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Theoretical Analysis And Optimization Of Process Parameters For Part Motion Time In Vibratory Part Feeders For Mass Production Assembly Lines

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Abstract: ***Low cost automation techniques play a significant role in reducing the lead time and production cost. Automation technique is implemented by developing a part feeding system. Its effectiveness is verified both experimentally and theoretically. Drop test is used to find the natural resting orientation. Real time experiments are conducted using designed trap to determine the part motion time. The Input parameters considered for the research are trap angle and frequency of vibration and they are varied while conducting the experiments. An ANOVA model is developed to verify its accuracy. The developed model shows that the value of R-sq is 90.32 % and it reveals that forecasted values seem very nearer to the real response values. Regression equation is evolved to forecast the optimum values of trap angle and frequency and the same is solved using LINGO software. It was found both experimentally and theoretically that greater values of both the input parameters resulted in least part motion time.***

Keywords: Cost-effectiveness; Rocker arm; part feeding system; Taguchi method; ANOVA

1. INTRODUCTION

In order to learn the natural resting orientation of brake pad, drop test is performed and the same can be compared with the theoretical methods[14].Resting Orientation can be determined by dropping the object both on hard and soft surface[11].Drop test and modeling simulation was performed to investigate the effect of drop impact of cell phone().The effect of initial orientations of an object dropped from different heights can be found by drop test and it can be compared with theoretical methods [1]. The different drop test modelling methods were systematically introduced, integrated, compared and recommended for various applications[22].In drop test simulation and while performing shock analysis, Finite Element method (FEM) is widely used[12]. Design instructions to attain the needed impact pulse and to precise the drop test characterization process, dynamic simulation test using free-fall drop model is executed [10]. The most endangered drop condition for the HDD is found after identification of non-operational shock response for the one-inch drive. Accelerated drop test method was developed and the shock resistance of an HDD was also evaluated quickly[19].The characterization of industrial part feeders with introduction to mechanical part feeders is discussed and the guidelines for feeder development for small parts orientation in the industry is studied[4].Markov model is used for developing trap and gates for handling asymmetric/symmetric component to determine the part time motion [14]. The productive way of trap design for feeder is Markov model [8]. For handling smaller component, an economical way to design the conveyor based on the part is studied. [19]. A flexible part feeding system made of three conveyors simultaneously was designed and implemented. Few rules to design the part and maximise the feeding system's performance was presented [20]. The behaviour of a linear vibratory feeder for conveying small parts was found using a mathematical model [16]. The jamming of parts in the automatic machine feeder was studied [18] and it was observed that part jamming is due to the deviations of the part, the feeder sizes, velocity of part motion, and length of motion. The method of identifying the orientations of non-rotational parts and laboriously reorganizing them into the preferred orientation was studied by developing a new part feeding system [2].

An automatic feeding system was developed using PLC and electro pneumatics for cylindrical parts that are fragile and powdery in nature[8].There was a vibrational effect on a mobile-based body resting on an inclined plane and it was concluded that impact displacement occurs under transient regimes of motion from static to dynamic equilibrium[19].For Object simulation, feeding and orienting in a vibratory bowl feeders, a 3D computer simulation software using Java 3D API was developed and studied[7].A new method was proposed to make sure that there is best operating performance of the latest feeder at single- or double-line frequency[23].Sensor less orientation of a polygonal part by a sequence of fences and any polygonal part can be oriented by a sequence of fences placed along a conveyor belt, thereby settling a conjecture was shown[3].In order to feed a wide class of 3D parts by reorienting and rejecting all but those in a preferred orientation, a simple new primitive was proposed [24]

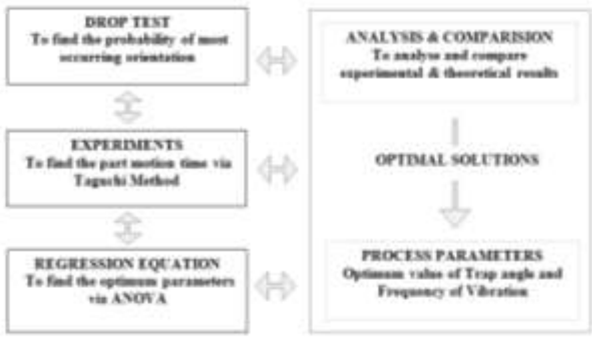
The accuracy of the models is determined by techniques such as Analysis of Variance, R-squared and normal plot of residuals. [5]. The Minitab 17 statistical package was employed to find the optimum level of three factors namely number of turns, spring index and wire diameter that affect the value of response variable. The effect of different levels of the three factors on the response variable as well as regression equation is also modeled in this paper [6]. The impact of cutting variables on tool wear in turning operation is analyzed by ANOVA. The link between cutting parameters and the tool wear using multiple regression analysis for each work piece material is also evaluated [7].

From the literature survey, it is clear that not much research has been made to find the optimum parameters for effective part motion time and compare the same with the experimental results. In this research work, the Experimental setup consists of Hopper, Linear vibrator, Trap system, Belt conveyor and pick and place robot with gripper. "Rocker arm" was chosen as the desired part due to smaller size, Low weight, moderate natural frequency and also it is used in mass production assembly lines.

2. MATERIALS AND METHODS

Figure 1 presents diagram of research methodology to optimize process parameters for part motion time in vibratory part feeders. Firstly, the drop test is conducted to find the probability of most occurring orientation. Secondly, the experiments are conducted to find the part motion time with L18 orthogonal array generated by Taguchi method, via the use of analysis tool in MINITAB software (www.minitab.com). Thirdly, the Analysis of Variance (ANOVA) technique and Equations of regression are applied to find the optimum parameters. Finally, the results of experimental and theoretical methods are analysed and compared, to obtain the optimum value of trap angle and frequency of vibration

Fig.1 A diagram of research methodology to optimise process parameters for part motion time in vibratory part feeders.



2.1 Experimentation

The most favourable resting orientation of rocker arm is found by drop test. In order to conduct the drop test, the part (rocker arm) is dropped in different orientations from height of 250mm into the experimental setup since the potential energy change occurs only from this stated height. The resting orientation is noted when the part comes to rest and the favourable orientation is the one that is most frequent. The procedure is repeated twenty times and the change of orientation is noted.

The total number of possible orientations observed while conducting drop test is eight and the possible orientations are shown in Figure 2. The occurrence probability of each possible orientation is calculated and discussed in results section.

Figure 3 presents Markov model for hopper design. Hopper is designed in this part feeding system in order to send the component one by one to the trap. It is made of acrylic plastic and designed using markov model. Wiper blade is found at the entrance of the hopper and it converges towards the middle of the hopper. Barrier is set at the exit of the hopper so that the parts fall one by one on the trap in any orientation. The hopper is kept at a height of 250 mm above the trap since the potential energy change occurs at this height.

Fig. 2 Eight possible orientations of rocker arm

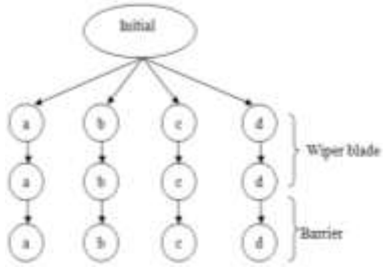


Fig. 3 Markov model for hopper design

Markov model was used to design the trap, as presented in Figure 4. Drop test is carried out to know the favourable orientation of the component (i.e.,) by dropping the component from a height of about 250mm with different initial orientations. The Probabilities of each orientation is computed from the drop test results. The final model of the trap is obtained by combining the markov model. A trap can contain 'n' number of gates to change the feasible orientations into desired orientation. The trap consists of 4 gates to convert any orientation into the desired orientation '3'. Orientation 5 and 6 orientation of the part is converted into 1st, 2nd, 3rd, 4th, 7th and 8th orientation in the first gate of the trap. The second gate is used to convert 2nd and 8th orientation into 3rd and 4th orientation. The third gate is used to convert 1st and 7th orientation into 3rd and 4th orientation. The gate 4 is a diverting pin converts 4th orientation to 3rd orientation.

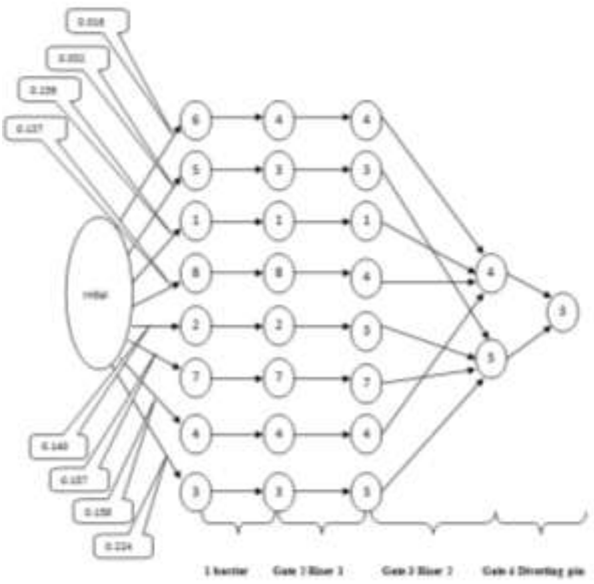


Fig. 4 Markov model for the hopper design

2.2 Determination of Part Motion Time via Design of Experiments

Design of experiments was carried out using MINITAB software to find the part motion time. The Orthogonal array was created using Taguchi method by giving the range values of input parameters. From the trail experiments, the range of values for trap angle and frequency values was given as 20º-30º and 65-70 Hz respectively. Based on these given values an array consisting of 18 set of values was generated.

Multi-Level Design is selected which is suitable for many factors and L18 Orthogonal array displaying 18 values for the parameters is generated and shown below. Real time experiments were conducted from the set of readings obtained from L18 orthogonal array. The time taken to change from initial orientation to final orientation is determined by changing the values of trap angle and frequency. The steps are repeated 18 times and the part motion time was recorded.

2.3 Analysis of Variance to find the optimum parameters

The significance of the developed model was tested using the ANOVA technique and coefficient of determination (R^2) is used to determine the quality of the developed models. The variation among and between groups is found by Analysis of Variance. In the Analysis of Variance setting, the observed variance in a particular variable is partitioned into components attributable to different sources of variation. The statistical test to find the whether or not the means of several groups are equal is performed and thus t-test is generalized.

3. RESULTS AND DISCUSSIONS

Table 1 shows that resting orientation obtained by dropping the part from different initial orientations at 250mm drop height. The occurrence value of resting orientation(y) for different initial orientations and cumulative values of the resting orientation are reported in the table. Probability for each resting orientation is calculated and tabulated.

Drop Height (mm)	Dropping Orientation	Probability of Occurrence of each Orientation							
		1	2	3	4	5	6	7	8
250	1	0.05	0.05	0.05	0.3	0.05	0.05	0.05	0.3
	2	0.05	0.05	0.45	0.1	–	0.1	0.2	0.05
	3	0.05	0.3	0.45	–	–	–	0.2	–
	4	0.1	–	0.25	0.35	–	–	0.1	0.2
	5	–	0.1	0.5	0.1	–	0.05	0.2	0.05
	6	0.2	–	0.15	0.4	–	–	0.1	0.15
	7	0.05	0.15	0.4	0.05	–	–	0.3	0.05
	8	0.05	0.05	0.25	0.25	–	–	0.2	0.2

Table 1. Cumulative results of the drop test

Drop height	Dropping orientation	Number of times dropped	Resting orientation – Occurrence value(y)							
			1	2	3	4	5	6	7	8
250mm	1	20	3	1	1	6	1	1	1	6
	2	20	1	1	9	2	0	2	4	1
	3	20	1	6	9	0	0	0	4	0
	4	20	2	0	5	7	0	0	2	4
	5	20	0	2	10	2	0	1	4	1
	6	20	4	0	3	8	0	0	2	3
	7	20	1	3	8	1	0	0	6	1
	8	20	1	1	5	5	0	0	4	4
Cumulative value(x)		$x = \sum y_i$	13	14	50	31	1	4	27	20

Table 2. Probability of occurrence of the dropping orientation

Table 2 presents Probability of occurrence of the dropping orientation. It shows that the orientation 3 has a cumulative value of 50 and has the highest probability of occurrence. Thus, the feasible output orientation was identified as orientation 3.

Figure 6 presents the hopper design, with different design models. Both the wiper blade and the barrier are used to send the component one by one to the trap. There is no change in orientation if the component passes through the hopper and it acts as singularising unit only.

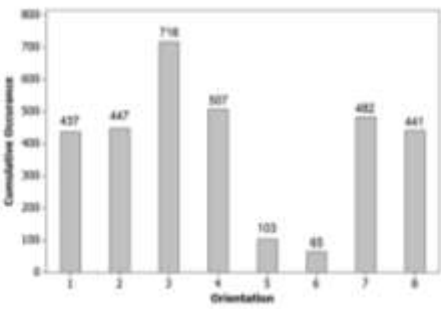


Fig.5 Drop test results for rocker arm dropped from various heights (10 mm to 500 mm)

Fig 6. Different hopper models. A: Model 1 – Wiper blade B: Model 2 – Barrier. C: Combination of Model 1 and Model 2 – Wiper blade and barrier.

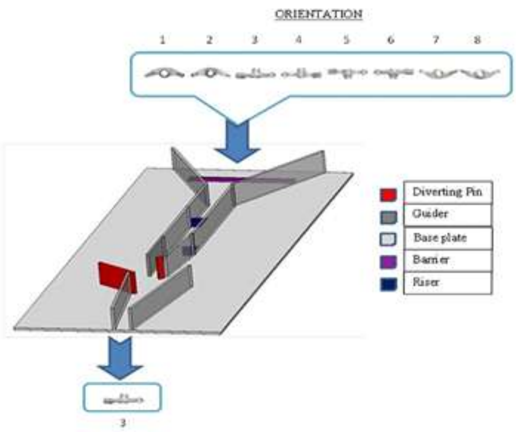


Fig.7 Description of a trap design and its components: base plate, barrier, riser and diverting pin

Figure 7 presents a trap design and its components: base plate, barrier, riser and diverting pin. The trap is fabricated using acrylic plastic. Trap is made to obtain the desired orientation 3 as the output.

The fabricated part feeder along with its components is shown in Figure 8. It has hopper, trap, linear vibrator, fixture and conveyor. Trial Experiments were conducted and it reveals that considerable part motion is obtained when the trap angle and frequency is between 20º - 30º and 65 Hz – 70 Hz respectively. Based on these range of values, L 18 orthogonal array is generated and the experiments were conducted from the values obtained from L 18 Orthogonal array. It was concluded that least part motion time is obtained for trap angle of 30º and 70 Hz frequency.

Fig.8 Fabrication of the part feeding system. A: Trap. B: Linear vibrator. C: Fixture and conveyor

Table 3 present the results of Design of Experiment, based on Taguchi methods. The experiments were conducted in the set up with the values acquired from Taguchi's L18 orthogonal array. The Input values of trap angle and frequency was set and the effective part motion time was noted.

Table 3. Design of Experiment results – Part motion time (Orientation 3)

Trap Angle (Degrees)	Frequency (Hertz)	Time (Seconds)
20	65	10.16
20	66	10.23
20	67	10.25
20	68	10.21
20	69	9.95
20	70	7.86
25	65	8.13
25	66	8.12
25	67	8.24
25	68	7.98
25	69	7.92
25	70	7.98
30	65	7.68
30	66	7.82
30	67	7.52
30	68	7.35
30	69	6.93
30	70	6.96

It is noted from the above results that the effective time of part motion is 6.72 seconds for the given input values of 30º trap angle and 70 Hz frequency.

Figure 8 presents the Effect of time with variation in trap angle and frequency. The main effects plot is used to determine whether the pattern is statistically significant or not. This plot indicates the optimal design conditions. Here in this plot, time(seconds) is indicated in Y axis and trap angle, frequency is indicated in X axis.

Figure10 indicates the surface plot of part motion time and Interaction of time with the two main factors namely trap angle and frequency. The Interaction plot clearly indicates that for a trap angle 30º and frequency 70 Hz, there is minimum part motion time.

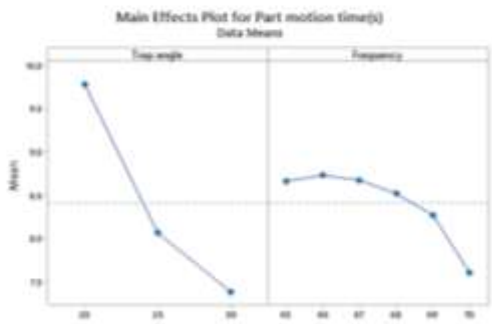


Fig. 9 Effect of time with variation in trap angle and frequency.

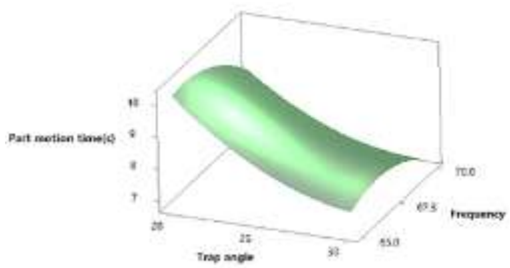


Fig. 10 Surface plot of part motion time vs frequency & trap angle

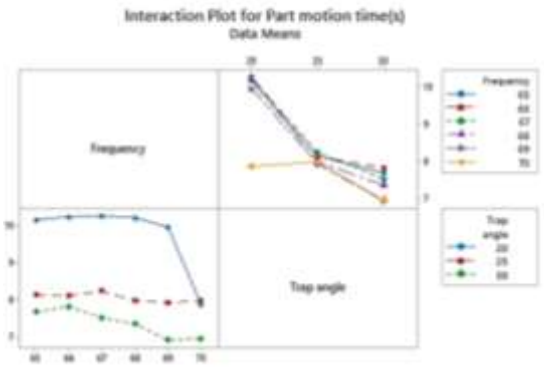


Fig. 11 Interaction of time with different trap angle and frequency

Figure 11 presents the interaction of time with different trap angle and frequency. It is clearly seen that; the part motion time is minimum for trap angle of 30º and frequency of 70 Hz. The figure also reveals that for a trap angle between 29º - 30º there is effective part motion. The Plot indicates that the Interaction of two factors namely trap angle and frequency with time is more significant at lower values of time.

Table 4 summarizes the analysis of variance for part motion time (T). The model terms are significant if the value of $P < 0.5$. Here from the table we can infer that the significant model for time T is A and B since the value of P is less than 0.05.The link between the predictor and response is tested from the value of P. Smaller the value of P indicates that there is significance in corresponding co-efficient and the contribution towards the response variable.

Table4. ANOVA for the part motion time

Source	DF	Sum of squares	Mean Square	F value	P value
Model	5	21.845	4.2569	22.40	0.000
Linear	2	19.2675	9.6338	50.69	0.000
Trap angle(A)	1	17.2800	17.2800	90.93	0.0001
Frequency(B)	1	1.9875	1.9875	10.46	0.007
Square	2	1.7650	0.8825	4.64	0.032
A^2	1	1.0609	1.0609	5.58	0.036
B^2	1	0.7041	0.7041	3.70	0.078
2 Way Interaction	1	0.2520	0.2520	1.33	0.272
AB	1	0.2520	0.2520	1.33	0.272
Error	12	2.2805	0.1900		
Total	17	23.5651			

The variation in the dependent variable of a sample is well explained using a regression model. The distribution seems normal when the residuals being plotted with the expected values. The difference between the observed and the fitted response value is considered as residuals. There must be normal distribution of residuals from the analysis.

Figure 12 presents Normal Probability plots of residual for time. From the above Figure 11, we can infer that the residuals are spread around the straight line and hence there is normal distribution of residuals. Thus, it can conclude as it satisfies normality assumption.

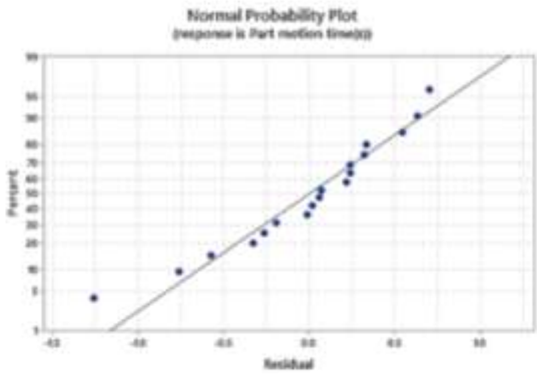


Fig. 12 Normal Probability plots of residual for time

The following is the summary of the models: S = 0.435940; R-Sq.= 90.32 %; R-sq.(ad) = 86.29%; and R-sq. (Pred.) = 65.98%. It means that 90.32 % of the total variation in the results was attributed to the Independent variables investigated. The model gives proper forecast values and it is inferred that the forecasted values are nearer to the real values. It is concluded that accuracy of the model is also high due to the reasonably high R2 values.

Regression Equation is presented as follows:

$$PMT = -292 - 2.42\,A + 10.08\,B + 0.02060\,A^2 - 0.0793\,B^2 + 0.0170\,AB$$

The variables included in this study are Trap angle(A) and Frequency of vibration(B).

Figure 13 presents the contour plots of time as the result of ANOVA for the obtained time values.

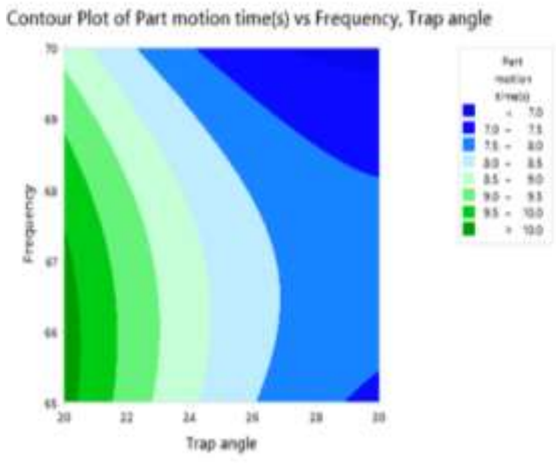


Fig.13 Contour plots of time, a result of ANOVA for the obtained time values.

In order to investigate the sensitivity analysis, contour plots show the interaction of time with the two parameters such as trap angle and frequency of vibration. From the results of the Contour plots, it is revealed that the for-trapangle 29º -30 º and frequency is 69 Hz – 70 Hz, the part motion time is effective.

The Regression equation obtained from ANOVA is solved using LINGO software and the optimum values of frequency and trap angle is obtained and presented in Figure 14.

```
Global optimal solution found.
Objective value:                              6.669563
Objective bound:                              6.669563
Infeasibilities:                              0.000000
Extended solver steps:                               0
Total solver iterations:                            23
Elapsed runtime seconds:                          0.84

Model Class:                                        QP

Total variables:                      2
Nonlinear variables:                  2
Integer variables:                    0

Total constraints:                    5
Nonlinear constraints:                1

Total nonzeros:                       6
Nonlinear nonzeros:                   3


                        Variable           Value        Reduced Cost
                       TRAPANGLE        29.85437        0.5896835E-08
                       FREQUENCY        70.00000       -0.5144757

                             Row    Slack or Surplus      Dual Price
                               1        6.669563          -1.000000
                               2        0.1456309          0.000000
                               3        9.854369           0.000000
                               4        0.000000           0.000000
                               5        5.000000           0.000000
```

The desirability for all the responses is equal to 1 as shown in the figure 14. It is clearly understood from the plot that the predicted response is close to the target values The Red solid line the figure represents the global solution and the dotted blue line represents the forecasted responses. From the above optimisation plot for time it is clear that 29.78 º trap angle and 70 Hz frequency are the optimum parameters to conduct the experiment to have an effective part motion.

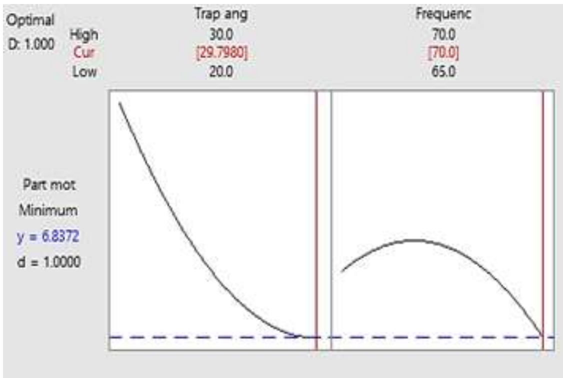


Figure 14. Optimisation plots of time

4. CONCLUSIONS

The usual resting orientation of the rocker arm dropped from 250mm height with different initial orientations was studied experimentally using drop test. Orientation 3 is predominant since it has highest value of occurrence in contrast with the other orientations. The Probability value for orientation 3 is higher compared with other orientations. Markov model was used for effective design of trap with four gates to get the orientation 3 as output. Design of experiments using Mini tab software was conducted and L18 orthogonal array was generated using taguchi design by giving range values for input parameters. The generated input parameters were set to determine the effective part motion time. Experimental analysis concludes that trap angle of 30º and frequency of 70 Hz gives least part motion time. Analysis of Variance (ANOVA) was performed and Interaction plot, main effects plot and contour plot were made and the results concluded that for least part motion time, the trap angle varies from 29º to 30º and frequency from 69 – 70 Hz. The Normal probability plots of residual also shows a higher significant value and the model summary shows the value of R2 to be 90.32%. From the results, it is evident that there is strong correlation between the experimental results and theoretical results.

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