086	0.983	0.88
24	64.4	62.8	10.1	0.825	0.175	0.740	0.53	0.53	0.00180	0.9190	0.0810	0.861	0.77
25	64	63.6	10.66	0.812	0.188	0.727	0.54	0.53	0.00250	0.8873	0.1127	0.816	0.75
26	63.3	62.9	5.2	0.937	0.063	0.888	0.51	0.51	0.00020	0.9914	0.0086	0.983	0.91
27	63.6	62.3	5.05	0.940	0.060	0.894	0.49	0.5	0.00010	0.9959	0.0041	0.992	0.92
		Max	46.100	0.000	1	1.000		Max	0.02210	1.056	1.00	1.000	
		Min	2.450	1.000	0.000	0.333		Min	0.00001	1.056	0.00	0.333	
		Range	43.650	1.000	1	0.667		Range	0.02209	0.001	1.00	0.667	

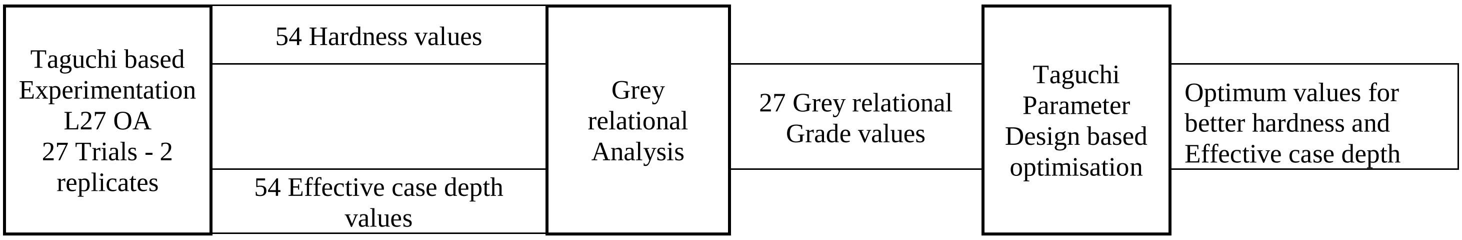

Figure 4 – Taguchi and Grey relational Analysis optimization model – Sleeve synchronizer induction hardening

Figure 4 clearly explains that how TGRA model works in sleeve synchronizer induction hardening experiment. Trials are conducted based on Taguchi based $L_{27}3^{13}$ Orthogonal array with two replicates in total 54 number of trials and response values of hardness and effective case depth values are noted. Hardness and ECD values are converted in to single grey relational grade using Grey relational analysis and is further optimized using Taguchi PDE.

Table 5 – Response table for Sleeve synchronizer Induction Hardening

Param	1st Heat Delay time (A)	1st Heating Time (B)	1st Heating Voltage (C)	2nd Heat Delay time (D)	2nd Heating Time (E)	2nd Heating Voltage (F)	Quench Flow (G)	Quench time (H)	Plug Time (J)	Plug Quench time (K)	Quench Air time (L)	Wash'g time (M)	Wash'g Air time (N)
L 1	0.63	0.72	0.78	0.8	0.69	0.77	0.72	0.68	0.67	0.71	0.74	0.68	0.64
L 2	0.74	0.71	0.74	0.67	0.74	0.71	0.72	0.76	0.71	0.72	0.68	0.73	0.74
L 3	0.75	0.7	0.6	0.66	0.7	0.63	0.69	0.69	0.74	0.69	0.71	0.71	0.74
Delta	0.12	0.02	0.18	0.14	0.05	0.14	0.03	0.07	0.07	0.03	0.06	0.05	0.1
Rank	4	13	1	2	9	2	11	6	6	11	8	9	5

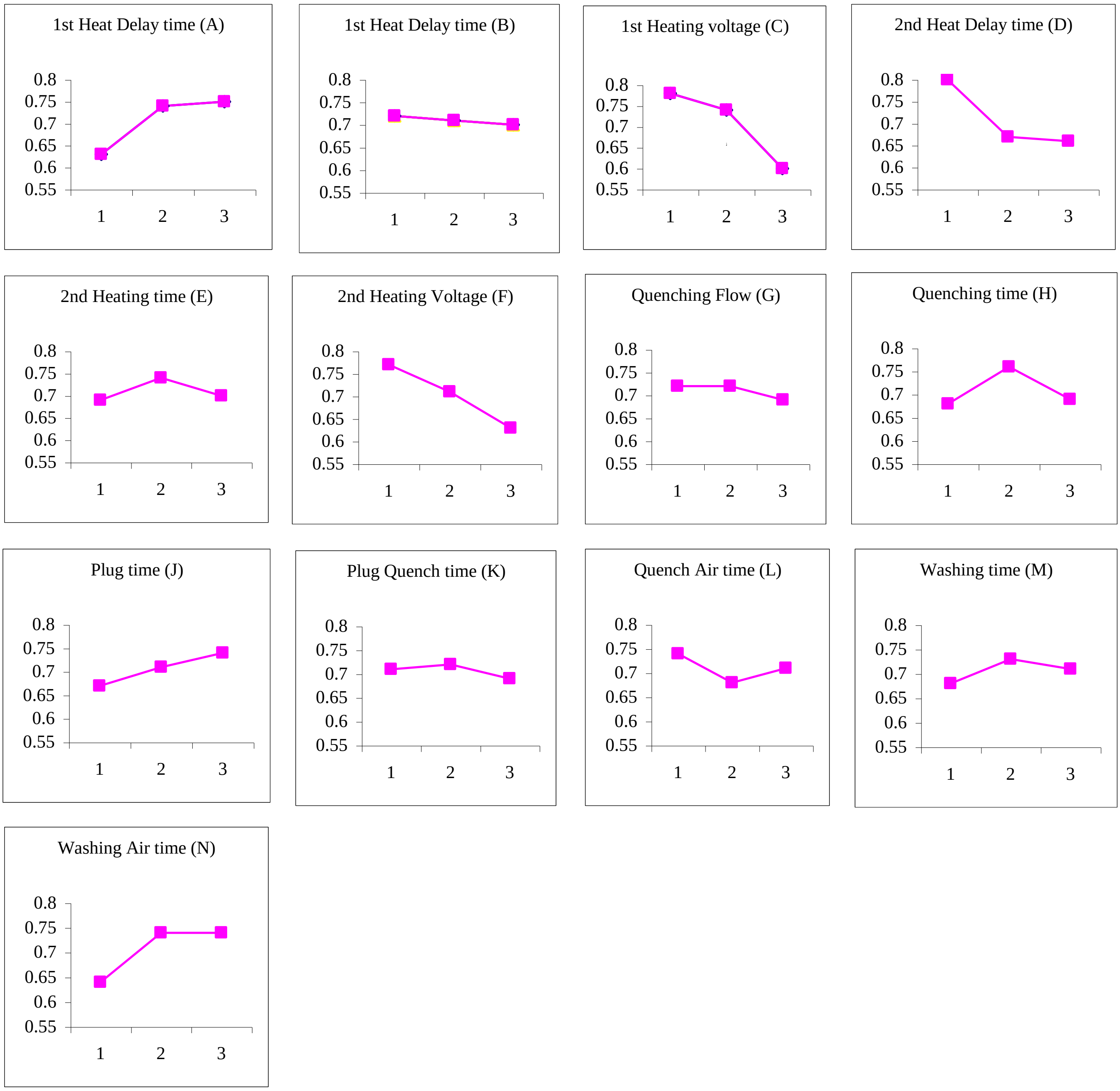

Figure 5 – Response Graph Sleeve synchronizer induction hardening Experiment

Table 6 – Optimum parametric combination sleeve synchronizer Induction hardening experiment

Param	1st Heat Delay time (A)	1st Heating Time (B)	1st Heating Voltage (C)	2nd Heat Delay time (D)	2nd Heating Time (E)	2nd Heating Voltage (F)	Quench Flow (G)	Quench time (H)	Plug Time (J)	Plug Quench time (K)	Quench Air time (L)	Wash'g time (M)	Wash'g Air time (N)
Optimum Levels	3	1	1	1	2	1	1	2	3	2	1	2	2

Table 7 – Confirmation Test results

Parameters	value	Hardness in HRC			Case Depth in mm		
1st Heat Delay time (A)	0.6	61.5 HRC	62 HRC	62 HRC	0.5 mm	0.5 mm	0.5 mm
1st Heating Time (B)	7.8						
1st Heating Voltage (C)	333						
2nd Heat Delay time (D)	2.8						
2nd Heating Time (E)	7						
2nd Heating Voltage (F)	258						
Quench Flow (G)	90						
Quench time (H)	12						
Plug Time (J)	3.5						
Plug Quench time (K)	3						
Quench Air time (L)	4						
Washing time (M)	5						
Washing Air time (N)	4						

Conclusion - Sleeve synchronizer induction hardening process is successfully optimized using Taguchi and Grey relational analysis. Optimum levels for all controllable factors are identified and Identified parametric combination is confirmed through confirmation tests. Experiments are conducted based on Taguchi $L_{27}2^{13}$ Orthogonal array, which reduces the number of trial runs from 1594323 to 27. Factor allocation was done as suggested by RABAL algorithm, hence the required results are achieved right first time in Taguchi parameter design

References

[1] Mert Onan, H Ibrahim unal, Kasim Banyal and Furkan Katre, Optimization of induction hardened AISI 1040 steel by experimental design method and material characterization analysis, Proceedings of the ASME 2012 International Mechanical Engineering Congress & Exposition IMECE 2012 November 9-15, 2012.

[2] Rajarasalnath S, Balasubramanian K, Rajeswari N, Optimization of Process parameters in Sleeve Synchronizer Groove turning (Hard turning) for better surface finish and Productivity using TGRA – A Practical Investigation , International Journal of Applied engineering research, Vol. 9, No. 24, pp. 27243-27254, 2014.

[3]P.G. Kocure, K.N Nandurkar, Application of Taguchi Methodology in Selection of Process Parameters For Induction Hardening Of EN8 D Steel, International Journal of Modern Engineering Research (IJMER) www.ijmer.com Vol.2, No.5, pp-3736-3742, 2012.

[4]Peter L. Sergeant, Luc R. Dupré, Marc De Wulf, Jan A. A. Melkebeek, Optimizing Active and Passive Magnetic Shields in Induction Heating by a Genetic Algorithm, IEEE Transactions on magnetics, Vol. 39, No. 6, pp. 3486-3496, 2003.

[5] Phuong-Xuan Dang, Improving the energy efficiency by process parameter optimization approach: a case study for induction heating, International Journal of Renewable Energy and Environmental Engineering, Vol. 01, No. 01, pp. 12 – 16, 2013.

[6]B. Lynn Ferguson, Z. (Charlie) Li, Valentin Nemkov, Robert Goldstein, Stress and Deformation during Induction Hardening of Tubular Products, Quenching Control and Distortion, Proceedings from the 6th International Quenching and Control of Distortion Conference, September 9–13, pp. 34 – 46, 2012.

[7] Natarajan N, Arunachalam RM, Optimization of micro-EDM with multiple performance characteristics using Taguchi method and Grey relational analysis, Journal of Scientific & Industrial Research, Vol. 70, No. 7, pp. 500-505, 2011.

[8] RajuShrihari P, Suhas S Joshi, Multi-objective optimization of surface roughness and cutting forces in high-speed turning of Inconel 718 using Taguchi grey relational analysis (TGRA), International journal of advanced manufacturing Technology, vol. 56, No. 1, pp. 47-62, 2011.

[9] Raghuraman S, Thiruppathi K, Panneerselvam T, Santosh S, Optimization of EDM parameters using Taguchi method and Grey relational analysis for mild steel IS 2026, international journal of innovative research in science, engineering and technology, Vol. 2, No. 7, pp. 3095 – 3105, 2013.

[10] Muthuramalingam T,

Mohan B, Taguchi – grey relational analysis based multi objective optimization of electrical process parameters in Electrical discharge machining, Indian Journal of Engineering and Material Science, Vol. 20, pp. 471-475, 2013.

[11] Amar nath, S.P. Shrivas, A K Kandelwal, Multi – objective optimization of machining parameters using Grey Taguchi method, Journal of Harmonised research in Engineering, Vol. 4, No. 1, pp 1-5, 2016.

[12] Binoy Krishna Biswas, Pradip Kumar Pal, and Asish Bandyopadhyay, Optimization of Process Parameters for Flux Cored Arc Welding of Boiler Quality Steel Using Response Surface, International Journal of Materials, Mechanics and Manufacturing, Vol. 4, No. 1,pp. 18-26, 2016.

[13] K. Vignesh, G. Ramasivam, U.Natarajan and C.Srinivasan, Optimization of process parameters to enhance the mechanical properties of bone powder and coir fiber reinforced polyester composites by Taguchi method, ARPN Journal of Engineering and Applied Sciences, Vol. 11, No. 2, pp. 1224-1231, 2016.

[14] Amit Chauhan, Onkar Singh Bhatia, optimization of multiple machining characteristic in wedm of nickel based super alloy using of taguchi method and grey relational analysis,International Journal of Advanced Technology in Engineering and Science, Vol. 03, No. 06, pp 187 – 197, 2015.