Mathematical Analysis of Vibratary Bowl Feeder

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Abstract- To cater to the inflating demands of the present competitive industrial world to run processes with minimal human involvement, automation not only saves labor and time but also results in improved quality, accuracy and precision of products and processes.

The objective of our research is to design, fabricate and analyze the performance of a modified path for a vibratory bowl feeder for feeding headed components like machine bolts. The existing path of the feeder was modified and a chute had been designed and attached to the exit to restrict multiple feeding and to ensure desired orientation of the parts. The feed rate was studied experimentally by varying the input parameters such as part population, frequency of vibration and length of screws.

A process model was formulated on the basis of Analysis of variance (ANOVA) using Design-Expert statistical package. Interaction among the factors was studied by using the two basic principles of experimental design - replication and randomization adopted by a full 2^3 factorial experimental approach. The outcome is represented graphically and in the form of empirical model which defines the performance characteristics of the modified Vibratory Bowl Feeder.

Keywords – Automation, vibratory feeder, feed rate, Design Expert, Full 2^3 factorial design, DOE

I. INTRODUCTION

In assembly or industrial production lines, part feeders are required for transferring parts to the initial stage of production. These are used when a randomly s bulk package of small components must be fed into A machine discretely, oriented in a particular direction.

It is critical for the feed rate of the feeder to be maintained at a value which is above the consumption rate of the parts by the machine to which the parts are being fed and hence performance of the part feeder is of utmost importance.

Part feeders provide a cost effective alternative to manual labor, saving manufacturer's valuable time and labor costs, nonetheless bringing consistency in quality. In chemical or pharmaceutical industries, where material handling by the worker could be detrimental, automatic part feeders become a necessity.

Since different kinds of feeders for various part geometries, thus it becomes important to understand the performance of the feeder under the prescribed conditions to optimize the feeding mechanism.

II. EXPERIMENTAL SETUP

The path of the vibrating feeder was altered by narrowing it down. A sheet metal gate was fabricated to restrict multiple feeding. A metal chute was constructed and attached to the exit of the path.

Figure 1

Figure 2

Features to be taken care of while fabrication of the gate and chute:

- The pathway obstructed by the gate should be wide enough to allow one bolt to pass at a time. This prevents jamming of the system.
- The axis of the slot on the chute should coincide with the axis of the path of the feeder.
- The width of the slot in the chute should be more than the diameter of the bolts but less than the diameter of the head of the bolts.[1]

Table 1: Specification

S.No	**SPECIFICATION**	**DESCRIPTION**
1	Material of chute	Mild Steel
2	Length of chute	12 cm
3	Width of chute	2.5 cm
4	Width of slot	0.5 cm
5	Length of gate	10 cm
6	Width of gate	1.5 cm
7	Diameter of bowl	30 cm

III. ESSENTIAL FACTORS AFFECTING THE FEED RATE CHOSEN FOR ANALYSIS

A. Frequency of Operation

The feed rate of the feeder was observed to increase with the increase in the frequency of operation.

B. Part Population

The feed rate varied significantly with the increase in part population. The increase in part population caused excessive interaction between the bolts causing a decrease in the feed rate.

C. Length of Bolts

The feed rate of the feeder decreased with the increase in length of parts. Due to increased length the bolts occupied more path length and hence a lower number of parts could be accommodated on the track at given time, thus decreasing the feed rate.

IV. RANGES OF PARAMETERS

A) Part population in the feeder : 250 to 550
B) Frequency of operation : 40 Hz to 48 Hz
C) Length of parts : 13 mm to 38 mm

V. FACTORIAL APPROACH

The aim of the experiment is to establish a statistical model to predict the output feed rate and its successful optimization using 2^k factorial design. The three factors chosen for experiment are the controllable variables that have a key role to play in the process characterization. These design factors have a certain range within which they can be varied for the useful functioning of the system. The ranges of individual factors were chosen on the basis of pilot runs and process knowledge based on practical experience .[2] The upper and lower bounds of the range of each factor, which were coded as +1 and -1, are given in the Table 2.

Table 2: Process Parameters

Process Parameters	**Low Level(-1)**	**High Level(+1)**
Frequency (Hertz)	40	48
Part Population (Number)	250	550
Part Length (mm)	13	38

Since we have three factors to be considered, the experiment design is called a 2^3 full factorial design which required eight test runs, each with combinations of the three factors across two -levels of each. According to the general statistical approach for experimental design three replicates were obtained to get a reliable and precise estimate of the effects. Therefore, twenty four observations were taken in all to employ full factorial design as shown in Table 3. Throughout the experiment it was assumed that: the factor is fixed, the design was completely randomized and the usual normality assumptions of the data were satisfied.

Table 3:Experimental Data

Run	**Factor 1 A: Part Length**	**Factor 2 B: Frequency**	**Factor 3 C: Part Population**	**Response 1 R1**	**Response 2 R2**	**Response 3 R3**
1	-1	+1	-1	112	98	110
2	+1	-1	-1	14	10	14
3	-1	+1	+1	84	79	82
4	+1	+1	-1	53	57	50
5	+1	+1	+1	38	40	39
6	-1	-1	+1	19	22	19
7	-1	-1	-1	23	13	18
8	+1	-1	+1	9	10	8

VI. ANALYSIS

DesignExpert® is an excellent statistical package that assists in data analysis. Various plots like Cube plot, Interaction plot and One factor plot are obtained to examine effects of factors on output. Pareto plot and Normal plot of the standardized effects are obtained to compare the significance of each effect. Analysis of Variance (ANOVA) table is constructed for the significant factors affecting the output response.

6.1 Effect of factors on feed rate

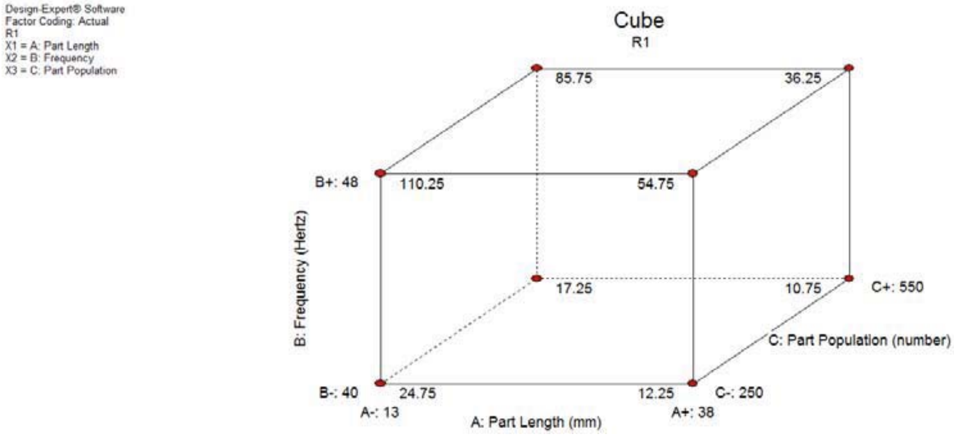

Figure 3: Cube plot for feedrate at limiting values (R1=feedrate)

The cube plot for feed rate (Figure 3) shows the average feed rates at critical points. The critical points are those points where all the parameters have limiting values.

Fgures below depict a plot for average output for each level of two factors with the level of third factor held constant. These plots called interaction plots are used to interpret significant interactions between the process parameters. Interaction is present when the response at a factor level depends upon the levels of other factors. Since they can magnify or diminish the main effects of the parameters, evaluating interactions is extremely important.[3] The extent of interaction can be deduced from the lack of parallelism of lines in the graphs. The greater the departure of the lines from the parallel state, the higher the degree of interaction.

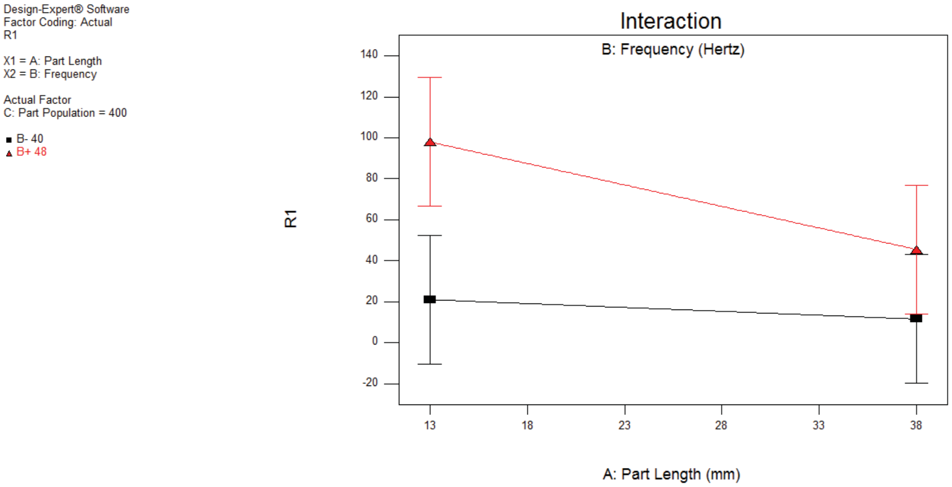

Figure 4: Interaction plot between A and B factors

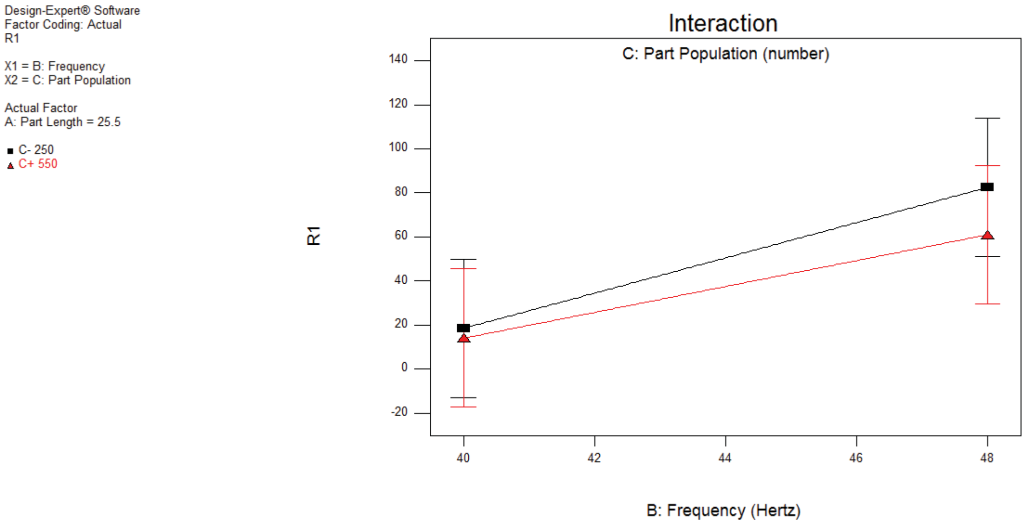

Figure 5: Interaction plot between B and C factors

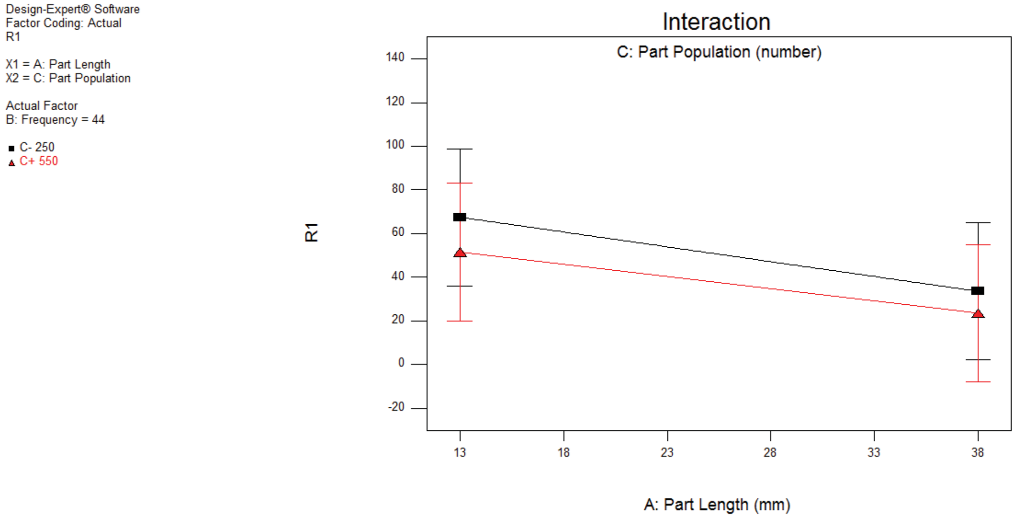

Figure 6: Interaction plot between A and C factors

In interaction plots 1 and 2, synergic interaction between the concerned factors can be seen. It can be concluded that the interaction between part length and frequency, and frequency and part population exhibit a significant effect on feed rate. In plot 3, the lines of part length versus part population are approximately parallel, indicating a lack of interaction between the two factors and a negligible effect on the feed rate.

Dependence of the system and the output over one varied parameter keeping the others constant can be deduced from the factor plots. The one factor graphs (Figure 7,8,9) can be used to compare the relative strength of the effects across factors. It can be asserted from the graphs that the part length and part population have negative effects while the frequency of operation has a positive effect on the output feed rate.

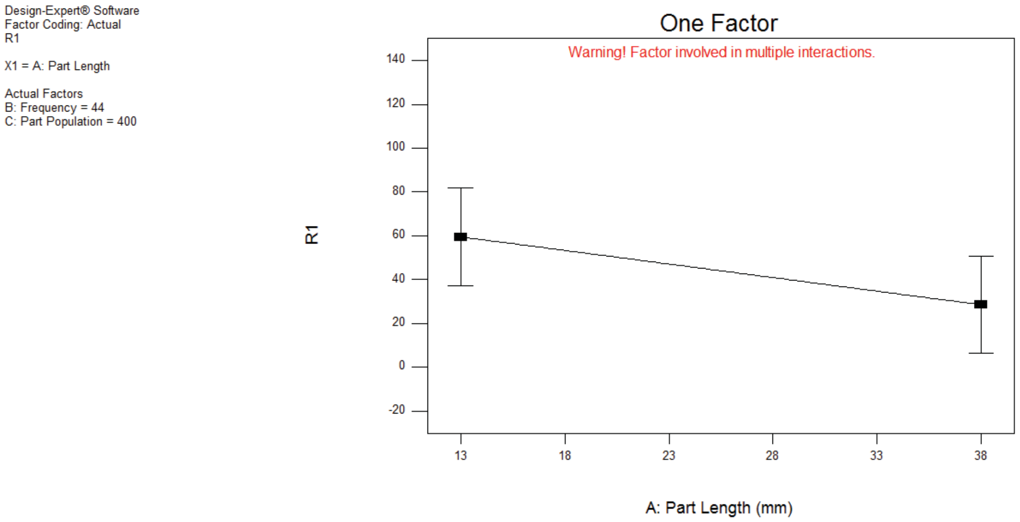

Figure 7: One factor plot for part length

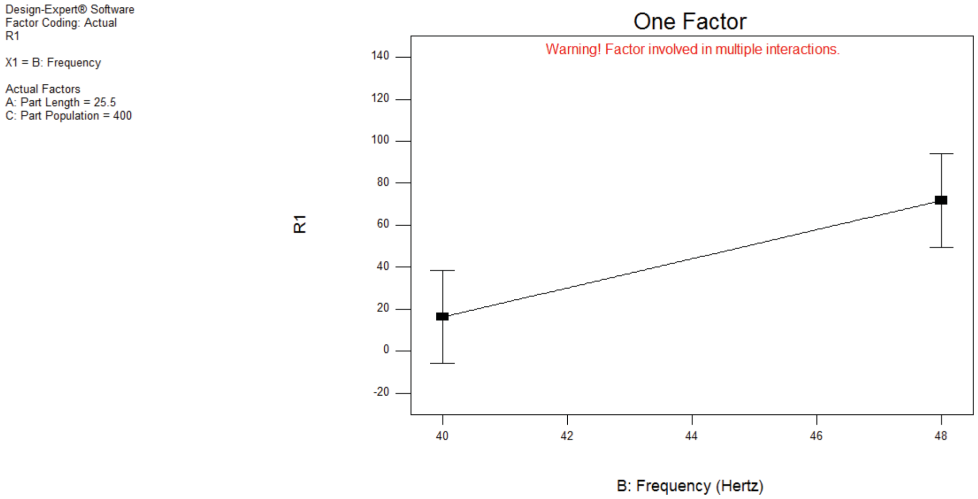

Figure 8: One factor plot for frequency

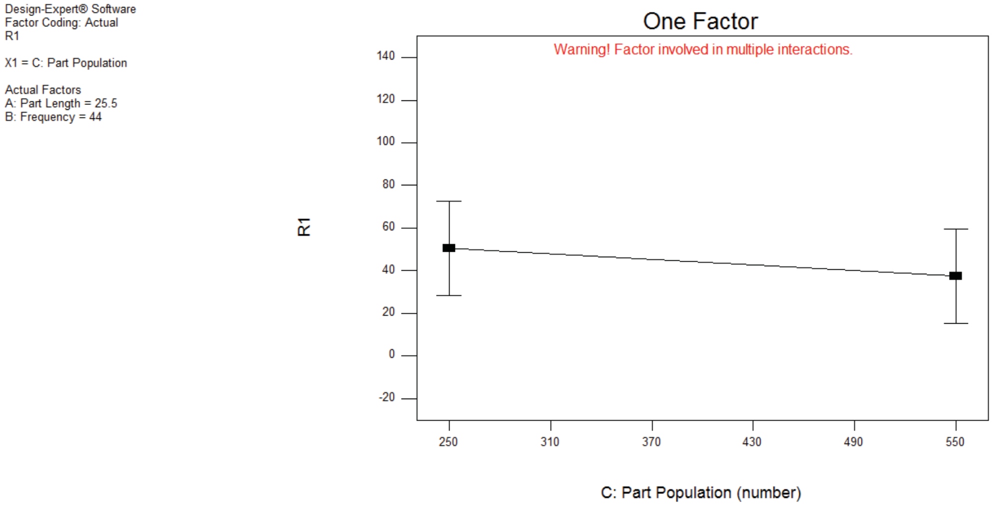

Figure 9: One factor plot for part poulation

6.2 Final Equation in Terms of Actual Factors:

FEED RATE = -566.08333 +197.50000 * part length+15.14583 * frequency +0.24833 * part population -5.37500 * part length * frequency +0.020000 * part length * part population -7.08333E-003 * frequency * part population

6.3 Significance of various parameters

The Pareto Chart of the Effects (Figure 10) and the Normal Plot of Standardized Effects (Figure 11) also assist to determine the magnitude and the importance of an effect. Pareto chart displays the absolute value of the effects and draws a reference line on the chart at t-value limit, where t is the (1 - α/2) quantile of a t-distribution with degrees of freedom equal to the degrees of freedom (24) for the error term. Any effect that extends within this reference line is statistically insignificant [4]. The effect of B has the highest standardized effect on the feed rate followed by A, AB, C, BC, ABC and AC. However only the effect of B extends above the t-value limit, hence significant. The chart indicates that the effect of all other factors is statistically insignificant. The significance of all factors can be reasserted from the normal plot, in which, the points that do not fall near the fitted line are important. The factors having negligible effect on the output response tend to be smaller and are centered on zero.The significance of factor B can also be reasserted from the normal plot and it can be seen that all other insignificant factors fall near the fitted line.

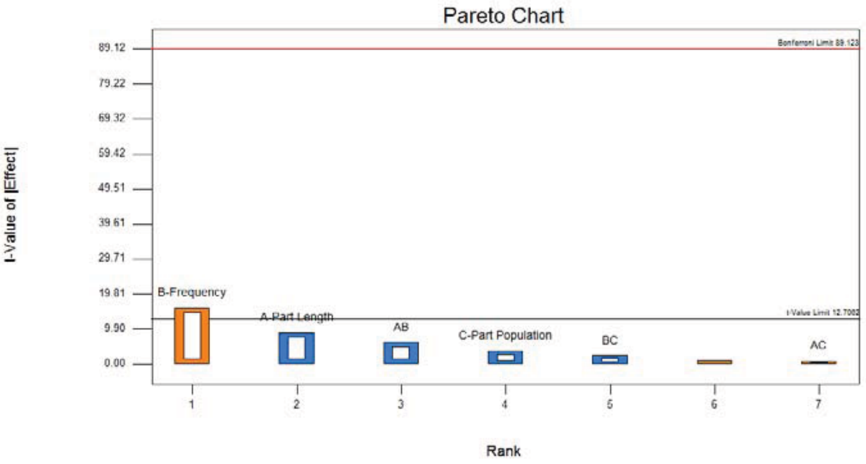

Figure 10: Pareto Chart

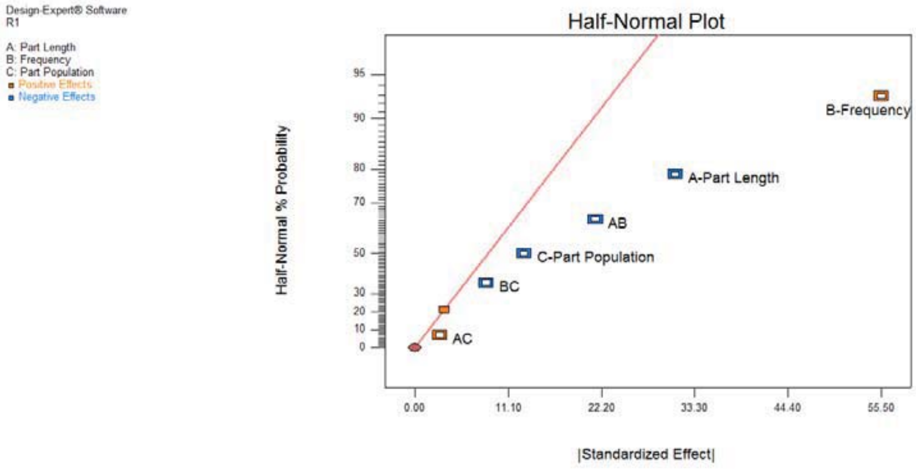

Figure 11: Half Normal Plot

Table 4:Analysis of Variance Table

Source	**Sum of Squares**	**df**	**Mean Square**	**F value**	**p-value Prob > F**
Model	9507.50	6	1584.58	64.68	0.0949 not significant
A-part length	1922.00	1	1922.00	78.45	0.0716
B-Frequency	6160.50	1	6160.50	251.45	0.0401
C-Part Population	338.00	1	338.00	13.80	0.1674
AB	924.50	1	924.50	37.73	0.1027
AC	18.00	1	18.00	0.73	0.5489
BC	144.50	1	144.50	5.90	0.2487
Residual	24.50	1	24.50		
Cor Total	9532.00	7			

The F Value for a term is the test for comparing the variance associated with that term with the residual variance. It is the Mean Square for the term divided by the Mean Square for the Residual. P value is the probability value that is associated with the F Value for this term. It is the probability of getting an F Value of this size if the term did not have an effect on the response.[2] The Model F-value of 64.68 implies there is a 9.49% chance that a "Model F-value"this large could occur due to noise.

The terms that have a probability value less than 0.05 are significant. A probability value greater than 0.10 indicate the model terms are not significant. In this case, B is the significant model term, while all others are insignificant.

Table 5: Diagnostic Case Statics

Standard Deviation	4.95	R-Squared	0.9974
Mean	44.00	Adj R-Squared	0.9820
C.V.%	11.25	Pred R-Squared	0.8355
PRESS	1568.00	Adeq Precision	21.490

R square measures the proportion of total variability explained by the model. From Table the value of R squared is 0.9974. A potential problem with this statistic is that it always increases as factors are added to the model even if these factors are insignificant. So the adjusted R squared was calculated to be 0.9820.

The “Predicted R-Squared” of 0.8355 is in reasonable agreement with the “Adj R-Squared” of 0.9820. “Adeq Precision” measures the signal to noise ratio. A ratio greater than 4 is desirable. Hence a ratio of 21.490 indicates an adequate signal. This model can be used to navigate the design space. The Diagnostics Case Statistics compares the actual and predicted values and obtains the residual.

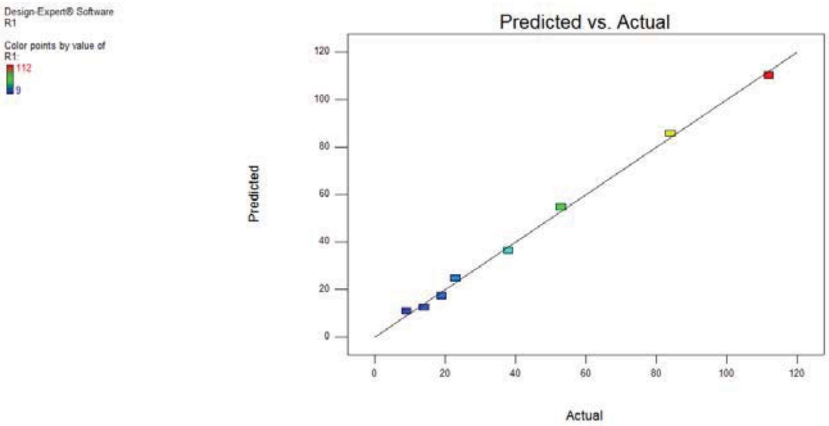

Figure 12: Predicted vs. Actual Values Plot

6.4 Optimization of Feedrate

This equation can be used to find out the values of the three factors to be set in order to achieve desired output feed rate. The optimization procedure picks several starting points from which search for the optimal factor settings is begun. [3] There are two types of solutions for the search:

Local solution: For each starting point, there is a local solution. These solutions are the combination of factor settings found beginning from a particular starting point.

Global solution: There is only one global solution, which is the best of all the local solutions. The global solution is the "best" combination of factor settings for achieving the desired responses. For each of the local solution, predicted value of the response is calculated. The desirability of each of the predicted values asses its closeness to the target value on a scale of 0 to 1.

A reduced gradient algorithm with multiple starting points is employed to maximize the desirability in order to determine the numerical optimal or the global solution.

Solutions found for the constraints in Table 6 are shown in Table 7. The selected solution is the global solution. [4]

Table 6: Constraints

NAME	GOAL	LOWER LIMIT	UPPER LIMIT	LOWER WEIGHT	UPPER WEIGHT	IMPORTANCE
Part Length	is in range	13	38	1	1	3
Frequency	is in range	40	48	1	1	3
Part Population	is in range	250	550	1	1	3
Feed Rate	Maximize	9	112	1	1	3

A total of 26 solutions were obtained, out of which 19 most desirable solutions have been tabulated below:

Table 7: Solutions

NUMBER	PART LENGTH	FREQUENCY	PART POPULATION	FEED RATE	DESIRABILITY
1	**13**	**48.00**	**250**	**110.248**	**0.983 selected**
2	13	48.00	251.40	110.135	0.982
3	13	48.00	252.83	109.998	0.981
4	13	48.00	250.00	109.941	0.980
5	13	47.95	250.00	109.663	0.977
6	13	48.00	258.16	109.583	0.977
7	13	47.89	250.00	109.028	0.971
8	13	48.00	250.00	108.535	0.966
9	13	48.00	273.40	108.339	0.964
10	13	47.70	277.41	108.011	0.961

In an exemplary situation, the feed rate of 80 was targeted and the corresponding optimum values of the remaining two factors were found. The results obtained from the optimization are shown below in Table 8:

Table 8: Constraints

NAME	GOAL	LOWER LIMIT	UPPER LIMIT	LOWER WEIGHT	UPPER WEIGHT	IMPORTANCE
Part Length(mm)	is in range	13	38	1	1	3
Frequency (Hertz)	is in range	40	48	1	1	3
Part Population (number)	is in range	250	550	1	1	3
Feed Rate	is target = 80	9	112	1	1	3

Table 9:Solutions

NUMBER	PART LENGTH	FREQUENCY	PART POPULATION	FEED RATE	DESIRABILITY
1	**13**	**46.36**	**412.63**	**80.0002**	**1.000 selected**
2	14	47.46	531.09	80.0001	1.000
3	23	47.55	288.35	80.0001	1.000

VII. CONCLUSION

A reliable statistical model based on full factorial experiment design has been developed which can be used for the optimization of output feed rate of the vibratory feeder. The model is significant to explain 83.55% of variability in new data. Such a model not only assists to estimate the magnitude and direction of the effects of change in factors but also predicts the effects of their mutual interactions.

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