Mathematical Analysis of magnetic Belt Type Feeder

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Abstract- Automation is the use of machines, control systems and information technologies to optimize productivity in the production of goods and delivery of services. The increasing standards of quality and quantity in production, and adoption of various techniques to reduce production time has led to a tremendous increase in the research and development of tools that automate the production either directly or indirectly.

The aim of our work is to design and fabricate a physical prototype of a conveyor type magnetic feeder and analyse the performance, which feeds the ferromagnetic parts in desired orientation and feed rate. The feeding behaviour was studied experimentally by varying the input parameters such as speed of conveying, number of magnets and part population.

The interaction among the factors was studied by a full 2^3 factorial experimental approach has been adopted using the two basic principles of experimental design- replication and randomization. The process model was formulated based on Analysis of variance (ANOVA) using Design-Expert® statistical package. The outcome is represented graphically and in the form of empirical model which defines the performance characteristics of the Magnetic Belt type Feeder.

Keywords – Automation, feeders, feed rate, Full 2^3 factorial design, ANOVA, DOE, Design Expert

I. INTRODUCTION

Parts feeders are required for transferring parts from one station of production to the next in automatic assembly lines.[I] They are effective in the conversion of random parts into consistent and discrete part. The parts are sequentially fed at a required feed rate and desired orientation.
Part feeders provide a cost effective alternative to manual labours, saving manufacturer's time, labour cost, ensuring consistency and safety.
The Designed feeder may achieve wider range feed rate by varying the different parameters studied during the experiment. The ease of changing the parameters has also been a very advantageous factor. The use of flexible magnets eases the motion of the conveyor belt and eliminates the requirement of high-torque motors.

II. EXPERIMENTAL ARRANGEMENT

A metallic frame was constructed which was provided with dedicated spaces for the 2 roller bearings, reservoir, chute, driving motor. The 2 roller bearings were placed on a vertical plane at a distance of 65cms and a conveyor belt was mounted on the rollers. The space for reservoir and the chute are on the opposite sides of the conveyor belt. The driving motor was coupled to the shaft of 1 of the bearing to provide the movement to the conveyor belt.[II]

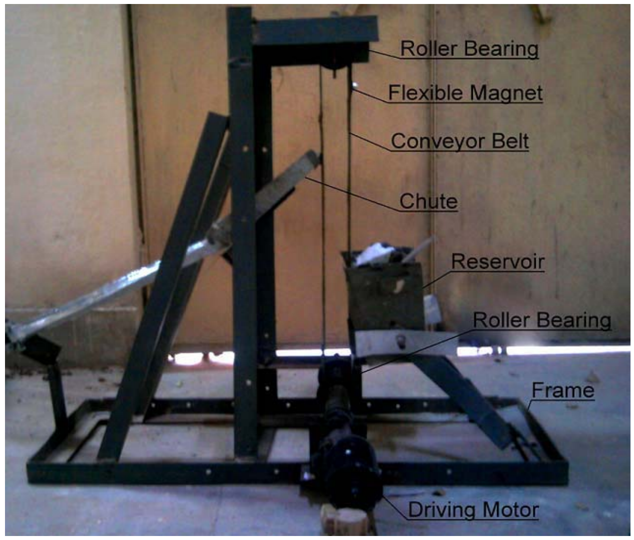

Figure 1: Magnetic Belt Type feeder Experimental Setup

Table 1: Specification

Length of conveyor belt	160cms
Width of conveyor belt	7.5cms
Thickness of conveyor belt	0.3cms
Diameter of roller bearing	4cms
Dimensions of each flexible magnetic pickups	1.5x1.5cms
Motor Rating	12V, 2Amps

2.1 Chief features taken care of while fabricating the experimental set up for this feeder:

i. *Using flexible magnet as pickup*

When the rigid conventional magnet would roll off and on to the roller bearing of the conveyor belt, a jerk would be produced, and the torque of the motor has to be tremendously increased to facilitate the movement of the magnet over the bearing. The use of flexible magnets eliminated this major problem.

ii. *Using a specially designed reservoir*

The reservoir designed, uses the conveyor belt as one of its wall and also has appropriate clearance for easy entry and exit of the pickups into and from the reservoir. While designing the reservoir care was taken that the parts must not fall off from the clearance provided. The reservoir is also provided with a restrictor so that only those parts that cling along their face may remain clinging with the magnetic pickup and rest all may fall back inside it.

iii. *Using a Orienting Chute*

The chute was so designed that the magnetic pickup may easily release the parts it had picked. The entry of the chute was constructed such that the parts get dropped along their face and slide down the chute resting on the same. The base of the chute was rotated through an angle of 90 degrees along its length. Thus the part resting on its face initially, exits the chute resting along its length.

III. ESSENTIAL FACTORS AFFECTING THE FEED RATE CHOSEN FOR ANALYSIS

A. Number of magnetic pickups

The feed rate varies positively with increase in the number of pickup, but the amount of magnetic pickups that can be used in the mechanism is constrained to the available space on the conveyor belt while maintaining a specific minimum gap between two consecutive pickups.

B. Parts population in the feeder

Significant variations in the feed rate take place with change in the total parts population inside the feeder. As the number of parts increase, the probability of the part getting picked up by the pickup each time it moves through the reservoir increases.

C. Speed of rotation of the motor driving the conveyor belt

The feed rate of the feeder was expected to be proportional to the speed of the driving motor that is with the increase in the speed of the conveyor belt, the feed rate increases.

IV. RANGES OF PARAMETERS

A) Number of Magnetic Pickups which is varied from 2 to 6
B) Population of parts in the feeder: Part population is varied from 50 to 150
C) Speed of the driving motor: RPM of the motor was varied from 52 to 102

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 2k 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 [V]. The upper and lower bounds of the range of each factor, which were coded as +1 and -1, are given in the Table 2.43

Table 2: Process parameters

Process parameters	Low level (-1)	High level (+1)
No of Magnets(A)	2	6
Part Population(B)	50	150
Speed of driving motor/RPM (C)	52	102

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

RUNS	FACTORS			Feed Rate(Response)		
	No. of magnets(A)	Part population(B)	Speed(C)	R1	R2	R3
1.	-1	-1	-1	18	20	19
2.	-1	1	-1	24	26	23
3.	-1	-1	1	32	35	33
4.	-1	1	1	47	46	49
5.	1	-1	-1	76	81	78
6.	1	1	-1	103	99	105
7.	1	-1	1	80	77	85
8.	1	1	1	108	115	110

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 Effects of factors on feed rate

The cube plot for feed rate (Figure 4) shows the average feed rates at critical points. The critical points are those points where all the parameters have limiting values.

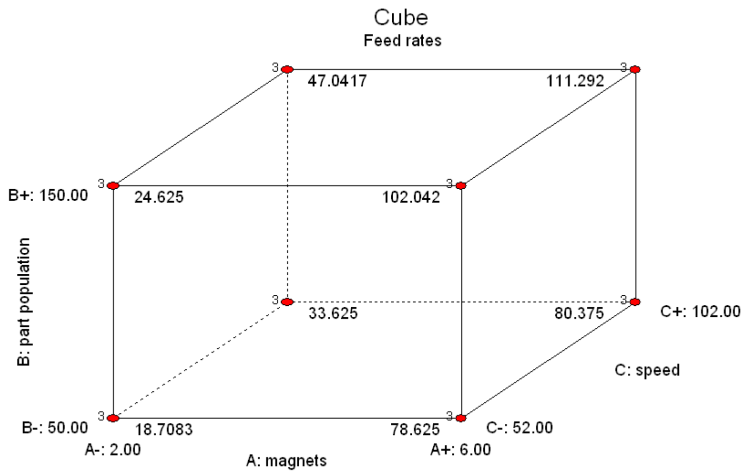

Figure 2: Cube plot for feedrate at limiting values

Figures below depict a plot of 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.[III] Since they can magnify or diminish the main effects of the parameters, evaluating interactions is extremely important.

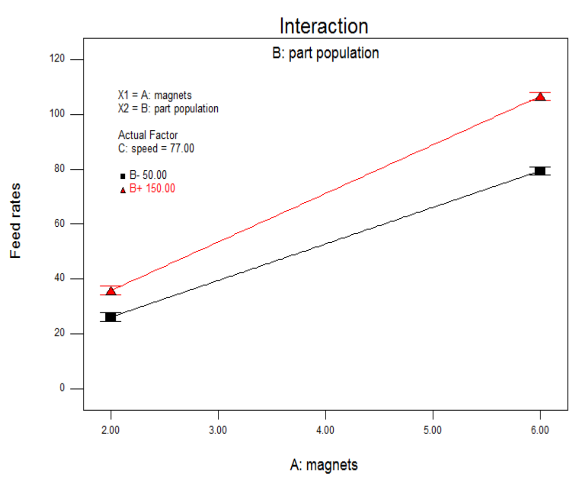

Figure 3: Interaction Plot between A and B factors

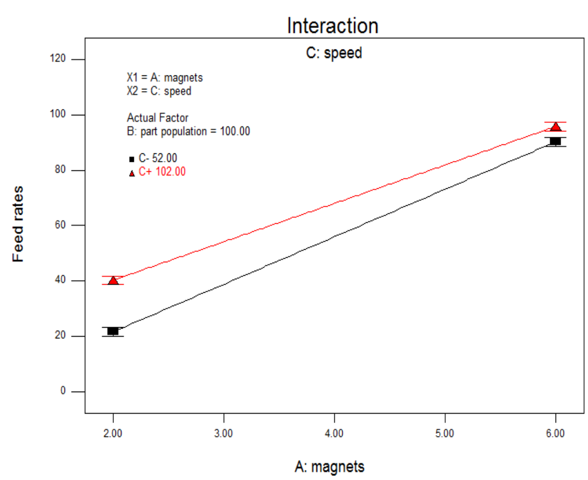

Figure 4: Interaction Plot between A and C factors

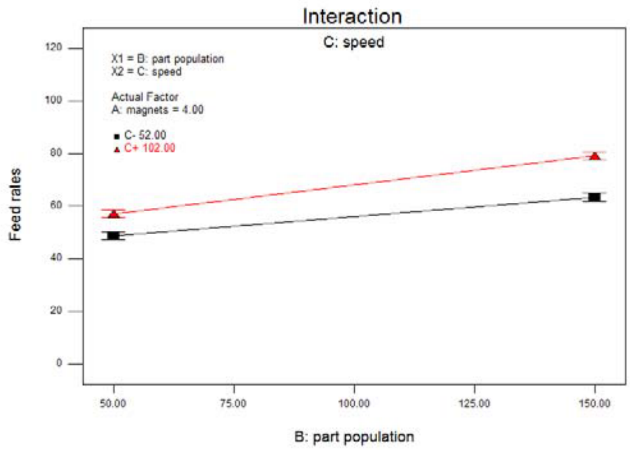

Figure 5: Interaction Plots between B and C factors

All three interaction plots(Figure 3,4,5) depict synergic interaction between the concerned factors in each graph. Although the lines on the plot do not cross each other but lack of parallelism of the lines exhibit significant interaction. The greater the departure of the lines from the parallel state, the higher the degree of interaction.

It is also important to know how the system behaves when variation is brought upon by varying only one parameter keeping the others constant. This gives the dependence of the system over the varied parameter. A main effect occurs when the mean response changes across the levels of a factor. The one factor graphs (Figure 6,7,8) can be used to compare the relative strength of the effects across factors. It can be asserted from the graph that the speed and part population have positive effects while the part size has negative effect on the output feed rate. It can also be concluded that No. of Magnets has profound effect on the output followed by Speed and Part Population.

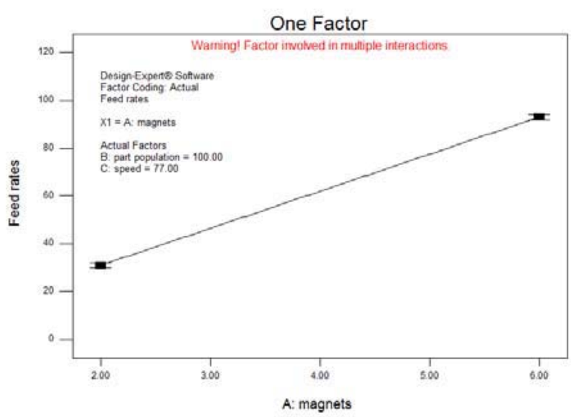

Figure 6: One Factor plot for Magnets(A)

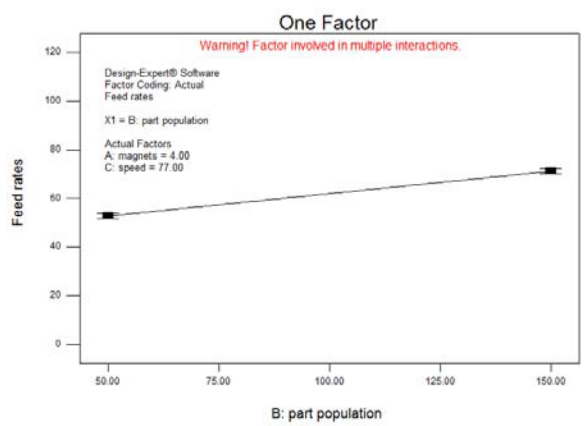

Figure 7: One factor plot for Part Population(B)

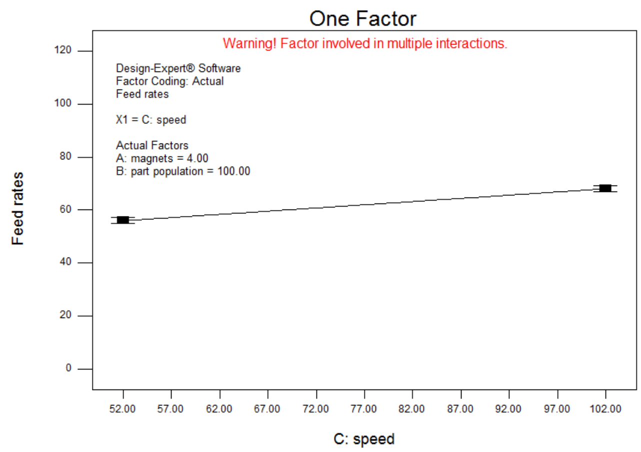

Figure 8: One factor plot for Speed©

6.2 Final Equation in Terms of Actual Factors:

Feed rate = *- 28.29333 + 16.21500*magnets – 0.10633 * part population + 0.35500*speed + 0.043750*magnets*part population – 0.065833*magnets*speed + 1.50000E-003* part population *speed*

6.3 Significance of various Parameters

The Pareto Chart (Figure 9) of the Effects and the Half Normal Plot of Standardized Effects 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 (16) for the error term. Any effect that extends within this reference line is statistically insignificant. [IV] The effect of A has the highest standardized effect on the feed rate followed by B, C, AB, AC and BC. However all effects extend above the t-value limit, hence significant. The significance of all factors can be reasserted from the half normal plot, in which the points that do not fall near the fitted line are significant.

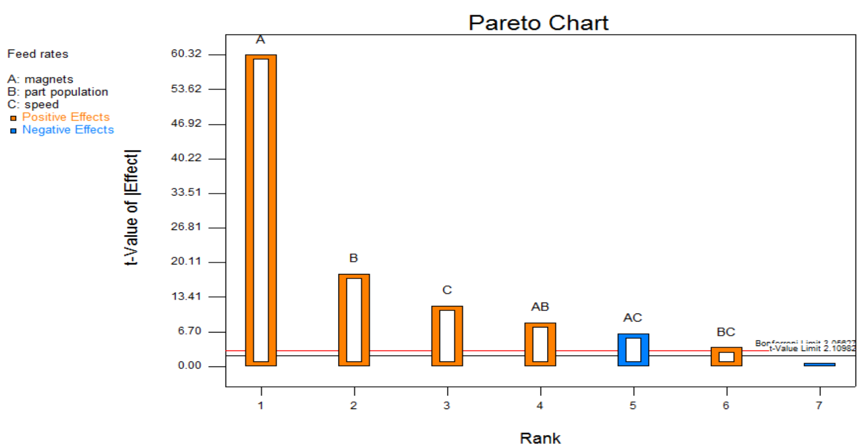

Figure 9: Pareto Chart

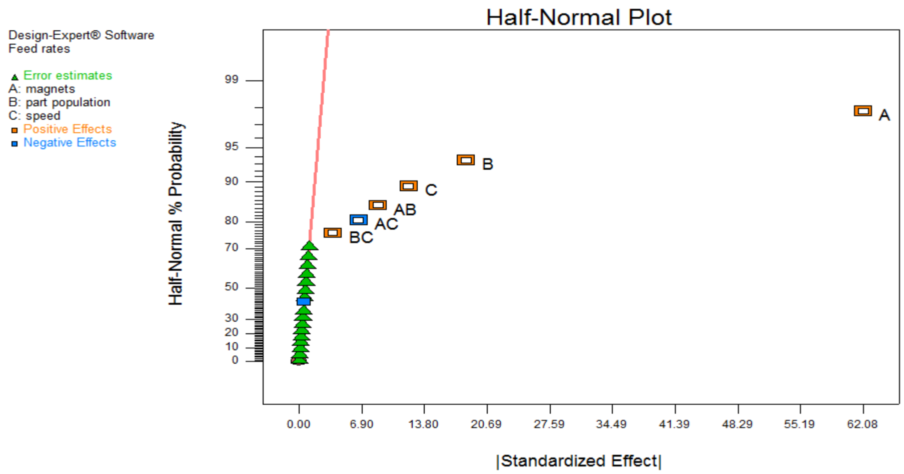

Figure 10: Half-Normal Plot

Table 4: Analysis of Variance Table

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F
Model	26840.92	6	4473.49	703.89	< 0.0001
A-magnets	23126.04	1	23126.04	3638.81	< 0.0001
B-part population	2035.04	1	2035.04	320.21	< 0.0001
C-speed	876.04	1	876.04	137.84	< 0.0001
AB	459.38	1	459.38	72.28	< 0.0001
AC	260.04	1	260.04	40.92	< 0.0001
BC	84.38	1	84.38	13.28	0.002
Residual	108.04	17	6.36		
Lack of Fit	2.04	1	2.04	0.31	0.5865
Pure Error	106	16	6.63		
Cor Total	26948.96	23			

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. [V] In general, a term that has a probability value less than 0.05 would be considered a significant effect. A probability value greater than 0.10 is generally regarded as not significant.

- The Model F-value of 703.89 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.
- Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, AC, BC are significant model terms.

Table 5: Diagnostic Case Statics

Std. Dev.	2.52	R-Squared	0.996
Mean	62.04	Adj R-Squared	0.9946
C.V. %	4.06	Pred R-Squared	0.992
PRESS	215.34	Adeq Precision	68.001

- R square measures the proportion of total variability explained by the model. From Table the value of R squared is 0.996. A potential problem with this statistic is that it always increases as factors are added to the model even if these factors are not significant. So the adjusted R squared was calculated which was 0.9946.

- The "Predicted R-Squared" of 0.9920 is in reasonable agreement with the "Adj R-Squared" of 0.9946.

- "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Hence a ratio of 68.001 indicates an adequate signal. This model can be used to navigate the design space.

- The mathematical equation for the feed rate was obtained for the actual factors. The Diagnostics Case Statistics compares the actual and predicted values and obtains the residual.

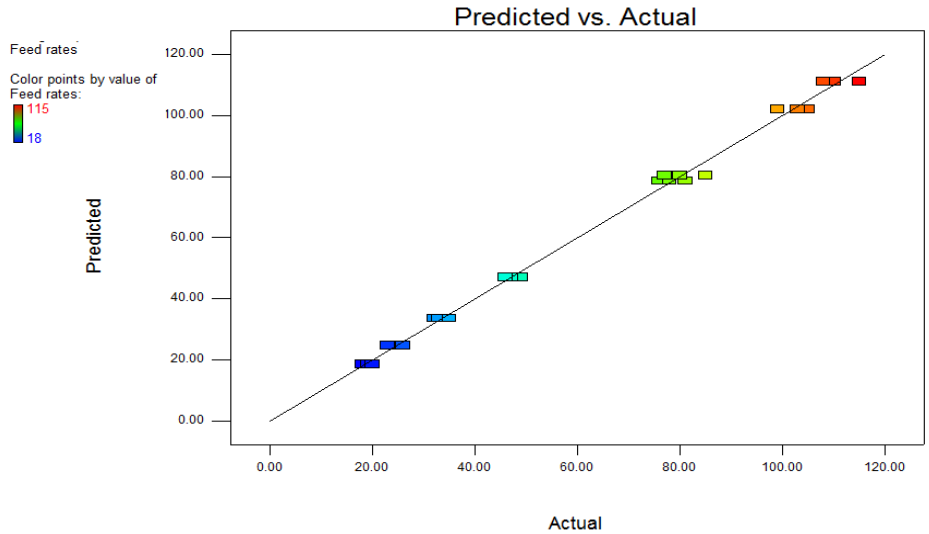

Figure 11: Predicted Vs Actual Values Plot

6.4 Optimization of Feed rate

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.[VI]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.

Table 6: Constraints

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:magnets	is in range	2	6	1	1	3
B:part population	is in range	50	150	1	1	3
C:speed	is in range	52	102	1	1	3
Feed rates	Maximize	18	115	1	1	3

A total of 26 solutions were obtained, out of which 10 most desirable solutions are tabulated below.

Table 7: Solutions

Number	Magnets	part population	speed	Feed rates	Desirability
1	6	150	102	111.292	**0.962 Selected**
2	6	150	101.37	111.175	0.961
3	6	149.58	102	111.163	0.96

4	6	149.18	102	111.039	0.959
5	5.98	150	102	111.016	0.959
6	6	150	100.04	110.902	0.958
7	6	150	99.85	110.894	0.958
8	6	150	99.12	110.758	0.956
9	5.94	150	101.75	110.272	0.951
10	6	147.95	98.62	110.041	0.949

In an exemplary situation, the feed rate of 85 was targeted with number of magnets equal to 4 and the corresponding optimum values of the remaining two factors need to be found. The results obtained from the optimization are shown below in Table 9.

Table 8: Constraints

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:magnets	is equal to 4	2	6	1	1	3
B:part population	is in range	50	150	1	1	3
C:speed	is in range	52	102	1	1	3
Feed rates	is target = 85	18	115	1	1	3

Table 9: Solutions

Number	magnets	part population	Speed	Feed rates	Desirability
1	4	150	102	79.1667	**0.913 Selected**
2	4	150	101.8	79.1018	0.912
3	4	150	98.59	78.0871	0.897

VII. CONCLUSION

An authentic statistical model based on full factorial experiment design has been developed which can be used for the optimization of output feed rate of the Magnetic Belt Type Feeder. The model is significant to explain 99% 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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