Chapter

Application of Taguchi Method in Optimization of Pulsed TIG Welding Process Parameter

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Abstract

Pulsed TIG welding is one of the most widely used welding processes in the metal manufacturing industry. In any fusion arc welding process, the bead width plays an important role in determining the welding strength and mechanical properties of the weld joint. This study present optimization of the pulsed TIG welding process parameter using Taguchi Philosophy. AISI 316/3136L austenite stainless steel 4mm is used for welding and for the establishment of the optimum combination of the process parameter and depending upon the functional requirement of the welded joint, the acceptable welded joint should have optimum bead width and minimum heat affected zone (HAZ) etc. An experiment was conducted using different welding condition and a mathematical model was constructed using the data collected from the experiment based on Taguchi L_{25} orthogonal array. Optimum parameter obtained for bead width is peak current 180 ampere, base current 100 ampere, pulse frequency 125Hz and pulse on time 40%.

Keywords: TIG welding, design of experiment, Taguchi methodology, S/N ratio, ANOVA

1. Introduction

After the Second World War, the associated powers found that the nature of the Japanese telephone system was incredibly poor and absolutely unacceptable for long term communication purposes. To improve the system, it is recommended to establishing research facilities in order to develop a state-of-the-art communication system. The Japanese founded the Electrical Communication Laboratories (ECL) with Dr. Genichi Taguchi in charge of improving R&D efficiency and improving product quality. He observed that a great deal of time and money was expended on engineering experimentation and testing [1]. Taguchi seen quality improvement as a progressing exertion. He continually strived to reduce the variation around the target value. To accomplish this, Taguchi designed experiments using specially constructed tables known as OA. The use of these tables makes the design of experiments very easy and consistent [2]. Design of Experiments (DOE) is powerful statistical technique presented by R. A. Fisher in England during the 1920s to study the impact of numerous factors at the same time. In his initial applications, Fisher needed to discover how much rain, water, fertilizer, sunshine, etc. are expected to deliver the best yield. Since that time, much improvement of the system has occurred in the scholarly condition yet helped create numerous applications on the generation floor [3]. In late 1940s Dr. Genechi Taguchi of Electronic Control Laboratory in Japan, carried out significant research with DOE techniques. He spent extensive exertion to make this trial procedure easier to use and to improve the quality of manufactured products. Dr. Taguchi's standardized version of DOE, popularly known as the Taguchi method or Taguchi approach, was introduced in the USA in the early 1980s. Today it is one of best optimization techniques used by manufacturing industry. The DOE using the Taguchi approach can monetarily satisfy the needs of problem-solving and product/process design in optimization projects. By learning and applying this procedure, specialists, researchers, and scientists can essentially decrease the time required for exploratory examinations [4].

2. Taguchi approach

Design of Experiments (DOE) is powerful statistical technique presented by R. A. Fisher in England during the 1920s to study the impact of numerous factors at the same time. In his initial applications, Fisher needed to discover how much rain, water, fertilizer, sunshine, etc. are expected to deliver the best yield. Since that time, much improvement of the system has occurred in the scholarly condition yet helped create numerous applications on the generation floor [3]. In late 1940s Dr. Genechi Taguchi of Electronic Control Laboratory in Japan, carried out significant research with DOE techniques. He spent extensive exertion to make this trial procedure easier to use and to improve the quality of manufactured products. Dr. Taguchi's standardized version of DOE, popularly known as the Taguchi method or Taguchi approach, was introduced in the USA in the early 1980s. Today it is one of best optimization techniques used by manufacturing industry. The DOE using the Taguchi approach can monetarily satisfy the needs of problem-solving and product/process design in optimization projects. By learning and applying this procedure, specialists, researchers, and scientists can essentially decrease the time required for exploratory examinations [4].

2.1 Orthogonal array

The orthogonal array is selected as per standard orthogonal given in **Table 1**. This technique was first given by Sir R. A. Fisher, in the 1920s [5]. The method is popularly known as the factorial DOE. A full factorial design results may involve a large number of experiments. A full factorial experiment as shown in **Table 2**.

2.2 Nomenclature array

Orthogonal array is defined as: Lx (Ny)
Where, L = Latin square
x = number of rows
N = number of levels
y = number of columns (factors)
Degrees of freedom associated with the OA = x – 1
Some of the standard orthogonal arrays are listed in **Table 3**.

- Level 1 and 2 in the matrix represent the low and high level of a factor respectively.

- Each column of the matrix has an equal number of 1 and 2.

Orthogonal array	**Number of rows**	**Maximum no. of factor**	**Maximum no. of columns at these levels**			
			2	**3**	**4**	**5**
L4	4	3	3	—	—	—
L8	8	7	7	—	—	—
L9	9	4	—	4	—	—
L12	12	11	11	—	—	—
L16	16	15	15	—	—	—
L’16	16	5	—	—	5	—
L18	18	8	1	7	—	—
L25	25	6	—	—	—	6
L27	27	13	1	13	—	—
L32	32	31	31	—	—	—
L’32	32	10	1	—	9	—
L36	36	23	11	12	—	—
L’36	36	16	3	13	—	—
L50	50	12	1	—	—	11
L54	54	26	1	25	—	—
L64	64	63	63	—	—	—
L’64	64	21	—	—	21	—
L81	81	40	—	40	—	—

Table 1.
Standard orthogonal.

Experiment no.	**A**	**B**	**C**
1	1	1	1
2	1	1	2
3	1	2	1
4	1	2	2
5	2	1	1
6	2	1	2
7	2	2	1
8	2	2	2

Table 2.
Full factorial experiments table.

- Any pair of columns has only four combinations [1, 1], [1, 2], [2, 1], and [2, 2] indicating that the pair of columns are orthogonal.

2.3 Signal to noise ratio

Taguchi method stresses the necessity of studying the response variable using the signal-to-noise ratio, resulting to decrease the effect of quality characteristic

Trial no.	Column						
	1	**2**	**3**	**4**	**5**	**6**	**7**
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

Table 3.
Standard L_8 orthogonal array.

variation due to the uncontrollable parameter. The S/N ratio can be used in three types:

i. Larger the better:

$$S/N\ \text{Ratio} = -10\log.\ 1/a\ [\textstyle\sum_{i=0} 1/yi2]$$

ii. Smaller the better:

$$S/N\ \text{Ratio} = -10\log.1/a\ [\textstyle\sum_{i=0} yi2]$$

iii. Nominal the best:

$$S/N\ \text{Ratio} = -10\log.\ [\textstyle\sum_{i=0}\bar{y}i\ 2/s2]$$

Where,
a = Number of trials
yi = measured value
ȳ = mean of the measured value
s = standard deviation

Parameters that affect the output can be divided into two parts: controllable (or design) factors and uncontrollable (or noise) factors. Uncontrollable factors cannot be controlled but its effect can be minimized by varying the controllable factors.

2.4 Analysis of variance

ANOVA were first introduced by Sir Ronald A, Fisher, the British biologist. ANOVA is a method of partitioning total variation into accountable sources of variation in an experiment. It is a statistical method used to interpret experimented data and make decisions about the parameters under study. ANOVA is a statistical method used to test differences between two or more means [1].

2.4.1 Hypotheses of ANOVA

H0: The (population) means of all groups under consideration are equal.

Ha: The (pop.) means are not all equal. (Note: This is different than saying. they are all unequal.)

2.4.2 ANOVA table

A detail of all analysis of variance computations is given **Table 4**.

Where,

N = total number of observations
SSf = sum of squares of a factor
K = number of levels of the factor
SSe = sum of squares of error
Fo = computed value of F
Vf = variance of the factor
Ve = variance of the error

2.4.3 One-way ANOVA and their notation

When there is just one explanatory variable, we refer to the analysis of variance as a one-way ANOVA.

Here is a key to symbols you may see as you read through this section.

k = the number of groups/populations/
xi j = the jth response sampled from the ith group/population.
$\overline{x}i$ = the sample mean of responses from the ith group $= \frac{1}{ni}\sum_{j=i}^{n} xij$
si = the sample standard deviation from the ith group $= 1/(ni-1)\sum_{j=1}^{ni}(\overline{x}ij\text{-}xi)^2$
n = the total sample $= \sum_{i=0}^{k} xi$
$\overline{x}$ = the mean of all responses $= 1/n\sum_{ij} xij$

2.4.4 Parting the total variability

Viewed as one sample one might measure the total amount of variability among observations by summing the squares of the differences between each xi j and x:

Sources of variability:

1. SST (stands for the sum of squares total) $\sum_{j=1}^{ni}\cdot\sum_{j=1}^{ni}(xij-\overline{x})^2$

2. Sum of Square Group between group

   SSG = $\sum_{i=0}^{k} ni(xij-x)^2$

   Sum of Square Group within groups means

3. SSE = $\sum_{j=1}^{ni}\cdot\sum_{j=1}^{ni}(xij-x)2 = \sum_{i=1}^{k}(ni-1)s_i^2$

   It is the case that SST = SSG + SSE.

Source of variation	Sum of squares	Degree of freedom	Mean square variance	Fo
Factor	SSf	K − 1	Vf = SSf/K − 1	Vf/Ve
Error	SSe	N − K	Ve = SSe/N − K	
Total	SStotal	N − 1		

Table 4.
Analysis of Variance Computations (ANOVA).

2.4.5 Calculation

An F statistic is obtained from ANOVA test or a regression analysis to find out if the means between two populations are significantly different [1]. F statistics is used to decide the acceptance or rejection of null hypothesis. F value is calculated from the data, if calculated is larger than F statistics the null hypothesis is rejected. The ANOVA table showing F value is given in **Table 5**.

SS = Sum of Squares (sum of squared deviations):
SST measures the variation of the data around the overall mean $\overline{x}$
SSG measures the variation of the group means around the overall mean x
SSE measures the variation of each observation around its group mean $\overline{x}$i

- Degrees of freedom

  k − 1 for SSG

  n − k for SSE, since it measures the variation of the n observations about k group means. n − 1 for SST, since it measures the variation of all n observations about the overall mean.

- MS = Mean Square = SS/df :

- This is like a standard deviation. Its numerator was a sum of squared deviations (just like our SS formulas), and it was divided by the appropriate number of degrees of freedom.

  It is interesting to note that another formula for MSE is

  $$\mathrm{MSE} = \frac{(n_1-1)+(n_2-1)+(n_3-1)+\dots\dots(n_k-1)s_k^2}{(n_1-1)+(n_2-1)+\dots\dots.+(n_k-1)}$$

- The F statistic = MSG/MSE

If the null hypothesis is true, the F statistic has an F distribution with k-1 and n-k degrees of freedom in the numerator/denominator respectively. If the alternative hypothesis is true, then F tends to be large. We reject Ho in favor of Ha if the F

Source	SS	df	MS	F
Model/group	SSG	k − 1	MSG $\frac{SSG}{K-1}$	$\frac{MSG}{MSE}$
Residual/Error	SSE	n − k	MSG $\frac{SSE}{n-1}$	
Total	SST	n-1		

Table 5.
ANOVA table.

	df	SS	MS	F	p-value
A	I − 1	SSA	MSA	MSA/MSE	
B	J − 1	SSB	MSB	MSB/MSE	
AXB	(I − 1) (J − 1)	SSAB	MSAB	MSAB/MSE	
Error	n − IJ	SSE	MSE		
Total	n − 1	SST			

Table 6.
Two-way ANOVA table.

statistic is sufficiently large. As with other hypothesis tests, we determine whether the F statistic is large by finding a corresponding P-value.

2.4.6 Two-way ANOVA

In the two-way ANOVA model, there are two factors, each with several levels as shown in **Table 6**.

3. Taguchi design of experiment (DOE)

Taguchi DOE is a well-known factual strategy that gives a legitimate and productive technique for process optimization. The Taguchi technique enables us to improve the consistency of production. Taguchi design recognizes that not all factors that cause variability can be controlled. These uncontrollable factors are called noise factor. Taguchi design tries to identify the controllable factor that minimizes the effect of noise factors. During experimentation, you manipulate the control factor to evaluate variability that occurs and then determines the optimal control factor setting, which minimizes the process variability. A process designed with this goal produces more consistent output and performance regardless of the environment in which it is used. It is world widely used for product design and process optimization. As a result, time is reduced considerably. Taguchi DOE methodology uses an orthogonal array that gives different combinations of parameters and their levels for each experiment [6].

3.1 The layout of the experiment

The following sequence is followed while forming the experiment.

- Base and filler material selection.
- Selection of process parameters.
- Calculating the upper and lower limits process parameters.
- Selection of standard orthogonal array.
- Experiment conducted.
- Calculating optimum condition [6].

4. Selecting base material and their mechanical properties

AISI 316 stainless steel sheets of dimension 100 × 75 × 4 mm are welded autogenously with the butt joint without edge preparation [7]. The chemical

Grade 316	C	Mn	Si	P	S	Cr	Mo	Ni	N
Min.	—	—	—	—	—	16.0	2.0	10.0	
Max.	0.08	2.0	0.75	0.045	0.030	18.0	3.0	14.0	0.10

Table 7.
Chemical composition of the base material (wt %).

Tensile strength	Tensile strength (MPa) min	Yield strength 0.2% proof (MPa)	Elongation (% in 50 mm) min	Hardness	
				Rockwell HR B max	Brinell HB max
564 MPA	515	205	40	95	217

Table 8.
Mechanical properties of AISI 316 stainless steel.

Process parameter	Code	Level 1	Level 2	Level 3	Level 4	Level 5
Peak current	P	140	150	160	170	180
Base current	B	60	70	80	90	100
Pulse frequency	F	50	75	100	125	150
Pulse on time	T	35	40	45	50	55

Table 9.
Process parameters working range.

composition and mechanical properties of 316 stainless steel sheet are given in **Tables 7** and **8**. The process parameter working range is given in **Table 9**.

4.1 An orthogonal array is selected

The input process parameters selected are four, and each parameter is divided into five levels [6]. Different Standard orthogonal array used for optimization is shown in **Table 10**.

These above standard orthogonal arrays provide full information for all possible combination of input parameter. In this experimental work, four factors with their five levels are used for which the corresponding orthogonal array is L_{25} as shown in **Table 11**. Minitab 18 statistical software is used to a developed orthogonal array, response table, main effect plot for mean and S/N ratio. AVOVA is developed by Minitab 18 software to determine the % contribution of each input parameter [8].

4.2 Conduction of experiment

By putting the values of four parameters in L_{25} Orthogonal array as shown in **Table 12** [8].

4.3 Signal to noise ratio

The S/N ratio help in measuring the sensitivity of quality characteristic to external noise factor which is not under control. The highest value of S/N ratio represent more impact of the process parameter on the output performance. On the basis of characteristic three S/N ratios are available namely lower the better, higher the better and nominal the better as shown in **Table 13**. In this paper, higher the better is used for maximizing depth of penetration as shown in Eq. (1) [6].

$$\mathrm{S/N\ Ratio} = -10\log\ 1/n\ \left[\sum\nolimits_{i=0} 1/yi2\right] \tag{1}$$

Orthogonal array	Number of rows	Maximum no. of factor	Maximum no. of columns at these levels			
			2	3	4	5
L4	4	3	3	—	—	—
L8	8	7	7	—	—	—
L9	9	4	—	4	—	—
L12	12	11	11	—	—	—
L16	16	15	15	—	—	—
L’16	16	5	—	—	5	—
L18	18	8	1	7	—	—
L25	25	6	—	—	—	6
L27	27	13	1	13	—	—
L32	32	31	31	—	—	—
L’32	32	10	1	—	9	—
L36	36	23	11	12	—	—
L’36	36	16	3	13	—	—
L50	50	12	1	—	—	11
L54	54	26	1	25	—	—
L64	64	63	63	—	—	—
L’64	64	21	—	—	21	—
L81	81	40	—	40	—	—

Table 10.
Standard orthogonal array.

4.4 Experiment conducted for all input parameter

Specimen 316 austenitic stainless steel is welded as per the combination of parameters given in orthogonal array L_{25}, five trails are performed for each combination of parameters for BW then average value is taken as shown in **Table 14**. S/N ratio is obtained by using Minitab 18 statistical software as shown in **Table 15**.

4.5 Response table for bead width

The response table is obtained for the S/N ratio and mean for bead width as shown in **Tables 16** and **17**. The response table is obtained by Minitab 18 statistical software which represents the significance of each individual input parameter. Delta value is obtained for peak current, base current, pulse frequency and pulse on time which is the difference between the highest value to the lowest value. The rank of the input parameter is decided as per the highest value of delta [8].

4.6 Main effect plot for bead width

The main effect plot will help to determine the optimum value of the input parameter. Main effect plot is obtained for S/N ratio and mean for bead width by using Minitab 18 statistical software [8]. The main effect plot will represent significant the level of each input parameter as shown in **Figures 1** and **2**. Optimum value to obtained optimum bead width with their significant level is given in **Table 18**.

Experiment no.	**Process parameter**			
	P	**B**	**F**	**T**
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	1	5	5	5
6	2	1	2	3
7	2	2	3	4
8	2	3	4	5
9	2	4	5	1
10	2	5	1	2
11	3	1	3	5
12	3	2	4	1
13	3	3	5	2
14	3	4	1	3
15	3	5	2	4
16	4	1	4	2
17	4	2	5	3
18	4	3	1	4
19	4	4	2	5
20	4	5	3	1
21	5	1	5	4
22	5	2	1	5
23	5	3	2	1
24	5	4	3	2
25	5	5	4	3

Table 11.
Orthogonal Array L25 (Minitab18).

4.7 Confirmatory test for bead width

After evaluating the optimal parameter settings, the next step is to predict and verify the quality performance characteristics using the optimal parametric combination. The predicted value of the bead width is estimated by using the Eq. (2). Five experiments are conducted at the optimum parameter. The result of predicted value and experimental value of bead width is shown in **Table 19**, and it represents that predicted value and experimental value are close to each other [9].

$$\eta = n_m + \sum_{i=0}^{0} n_{im} - n_m \tag{2}$$

where,
η – predicted value
n_m - is the total mean

Experiment no.	Process parameter			
	P	B	F	T
1	140	60	50	35
2	140	70	75	40
3	140	80	100	45
4	140	90	125	50
5	140	100	150	55
6	150	60	75	45
7	150	70	100	50
8	150	80	125	55
9	150	90	150	35
10	150	100	50	40
11	160	60	100	55
12	160	70	125	35
13	140	60	50	35
14	160	80	150	40
15	160	90	50	45
16	160	100	75	50
17	170	60	125	40
18	170	70	150	45
19	170	80	50	50
20	170	90	75	55
21	170	100	100	35
22	180	60	150	50
23	180	70	50	55
24	180	80	75	35
25	180	90	100	40

Table 12.
Orthogonal array actual value.

Signal-to-noise ratio	The goal of the experiment	Data characteristics	Signal-to-noise ratio formulas
Larger is better	Maximize the response	Positive	$-10\log\frac{1}{n}$ $[\sum_{i=0}1/yi2]$
Nominal is best	Target the response and you want to base the signal-to-noise ratio on standard deviations only	Positive, zero, or negative	$-10\log.[\sum_{i=0}\bar{y}i$ $2/s2]$
Smaller is better	Minimize the response	Non-negative with a target value of zero	$-10\log.1/n$ $[\sum_{i=0}yi2]$

Table 13.
S/N ratio.

Sr. No.	BW 1 (mm) trial 1	BW 2 (mm) trial 2	BW 3 (mm) trial 3	BW 4 (mm) trial 4	BW 5 (mm) trial 5	Average BW (mm)
1	2.78	2.8	2.77	2.785	2.806	2.79
2	2.405	2.425	2.395	2.41	2.431	2.41
3	2.13	2.15	2.12	2.135	2.156	2.14
4	2.935	2.955	2.925	2.94	2.961	2.94
5	2.515	2.535	2.505	2.52	2.541	2.52
6	2.28	2.3	2.27	2.285	2.306	2.29
7	3.095	3.115	3.085	3.1	3.121	3.10
8	2.565	2.585	2.555	2.57	2.591	2.57
9	2.325	2.345	2.315	2.33	2.351	2.33
10	3.11	3.13	3.1	3.115	3.136	3.12
11	2.615	2.635	2.605	2.62	2.641	2.62
12	2.345	2.365	2.335	2.35	2.371	2.35
13	3.345	3.365	3.335	3.35	3.371	3.35
14	2.68	2.7	2.67	2.685	2.706	2.69
15	2.475	2.495	2.465	2.48	2.501	2.48
16	3.585	3.605	3.575	3.59	3.611	3.59
17	2.775	2.795	2.765	2.78	2.801	2.78
18	2.63	2.65	2.62	2.635	2.656	2.64
19	3.375	3.395	3.365	3.38	3.401	3.38
20	2.74	2.76	2.73	2.745	2.766	2.75
21	2.425	2.445	2.415	2.43	2.451	2.43
22	3.645	3.665	3.635	3.65	3.671	3.65
23	3.13	3.15	3.12	3.135	3.156	3.14
24	2.65	2.67	2.64	2.655	2.676	2.66
25	3.87	3.89	3.86	3.875	3.896	3.88

Table 14.
Experiment value bead width.

n_{im} - is the mean value ratio at the optimal level

Average bead width = 2.83 mm

$$n_{bead\ width} = 2.83 + (3.152 - 2.83) + (2.950 - 2.83) + (3.068 - 2.83) + (3.027 - 2.83)$$

$$= 2.83 + 0.322 + 0.238 + 0.12 + 0.197 = 3.707 \text{ mm}$$

Average S/N ratio = 8.91

$$n_{average\ S/N} = 8.91 + (9.835 - 8.91) + (9.274 - 8.91) + (9.580 - 8.91) + (9.528 - 8.91)$$

$$= 8.91 + 0.925 + 0.364 + 0.67 + 0.6 = 11.5 \text{ mm}$$

$$\% \text{ Error} = \frac{Experimental\ value - Predicted\ Value}{Predicted\ Value} * 100$$

$$\% \text{ Error} = \frac{3.744 - 3.6707}{3.6707} * 100 = 1.99\ \%$$

4.8 Regression equation for all the response

The regression equation has been developed by using Minitab18 statistical software. The second-order polynomial regression equation representing the bead

Exp. no.	Process Parameter				1
	P	B	F	T	BW
1	140	60	50	35	8.91
2	140	70	75	40	7.65
3	140	80	100	45	6.60
4	140	90	125	50	9.38
5	140	100	150	55	8.04
6	150	60	75	45	7.19
7	150	70	100	50	9.84
8	150	80	125	55	8.21
9	150	90	150	35	7.36
10	150	100	50	40	9.88
11	160	60	100	55	8.38
12	160	70	125	35	7.43
13	140	60	50	35	10.51
14	160	90	50	45	8.59
15	160	100	75	50	7.90
16	170	60	125	40	11.11
17	170	70	150	45	8.89
18	170	80	50	50	8.43
19	170	90	75	55	10.59
20	170	100	100	35	8.78
21	180	60	150	50	7.72
22	180	70	50	55	11.25
23	180	80	75	35	9.93
24	180	90	100	40	8.49
25	180	100	125	45	11.77

Table 15.
S/N Ratio from MINITAB 18.

Level	Peak current (P)	Base current (B)	Pulse frequency (F)	Pulse on time (%)
1	8.115	8.661	9.411	8.483
2	8.495	9.013	8.652	9.528
3	8.562	8.736	8.417	8.609
4	9.559	8.881	9.580	8.653
5	9.835	9.274	8.504	9.293
Delta	1.720	0.613	1.163	1.045
Rank	1	4	2	3

Table 16.
Response table for S/N ratio.

Level	Peak current (P)	Base current (B)	Pulse frequency (F)	Pulse on time (%)
1	2.561	2.745	2.977	2.672
2	2.683	2.861	2.741	3.027
3	2.700	2.768	2.654	2.755
4	3.029	2.801	3.068	2.720
5	3.152	2.950	2.685	2.951
Delta	0.591	0.205	0.414	0.355
Rank	1	4	2	3

Table 17.
Response table for mean.

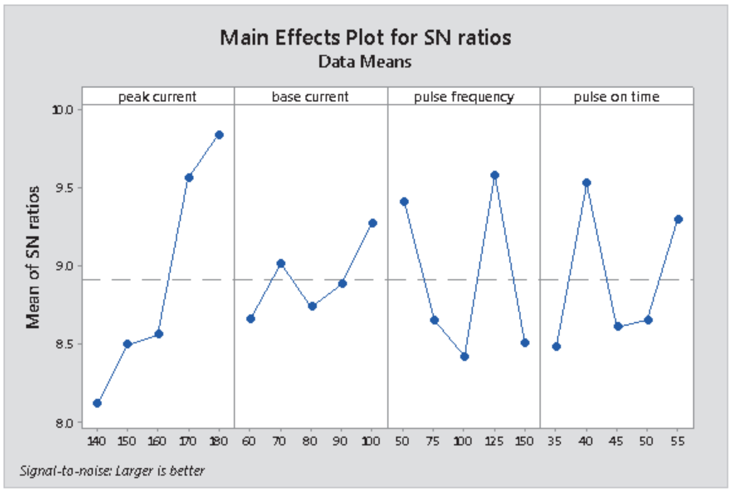

Figure 1.
Main effect plot for S/N ratio: BW.

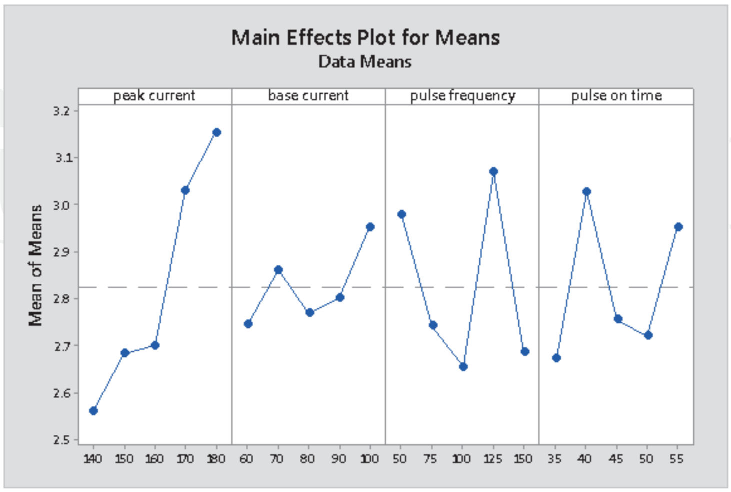

Figure 2.
Main effect plot for mean: BW.

geometry expressed as a function of peak current, base current, pulse frequency and pulse on time as given in Eq. (3). The predicted result as per the regression equation is shown in **Table 20**. After that % error between predicted value and experimental value is obtained as given in **Table 21** [10].

Parameter/control factor	Optimum parameter	Level	Optimum value
Peak current	1	5	180A
Base current	4	5	100A
Pulse frequency	2	4	125Hz
Pulse on time	3	2	40%

Table 18.
Optimum parameter for bead width.

	Prediction	Experiment				
Level	P5B5F4T2 (180A, 100A, 125Hz, 40%)	P5B5F4T2 (180A, 100A, 125Hz, 40%)				
		Exp.1	Exp.2	Exp.3	Exp.4	Exp.5
		3.75 mm	3.72 mm	3.70 mm	3.78 mm	3.72 mm
		Average				
Bead width	3.707 mm	3.744 mm				
S/N Ratio	11.5	11.86				

Table 19.
Confirmatory results for bead width.

Exp. no.	Process parameter				1
	P	B	F	T	BW
1	140	60	50	35	2.82
2	140	70	75	40	2.44
3	140	80	100	45	2.17
4	140	90	125	50	2.97
5	140	100	150	55	2.55
6	150	60	75	45	2.32
7	150	70	100	50	3.13
8	150	80	125	55	2.60
9	150	90	150	35	2.36
10	150	100	50	40	3.15
11	160	60	100	55	2.65
12	160	70	125	35	2.38
13	140	60	50	35	3.38
14	160	90	50	45	2.72
15	160	100	75	50	2.51
16	170	60	125	40	3.62
17	170	70	150	45	2.81
18	170	80	50	50	2.67
19	170	90	75	55	3.41

Exp. no.	Process parameter				1
	P	B	F	T	BW
20	170	100	100	35	2.78
21	180	60	150	50	2.46
22	180	70	50	55	3.68
23	180	80	75	35	3.17
24	180	90	100	40	2.69
25	180	100	125	45	3.91

Table 20.
Predicted result from the regression equation.

Exp. no.	Process parameter				1
	P	B	F	T	BW
1	140	60	50	35	1.1%
2	140	70	75	40	1.2%
3	140	80	100	45	1.4%
4	140	90	125	50	1.0%
5	140	100	150	55	1.2%
6	150	60	75	45	1.3%
7	150	70	100	50	1.0%
8	150	80	125	55	1.2%
9	150	90	150	35	1.3%
10	150	100	50	40	1.0%
11	160	60	100	55	1.1%
12	160	70	125	35	1.3%
13	140	60	50	35	0.9%
14	160	90	50	45	1.1%
15	160	100	75	50	1.2%
16	170	60	125	40	0.8%
17	170	70	150	45	1.1%
18	170	80	50	50	1.1%
19	170	90	75	55	0.9%
20	170	100	100	35	1.1%
21	180	60	150	50	1.2%
22	180	70	50	55	0.8%
23	180	80	75	35	1.0%
24	180	90	100	40	1.1%
25	180	100	125	45	0.8%

Table 21.
Percentage error between predicted & experimental results.

Source	DF	Adj SS	Adj MS	F	P	% contribution
Peak current	4	1.2702	0.31754	0.97	0.475	24.42 %
Base current	4	0.1357	0.03393	0.10	0.978	2.61 %
Pulse frequency	4	0.6903	0.17256	0.53	0.720	13.27 %
Pulse on time	4	0.4801	0.12002	0.37	0.827	9.23 %
Error	8	2.6249	0.32812			
Total	24	5.2012				

Table 22.
ANOVA for bead width.

$$\begin{aligned}\text{Bead width (mm)} = {} & 2.825 - 0.264\ \text{peak current\_140} - 0.142\ \text{peak current\_150} \\ & - 0.125\ \text{peak current\_160} + 0.204\ \text{peak current\_170} \\ & + 0.327\ \text{peak current\_180} - 0.080\ \text{base current\_60} \\ & + 0.036\ \text{base current\_70} - 0.057\ \text{base current\_80} \\ & - 0.024\ \text{base current\_90} + 0.125\ \text{base current\_100} \\ & + 0.152\ \text{pulse frequency\_50} - 0.084\ \text{pulse frequency\_75} \\ & - 0.171\ \text{pulse frequency\_100} + 0.243\ \text{pulse frequency\_125} \\ & - 0.140\ \text{pulse frequency\_150} - 0.153\ \text{pulse on time\_35} \\ & + 0.202\ \text{pulse on time\_40} - 0.070\ \text{pulse on time\_45} \\ & - 0.105\ \text{pulse on time\_50} + 0.126\ \text{pulse on time\_55}\end{aligned} \tag{3}$$

4.9 ANOVA for all the response

ANOVA test the hypothesis that the means of two or more population are equal. AVOVA is a computational technique to quantitatively estimate the contribution that each parameter makes on the overall observed response. By using ANOVA percentage contribution of each parameter is obtained as shown in **Table 22**.

1. Peak Current $\frac{1.2702}{5.2012}$ X 100 $= 24.42$ %

2. Base current $\frac{0.1357}{5.2012}$ X 100 $=2.67$ %

3. Pulse frequency $\frac{0.6943}{5.2012}$ X 100 $=13.27$ %

4. Pulse on time $\frac{0.4801}{5.2012}$ X 100 $= 9.230$%

5. Conclusion

In this Taguchi approach is applied to determine the most influencing process parameter which effect the output response i.e BW (Bead Width). By using Minitab 18 statistical analysis software all possible combination of all input process parameter has been established Using L_{25} orthogonal array experiment has been conducted to determine S/N ratio. The response table is developed to determine the rank of each parameter. Main effect plot obtained from Minitab 18 statistical analysis software is used to determine the most influencing process parameter and their significant level. Optimum parameter for bead width is 180A peak current, 100A base current, 125 Hz pulse frequency and 40% pulse on time. The confirmatory test has been conformed to verify the optimum result obtained. ANOVA is representing the significance of each individual parameter with their % contribution.

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