MATHEMATICAL ANALYSIS OF PERFORMANCE OF A VIBRATORY BOWL FEEDER FOR FEEDING BUTTONS

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ABSTRACT *– In today's world, automation of manufacturing processes has become more important than ever in different types of industries, as it delivers the product in right quality, quantity, consistency and also with reduced time consumption. There are many aspects of industrial automation depending upon the type of product and industry. Assembly line is one of the aspect where we need streamlined flow of the product from one assembly station to another so as to serve the needs of assembly line in a given cycle-time. Many a times discrete part feeding, done in required quantity and in desired orientation becomes indispensable. This task can successfully be done with the help of a suitable feeding mechanism. Vibratory bowl feeder has been a choice of industry for its versatility. The present study is aimed at mathematically analysing the performance of a vibratory bowl feeder with different size of buttons in garment fabrication industry. The desired outcome in this case is the feed rate and the various input parameters for the study are – part population, part size and frequency of bowl. A statistical technique known as design of experiments was used to develop a mathematical model, expressing the relationship between input and output parameters in the form of an equation. ANOVA analysis was then carried out with significance testing of the developed model. The model was optimized by using response surface methodology. The mathematical model thus developed can be used to predict the performance behaviour of the feeder.*

Key words*: Automation, Response surface methodology, ANOVA, Feed rate, Mathematical Analysis*.

1.0 INTRODUCTION

A feeder is a machine or device that is used to feed any kind of material, chemical or product to the assembly line, manufacturing stations or wherever necessary. The specification of a feeder is to feed material one by one at any desired rate.

The feeder selection is an important part in obtaining a feed rate with accurate results. Hence, different types of Feeders have been designed to serve various types of feeding requirement which are:

1. Centrifugal Feeder
2. Vibratory Feeder
3. Linear Feeder
4. Flex Feeder
5. Step Feeder
6. Elevator Feeder

The feeder used during this experiment is Vibratory Bowl Feeder. It is an instrument that uses vibration to feed material. Both vibration and gravity are used to move materials in this feeder. Direction is determined by gravity, either down, or down and to a side, and then material is moved by vibration. They are mainly used to transport smaller objects in large quantity.

A number of research papers have been surveyed to understand the importance of mechanized feeding and the various techniques used by the experimenters to analyse the behaviour of these feeders. According to Chauhan et. al. [1], factorial approach to study the effects of various parameters on vibratory bowl feeder gives satisfactory results.

Bhagat et. al. [2 &3], conducted graphical as well as mathematical analysis on the performance of vibratory bowl feeder for feeding headed components and concluded that the developed model not only was able to estimate the magnitude and direction of the effects of change in factors but also predicts the effects of their mutual interactions.

Jindal et. al. [4 & 5] carried out experimentation, graphical as well as mathematical, with vibratory bowl feeder on clip shaped components and observed that the maximum feed rate is obtained for highest part population and at the highest frequency and for the smallest part size in graphical analysis. Whereas mathematical model along with interaction study revealed that part length was least significant a factor.

Jain et. al. [6] applied Taguchi approach in optimizing the performance of vibratory bowl feeder and found that Frequency has a positive effect on feed rate whereas part population has a negative effect on feed rate. Initially the effect of part size is negative but it becomes positive after a while due to its interaction with frequency and part population.

2.0 PLAN OF INVESTIGATION

The investigation was carried out by following the steps given below:

1. Identification of process parameters and their working ranges
2. Development of the design matrix
3. Conducting the experiments as per the design matrix
4. Recording the observations
5. Development of mathematical model
6. Testing the significance of the model
7. Results and their analysis
8. Conclusions

2.1 Identification of process parameters and their working ranges

Literature survey and past experience has shown that there are many part parameters, process parameters which could affect the performance of feeder. These parameters are part size, part population, frequency, part weight, part thickness, part material and shape. A number of trial experiments however revealed that frequency, part population and part size were the most significant process parameters and were therefore selected for the present study. The working ranges for these parameters were determined by using a series of trial runs. These ranges are shown in table 1. The lower limit is represented by -1 and the upper limit by +1.

Table 1: Process parameters and their working ranges

Process Parameters	(-1)	(0)	(+1)
Frequency	35	40	45
Part Size	16	21	26
Part Population	100	150	200

2.2 Development of Design Matrix

To analyse the individual and interaction effects of process parameters, statistical approach of design of experiment was opted. Central composite face centred technique was used to decide the number of experiments as per the design matrix given in table 2. A total of 20 (2^3+2*3+6=20) experiments were conducted with single replication and the corresponding feed rate readings were recorded in table 2.

2.3 Conducting the experiments as per the design matrix

The experiments were conducted on a feeding system having bowl diameter of 300mm supplied with a frequency control unit, which facilitates stepless control of frequency of vibrations that acts as an important factor affecting the feed rate of this feeder.

Fig. 1: Bowl Feeder

2.4 Recording the observations

Statistical approach of design matrix was opted and 20 experiments were conducted according to design of expert. The observations are shown in table 2.

Table 2: Recording of observations

Run	Frequency(A)	Part Size(B)	Part Population(C)	Feed Rate
1	0	0	0	80
2	0	1	0	93
3	0	0	0	78
4	0	0	0	79
5	0	0	0	82
6	-1	-1	-1	12
7	1	1	1	191
8	-1	1	-1	42
9	0	-1	0	63
10	0	0	1	102
11	-1	-1	1	43
12	1	-1	1	213
13	0	0	0	87
14	1	1	-1	103
15	0	0	-1	65
16	-1	0	0	19
17	1	0	0	152
18	1	-1	-1	35
19	0	0	0	84
20	-1	1	1	12

2.5 Development of mathematical model

The dependence of response parameters which is feed rate on input parameters part size, part population and frequency can be shown by "feed rate = f (A, B, C)" the general regression equation is

feed rate $=\beta_0+ \beta_1A+ \beta_2B+ \beta_3C+ \beta_{12}AB+ \beta_{13}AC+ \beta_{23}BC+ \beta_{11}A^2+ \beta_{22}B^2+ \beta_{33}C^2$

where β_1, β_2, β_3 are regression coefficients for linear terms

β_{12}, β_{13}, β_{23} are regression coefficients for interaction

β_{11}, β_{22}, β_{33} are regression coefficients for square terms.

The actual regression equation for the developed model is given below

Feed rate = $82+66.5A+15B+18.5C+5.87AB+33.12AC-18.88BC+3A^2-4.5B^2+C^2$

2.6 Testing the significance of the model

The developed model was tested for its adequacy by using ANOVA analysis and the significance of regression coefficients was also checked by using design expert software. The final mathematical equation after dropping insignificant cubic terms has already been given (eqn. A). the ANOVA analysis of he developed model has been given in table 3.

Table 3: ANOVA Analysis

Source	**Sum of squares**	**dF**	**Mean Value**	**f-value**	**p-value**	
Model	54650.13	13	4203.86	423.03	< 0.0001	significant
A-Frequency	8844.50	1	8844.50	890.01	< 0.0001	
B-Part Size	450.00	1	450.00	45.28	0.0005	
C-Part Population	684.50	1	684.50	68.88	0.0002	
AB	276.13	1	276.13	27.79	0.0019	
AC	8778.13	1	8778.13	883.33	< 0.0001	
BC	2850.13	1	2850.13	286.81	< 0.0001	
A^2	24.75	1	24.75	2.49	0.1656	
B^2	55.69	1	55.69	5.60	0.0557	
C^2	2.75	1	2.75	0.2767	0.6177	
ABC	105.13	1	105.13	10.58	0.0174	
A^2B	140.63	1	140.63	14.15	0.0094	
A^2C	354.03	1	354.03	35.63	0.0010	
AB^2	245.03	1	245.03	24.66	0.0025	
AC^2	0.0000	0				
B^2C	0.0000	0				
BC^2	0.0000	0				
A^3	0.0000	0				
B^3	0.0000	0				
C^3	0.0000	0				
Residual	59.62	6	9.94			
Lack of Fit	2.29	1	2.29	0.1999	0.6735	not significant
Pure Error	57.33	5	11.47			
Cor Total	54709.75	19				

The accuracy of the fit of the developed model is also significantly high as indicated by the high value of R^2. The fit statistics is given in table 4.

Table 4: Fit Statistics

Std. Dev.	3.15	**R^2**	0.9989
Mean	81.75	**Adjusted R^2**	0.9965
C.V. %	3.86	**Predicted R^2**	0.9472
Std. Dev.	-	**Adeq Precision**	76.2094

2.7 Result and their analysis

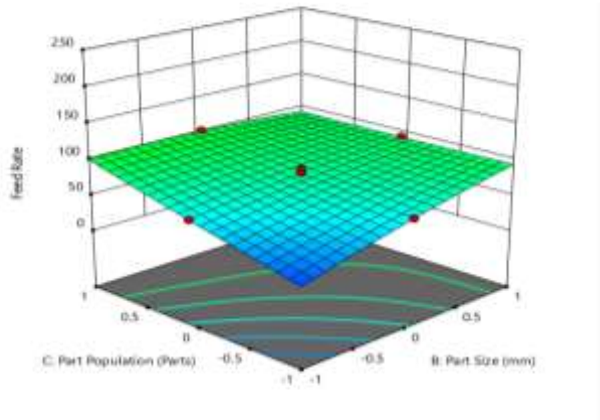

Fig. 2: Effects of part size and part population on feed rate

Figure 2 shows the effects of part population and part size on the feed rate of buttons. It is clearly visible from the graph that with the increase in part size, there is increase in feed rate. The effect of part population is positive for the smaller size but constant for the larger size.

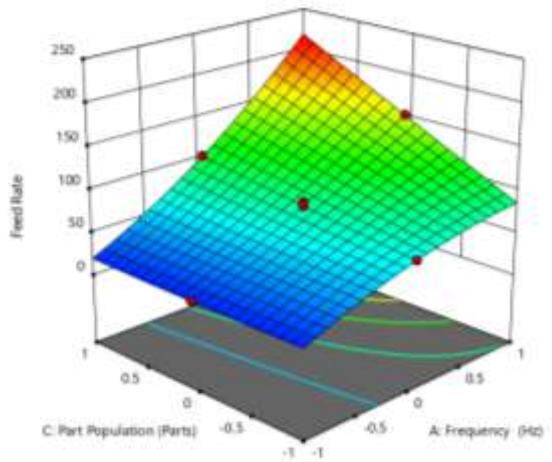

Fig. 3: Effects of frequency and part population on feed rate

The above graph shows the effect of part population and frequency on feed rate while keeping part size unaltered. It is clearly visible form the graph that feed rate is directly proportional to frequency and with increase in part population, there is an increase in feed rate.

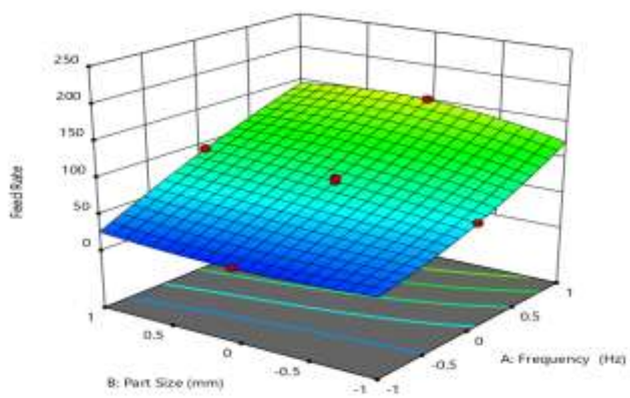

Fig. 4: Effects of part size and frequency on feed rate

The graph in figure 4 shows the effect of part size and frequency on feed rate. It is very clear from the graph that with increase in frequency, the feed rate increases and with increase in part size there is an increase in feed rate for lower frequency but for higher frequency there is a parabolic path obtained and highest feed rate is obtained for the intermediate size.

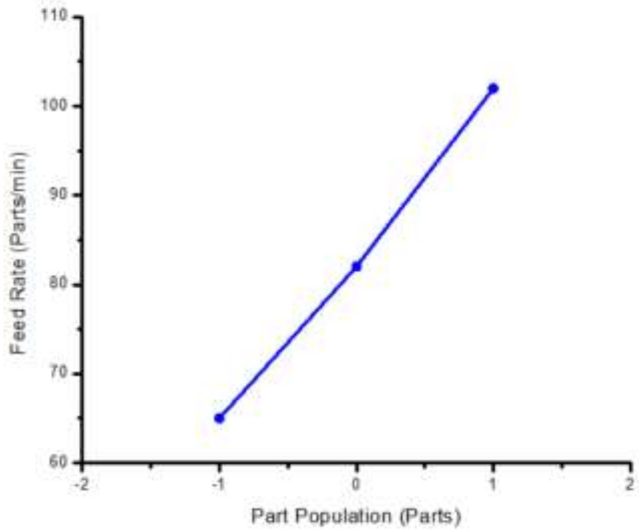

Fig. 5: Effect of part population on feed rate

The graph in figure 5 shows the relation between feed rate and part population. It is clearly visible form this graph that with increase in part population, there is an increase in feed rate. This is probably due to the fact that the number of opportunities has increased and more the number of vibrating parts more will be the pushing force. Hence, more is the feed rate.

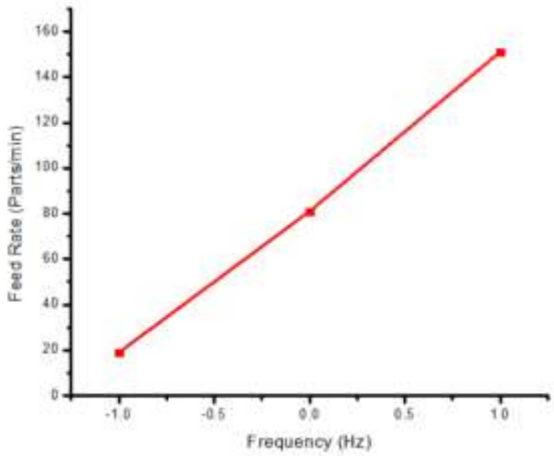

Fig. 6: Effect of frequency on feed rate

The graph in figure 6 the relation between feed rate and frequency. It can be seen that with increase in frequency, the feed rate also increases. It is owing to the fact that higher the frequency, higher is the agitation of the parts about its mean position. Therefore, there will be an increase in feed rate as the pushing force will increase

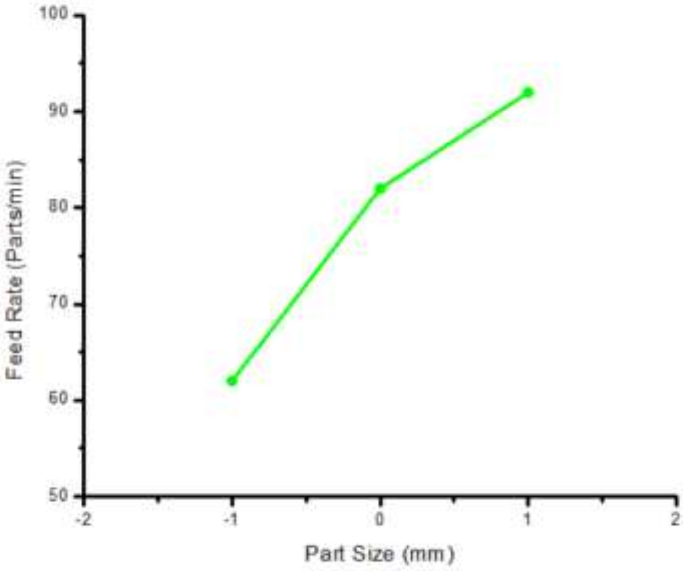

Fig. 7: Effect of part size on feed rate

The graph in figure 7 shows the relation between part size and feed rate. It can be concluded from the graph that with increase in part size, the feed rate is increasing. This is probably because with increase in part size, the mass of the part also increases and also their size increases which helps more in increasing their pushing tendency to the fellow parts. Hence, more the size, more will be the pushing force and more feed rate.

2.8 CONCLUSIONS

1. Central composite face centred has been found to be satisfactory and useful in predicting the behaviour of a vibratory bowl feeder.

2. Part population parts size and frequency were found to have positive effect on feed rate.

3. With increase in part size there is an increase in feed rate and the effect of part population for smaller size is positive on feed rate but constant for larger size.

4. Frequency and part population were found to have positive effect on feed rate when taken together.

5. Frequency had positive effect on feed rate whereas part size was having slight positive effect at lower frequencies whereas it had first increasing then decreasing effect at higher frequencies.

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