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DETERMINING THE OPTIMAL PARAMETERS FOR MAXIMUM CONVEYING VELOCITY OF PART FEEDERS USING ARTIFICIAL NEURAL NETWORK (ANN) AND ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM (ANFIS)

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Abstract:

A parts feeder is a device that receives randomly oriented parts at its input and delivers parts in a unique orientation at its output. Due to high tooling costs and long down times for retooling, the traditional part specific feeders are becoming unpopular. Hence, new designs are being proposed to make these feeders flexible, adaptive and capable of conveying the parts at optimal conveying velocity irrespective of the parts being conveyed. A feeder setup with provisions to adjust the track angle and the co-efficient of friction between the part and the track was fabricated with a control system based on MOSFET switch mode power converters. Experimental studies were carried out to determine the effect of feeder parameters (angle of vibration, track angle, duty cycle, frequency of excitation, amplitude of vibration), part parameters (length to width (l/w) ratio of the component, mass of the component) and coefficient of friction between the contact surfaces, on the conveying velocity. A linear regression model to fit the experimental data was determined. The obtained experimental data were used to train the Artificial Neural Network (ANN) and Adaptive Neuro-Fuzzy Inference System (ANFIS) and an adaptive control algorithm was determined for finding the optimum values of feeder parameters that would result in the maximum conveying velocity of parts. A comparison shows ANN was able to model the actual system more accurately than ANFIS.

Keywords : Adaptive Vibratory Part Feeder, Conveying Velocity, ANOVA, ANN, ANFIS.

1 INTRODUCTION

Automation of material handling of small sized components of bulk quantity is a major challenge which consumes more time and labor. Vibratory feeders and hoppers have been used widely to convey and feed small engineering parts for automatic assembly in a cost effective way. Numerous studies have been conducted on the performance of vibratory feeders. Taxonomy of various industrial parts and feeders, and orienting devices to improve its efficiency was developed [1-2].

Mathematical and dynamic simulation models for bowl feeders have been determined by several authors [3-6]. The equations of motion for a bowl feeder have been transformed with due considerations for a linear vibratory feeder and the modes of motion of the components on the track, namely, sliding, sliding and hopping have been investigated [7-8].

Some of the feeder parameters which affect the conveying velocity of a component in a linear vibrator are angle of vibration, track angle, frequency of vibration, amplitude of vibration, coefficient of friction between the contact surfaces. The effect of these parameters on the conveying velocity of feeders has been studied by many researchers in the past [9-17].

But the effect of part parameters, like length to width (l/w) ratio of the part, mass of the part and duty cycle for vibration excitation also have a crucial impact on the conveying velocity. This paper has considered the effect of other parameters on maximizing the conveying velocity.

Vibratory part feeders are easy to control and adapt well for different processing requirements - thereby reducing manual labor and saving the cost and time for the manufacturer. But designing a feeder each time for specific application consumes more time. This makes it necessary to develop an adaptive part feeding system capable of adjusting the feeder parameters to feed parts at the maximum conveying velocity [18-23]. In order to achieve this, it is essential to determine the optimum parameters that produce the maximum conveying velocity.

This paper is an attempt to find the optimal parameters to maximize the conveying velocity using Artificial Neural network (ANN) and Adaptive Neuro-Fuzzy Inference System (ANFIS) [26-29]. A comparison of the experimental values with both methods has been made and the results provided.

2 DEVELOPMENT OF EXPERIMENTAL SETUP

The setup to conduct the experimental studies is discussed in this section. The effect of feeder parameters (angle of vibration, track angle, duty cycle, frequency of excitation, amplitude of vibration), part parameters (length to width (l/w) ratio of the component, mass of the component) and coefficient of friction between the contact surfaces, on the conveying velocity is to be determined.

2.1 Feeder

The vibratory feeder fabricated for conducting few experimental studies is as shown in Fig. 1. The three main constituents of the vibratory feeder are:

- A driving (cam and follower) mechanism, which is responsible for generation of motion.

- A track, which is excited by the drive mechanism, and conveys it by providing a motion to the part.

- An elastic support (spring), which is used to bring the vibratory trough to its initial position after one half cycle of excitation, in order to transmit the motion from the drive to the track.

A vibratory trough of width 300 mm and length 600 mm is designed based on which the rest of the components are designed and fabricated. A support is used to clamp the trough to the cam and follower mechanism to transmit the vibratory motion. The support is connected to the springs in order to bring the trough to its initial position after one half cycle of excitation, to transmit the motion from the drive to the track. The support also has a bolt and nut arrangement to adjust the track angle. The track angle is adjusted using two adjusting bolts of pitch 1.5 mm at one end of the track. The values of the track angle are spaced close to each other in order to study the effect of small variations in track angle on the conveying velocity.

The rotary motion of the motor is converted into linear vibratory motion by using a cam and follower mechanism. The rotary motion is transmitted to the cam with the help of a pulley, V-belt and a shaft. The shaft carries the pulley and the cam on it and is supported with the help of deep groove ball bearings. The motion profile desired is a sine wave. Simple harmonic motion and cycloidal motion are the two types of motions, which produce sine waves as motion profiles. Simple harmonic motion is chosen largely due to its simplicity and versatility.

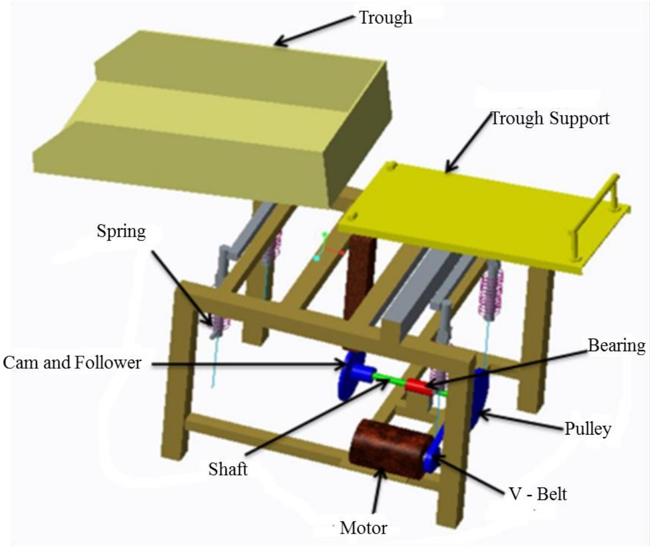

Figure 1: Design of the experimental setup

2.2 Control System for Duty Cycle and Frequency Excitatation

A control system is developed to achieve independent duty cycle and frequency control of the excitation force to the motor. The duty cycle for the experimental studies is chosen above 91% because the torque on the rotor becomes insufficient to drive the feeder for values less than 91%. Similarly, the frequency is chosen in the range of 35 to 50 Hz because the variation of the conveying velocity was found to be more evident in that range of values in the pre-experimental studies. The block diagram of the control system is shown in the Fig. 2.

Single phase 230 V power supply is given to the step down transformer. The step down transformer has one primary coil and two secondary coils. The number of turns of windings on the two secondary coils is in such a way that the output voltage from one secondary coil is 9 V and the output from the other secondary coil is 15 V. The 9 V AC output is connected to a rectifier circuit in order to obtain a rectified 5 V DC power supply needed to operate the micro-controller. The bridge rectifier circuit is used along with a large filter capacitor, a voltage regulator and a decoupling capacitor to maintain a constant output of 5 V irrespective of the fluctuations in the input. A large filter capacitor is used for filtering the pulsating output from the bridge rectifier and producing DC output. A decoupling capacitor is used to eliminate the ripples and obtain a smooth signal at the output. The 12 V rectifier circuit is used for operating the opto-couplers, MOSFET (Metal-oxide-semiconductor field-effect transistor**)** drivers and the MOSFETs. The designed control system is shown in the Fig. 3.

An opto-coupler or optical-isolator is a component that transfers electrical signals between two isolated circuits by using light. The opto-couplers are used to prevent the flow of high voltages from the MOSFET driver circuit to the Micro-controller. A MOSFET driver is a power amplifier that accepts a low-power input from a controller IC and produces a high-current drive input for the gate of a high-power transistor such as an IGBT or power MOSFET. The MOSFET is a type of Field Effect Transistor which is widely used for switching and amplifying electronic signals in electronic devices. Four opto-couplers are used to operate two MOSFET drivers which in turn operate two MOSFETs each. The required duty cycle and frequency control of the output signal is achieved through the adjustment of the timing of pulses from the micro-controller which controls the switching of the MOSFETs.

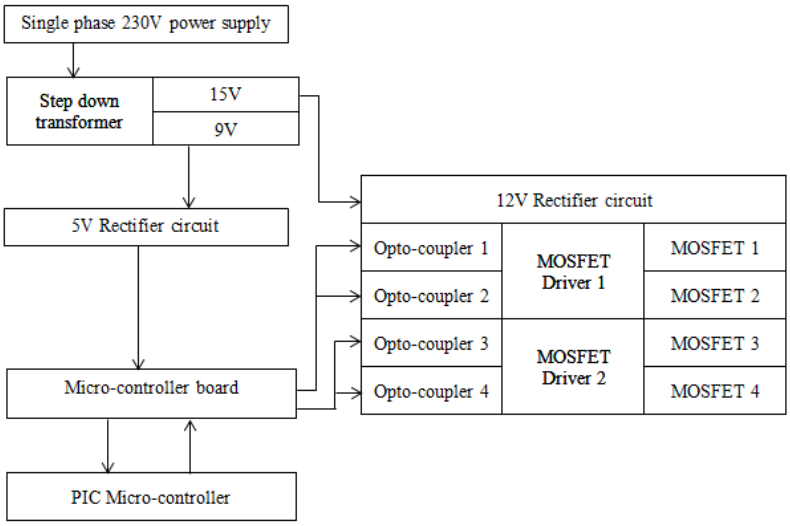

Figure 2: .Block diagram of the control system

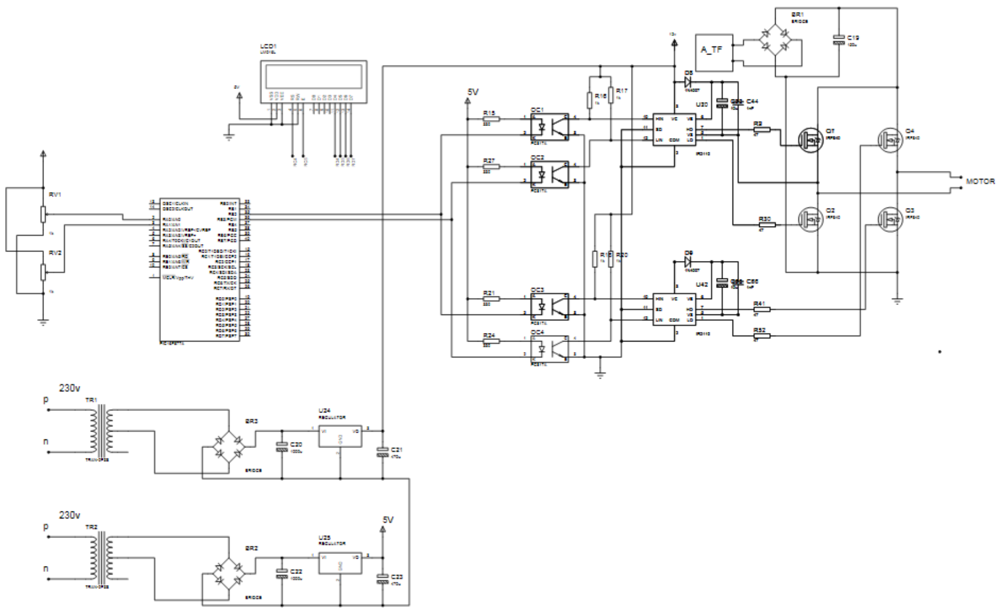

Figure 3: Control system for independent duty cycle and frequency control

When a pulse is sent to the opto-coupler, the LED is activated and it emits light, which falls on the phototransistor thereby sending a signal to the connected MOSFET driver. At any point of time, only two opto-couplers are active, which means that two MOSFET switches are active. The connections are given in such a way that two MOSFETs connected across one diagonal are activated and the other two MOSFETs connected across the other diagonal are de-activated at the same time. The motor is connected in between the four MOSFETs. When the opto-couplers OC1 and OC3 receive pulses, the MOSFETs Q1 and Q3 are switched on, and the signal flows through the motor in the positive direction. When the opto-couplers OC2 and OC4 receive pulses, the MOSFETs Q2 and Q4 are switched on, and the signal flows through the motor in the negative direction. In this manner, an AC waveform is generated at the output which is used to drive the AC induction motor.

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2.3 Parts Considered for Experimentation

The work piece for the experimental studies was chosen as brass because of the low cost, easy machinability, ready availability and the wide range of applications of the material. Brass parts of different masses and length-to-width (l/w) ratios fabricated as shown in Fig. 4 were used to study the effect of part parameters such as mass and length-to-width ratio of the part on the conveying velocity. The brass parts of mass 100 g, 50 g, 25 g mass and l/w ratio of 1, 1.5, and 2 were chosen for the experimental studies.

The coefficient of friction was varied by changing the track material. Mild steel, Acrylic and Polyurethane are some of the commonly used lining materials for the tracks of the vibratory feeders. The co-efficient of friction between Brass and Mild steel, Brass and Acrylic and Brass and Polyurethane are 0.44, 0.33 and 0.28 respectively.

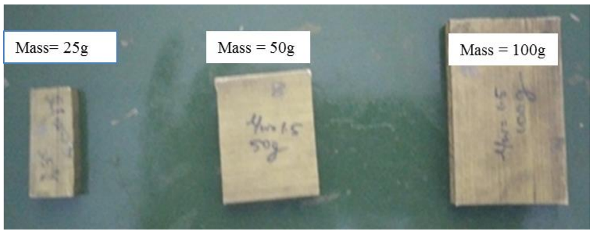

Figure 4: Brass parts with different masses and l/w ratio of 1.5

3 EXPERIMENTAL STUDIES

Experimental studies were carried out to find the effect of the feeder and the part parameters on conveying velocity and to determine the parameters that have the most crucial effect on the conveying velocity of parts. The obtained experimental data was then used to compute a linear regression model, train the ANN and the ANFIS to develop an adaptive control algorithm.

3.1 Effect of Feeder and Part Parameters on Conveying Velocity.

A set of experiments were conducted to study the effect of feeder parameters (angle of vibration, track angle, duty cycle, frequency of excitation, amplitude of vibration), part parameters (length to width (l/w) ratio of the component, mass of the component), and the coefficient of friction on the conveying velocity. Out of the six parameters (as in Table 1) one parameter is varied and the others are held constant cyclically and the conveying velocity is computed from the time taken by the part to move 200 mm along the track. The constant values of the six parameters are 0.44 (Coefficient of Friction), 7.75º (Track angle), 98% (Duty cycle), 42 Hz (Frequency of Vibration), 2 (l/w ratio) and 25 g (Mass). Three levels of each factor are selected, varied and listed in Table 1.

It is found that the conveying velocity decreases with an increase in the length-to-width (l/w) ratio, mass of the part and the co-efficient of friction between the part and the track as shown in Fig. 5a, 5b, and 5c.

Table 1: Factors and levels chosen for experimentation

FACTORS	**LEVELS**		
	L1	**L2**	**L3**
Co-efficient of friction μ	0.28	0.33	0.44
Track angle (˚)	7.75	7.90	8.06
Duty cycle (%)	92	95	98
Frequency f (Hz)	36	42	48
Mass m (kg)	0.025	0.05	0.1
l/w ratio	1	1.5	2

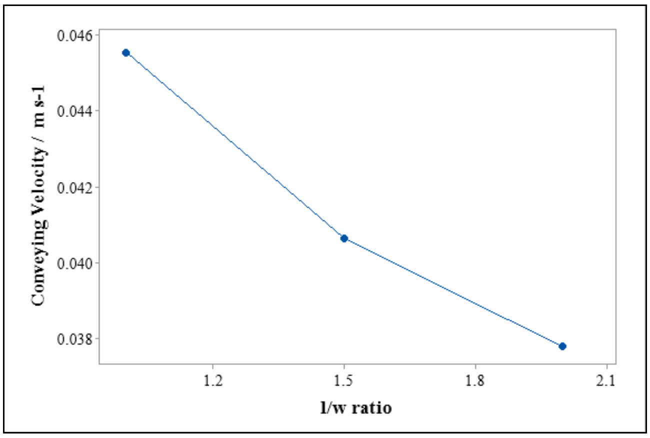

Figure 5a: Effect of l/w ratio on Conveying Velocity

The conveying velocity increases with an increase in the frequency, duty cycle and track angle as shown in Fig. 5d, 5e and 5f

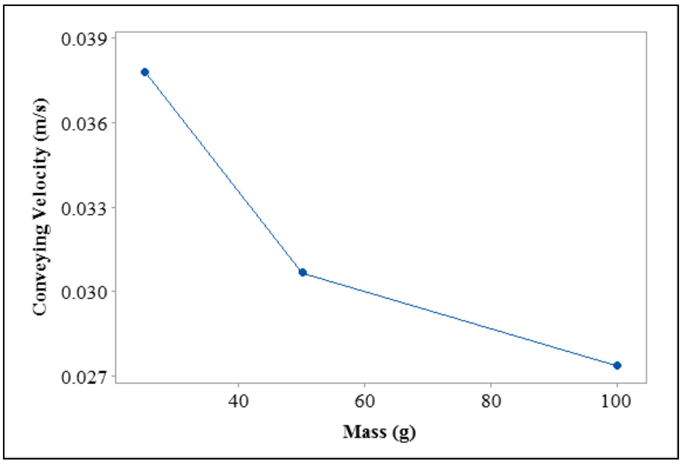

Figure 5b: Effect of Mass on Conveying Velocity

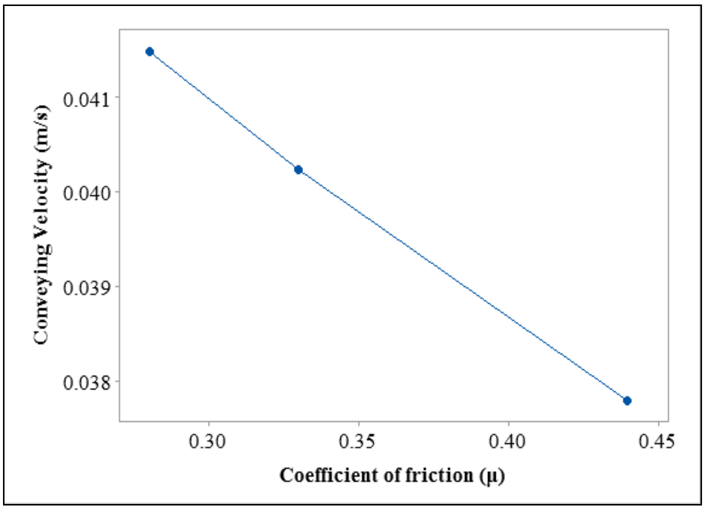

Figure 5c: Effect of Coefficient of Friction on Conveying Velocity

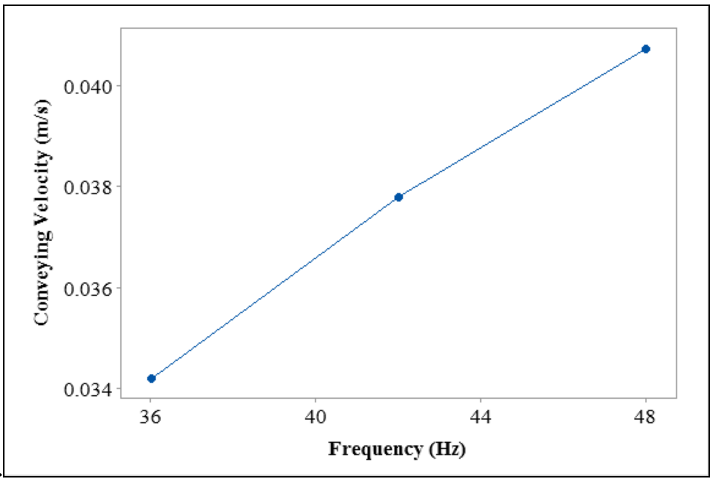

Figure 5d**:** Effect of frequency on conveying velocity

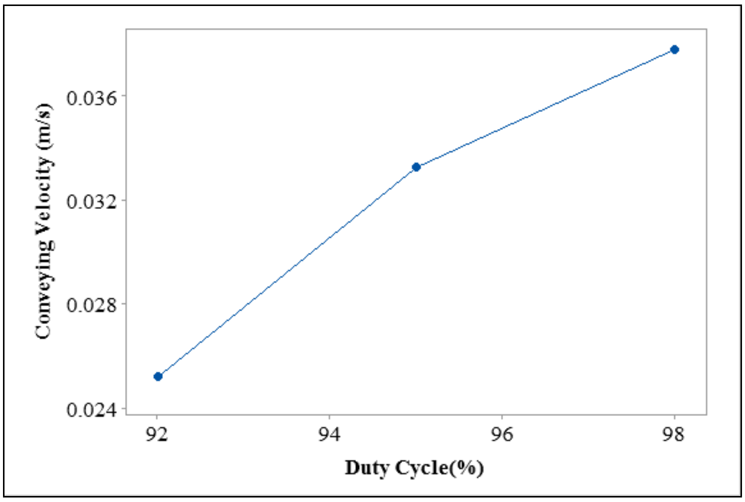

Figure 5e**:** Effect of duty cycle on conveying velocity

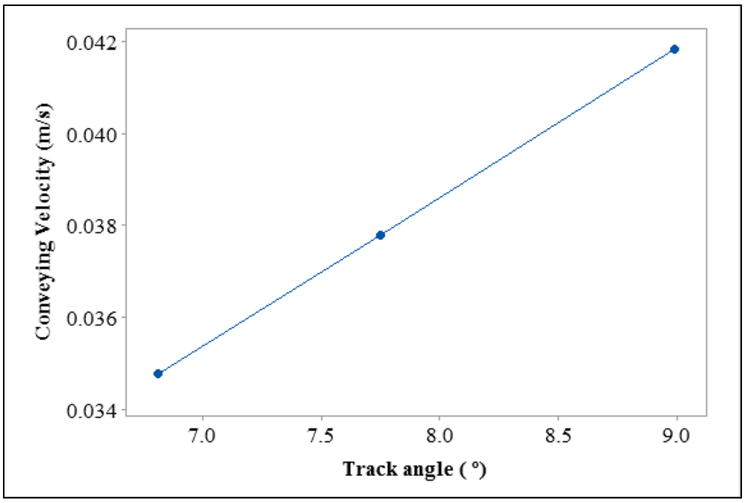

Figure 5f: Effect of track angle on conveying velocity

3.2 Design of Experiments

The Design of Experiments has been employed in this paper in order to reduce the number of trials required to study the effect of the feeder and part parameters on conveying velocity. Taguchi orthogonal array L_{27} is used for the DOE. Table 2 shows the Taguchi design for 6 factors at 3 levels.

The distance of 200 mm is marked on the vibratory track and the lining materials. The time taken by the parts to move 200 mm on the vibratory track was recorded and the conveying velocity was calculated. The time taken is measured using a stopwatch. For each combination, three trials were conducted and the time taken was calculated as the average of the time recorded in the trials.

3.3 Analysis of Variance

In order to determine the parameters that have the most crucial effect on the conveying velocity, Analysis of Variance (ANOVA) is carried out on the experimental data using the Minitab 18 software. Table 3 shows the tabulated data of Analysis of Variance. To decide on the statistical significance of each main effect on its interaction effect, the p-value for each term is compared to the critical significance level to assess the null hypothesis. A significance level of 0.05 was chosen and it indicates a 5% risk of concluding that an effect exists.

Table 2: Factors and levels chosen for experimentation

S. No	Co-efficient of friction, μ	Track angle , θ (˚)	Duty cycle (%)	Freq.,f (Hz)	Mass, m (g)	l/w ratio
1	0.33	7.75	92	36	25	1
2	0.33	7.75	92	36	50	1.5
3	0.33	7.75	92	36	100	2
4	0.33	7.9	95	42	25	1
5	0.33	7.9	95	42	50	1.5
6	0.33	7.9	95	42	100	2
7	0.33	8.06	98	48	25	1
8	0.33	8.06	98	48	50	1.5
9	0.33	8.06	98	48	100	2
10	0.28	7.75	95	48	25	1.5
11	0.28	7.75	95	48	50	2
12	0.28	7.75	95	48	100	1
13	0.28	7.9	98	36	25	1.5
14	0.28	7.9	98	36	50	2
15	0.28	7.9	98	36	100	1
16	0.28	8.06	92	42	25	1.5
17	0.28	8.06	92	42	50	2
18	0.28	8.06	92	42	100	1
19	0.44	7.75	98	42	25	2
20	0.44	7.75	98	42	50	1
21	0.44	7.75	98	42	100	1.5
22	0.44	7.9	92	48	25	2
23	0.44	7.9	92	48	50	1
24	0.44	7.9	92	48	100	1.5
25	0.44	8.06	95	36	25	2
26	0.44	8.06	95	36	50	1
27	0.44	8.06	95	36	100	1.5

From the analysis of variance, it is found out that the parameters track angle (p=0.009), frequency of the excitation force (p=0.011) and duty cycle (p=0.031) have a significance level of less than 0.05. It means that these three parameters have a crucial effect on the conveying velocity of the parts. Track angle has the lowest significance level of 0.009 which means that it has the most crucial effect on the conveying velocity. The parameters co-efficient of friction between the part and the track (p=0.117), length-to-width (l/w) ratio (p=0.567) and mass of the part (p=0.656) have a significance level of greater than 0.05 which means that they do not have a crucial effect on the conveying velocity.

3.4 Linear Regression Model

A linear regression model for the Taguchi design, indicated as equation (1), has been computed using Minitab 18 software, to fit the experimental data of the conveying velocity.

The regression model used to fit the data is given by,

v = 8.37 - 0.339 Coefficient. of friction - 2.818 Track angle + 0.0674 duty cycle - 0.00994 Frequency + 0.00271 Mass - 0.269 l/w ratio + 0.249 Coefficient of friction*Coefficient. of friction + 0.1767 Track angle*Track angle-0.000353 duty cycle*duty cycle + 0.000125 Frequency*Frequency - 0.000001 Mass*Mass + 0.01509 l/w ratio* l/w ratio + 0.000918 Coefficient of friction *Mass + 0.0929 Coefficient of friction * l/w ratio - 0.000180 Track angle*Mass + 0.0155 Track angle* l/w ratio - 0.000014 duty cycle*Mass + 0.00063 duty cycle* l/w ratio - 0.000006 Frequency *Mass + 0.000188 Frequency * l/w ratio (1)

The accuracy of the model can be determined using the S and the R-square value which is 0.0027772 and 96.15 % respectively. If the R^2 value is higher, the model fits the data better. S represents the standard deviation of the data values from the fitted values. If the value of S is lower, the model described by the response is better.

3.5 Residual Plots

The residual plots can be used to decide whether the model meets the assumptions of the analysis. The residuals versus fits plot, residual versus order plot, normal probability plot of residuals and histogram are shown in Fig. 6.

The inference that the residuals are randomly distributed and have constant variance is arrived at on the fact that the points are randomly arranged on either side of the zero line and also appear to be scattered in the residuals vs fits plot

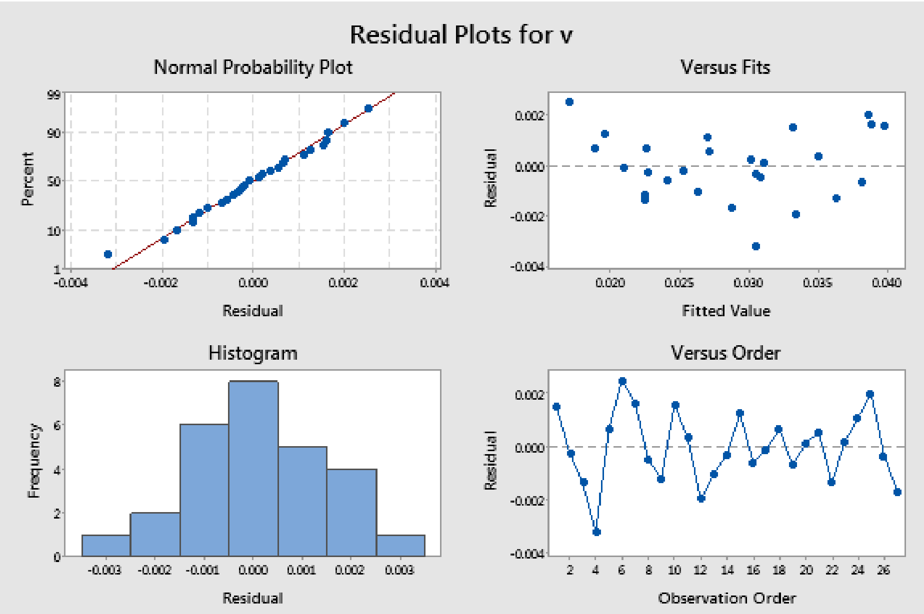

Figure 6: Residual plots for conveying velocity v

Table 3: Analysis of variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	20	1.16E-03	5.80E-05	7.49	0.010
Coefficient. of friction	1	2.60E-05	2.60E-05	3.35	0.117
Track angle	1	1.10E-04	1.10E-04	14.21	0.009
Duty cycle	1	6.10E-05	6.10E-05	7.89	0.031
Frequency	1	1.00E-04	1.00E-04	12.94	0.011
Mass	1	2.00E-06	2.00E-06	0.22	0.656
l/w ratio	1	3.00E-06	3.00E-06	0.37	0.567
Coefficient. of friction *Coefficient. of friction	1	1.10E-05	1.10E-05	1.39	0.282
Track angle*Track angle	1	1.08E-04	1.08E-04	13.99	0.010
Duty cycle*Duty cycle	1	6.10E-05	6.10E-05	7.87	0.031
Frequency* Frequency	1	1.21E-04	1.21E-04	15.67	0.007
Mass*Mass	1	1.00E-06	1.00E-06	0.14	0.723
l/w ratio* l/w ratio	1	2.10E-05	2.10E-05	2.77	0.147
Coefficient. of friction*Mass	1	1.70E-05	1.70E-05	2.14	0.194
Coefficient. of friction* l/w ratio	1	2.90E-05	2.90E-05	3.76	0.101
Track angle*Mass	1	1.00E-06	1.00E-06	0.17	0.692
Track angle* l/w ratio	1	2.00E-06	2.00E-06	0.22	0.655
Duty cycle*Mass	1	3.00E-06	3.00E-06	0.42	0.541
Duty cycle* l/w ratio	1	1.00E-06	1.00E-06	0.14	0.725
Frequency*Mass	1	3.00E-06	3.00E-06	0.34	0.583
Frequency* l/w ratio	1	0.00E+00	0.00E+00	0.05	0.833
Error	6	4.60E-05	8.00E-06		
Total	26	1.20E-03			

It can be concluded that the residuals are not dependent on one another if the residuals are seen randomly arranged around the centerline and do not show any pattern or trend in variation in the residual vs order plot.

Verification of the assumptions that the residuals are distributed normally is done using the normal probability plot of residuals. The plot should follow a straight line approximately.

4 ADAPTIVE CONTROL ALGORITHM

A control algorithm is designed to determine the optimal feeder parameters to achieve the maximum conveying velocity for a part having the 6 factors at 3 levels. The control algorithms were developed using two methods: Artificial Neural Network (ANN) and Adaptive Neuro-Fuzzy Inference System (ANFIS). The data that were obtained from the experimental studies were used to train the system in both the methods. The results obtained from the two methods are compared against the experimental values to determine the better system.

The ANN and ANFIS are trained and developed in the MATLAB R2015a program development environment. The method of training ANFIS is similar to training the ANN with differences in the syntax used for training the system. The trained ANN and ANFIS can now be used in developing an adaptive control algorithm. The algorithm is developed in such a way that when the co-efficient of friction between the part and the track, the mass and the length-to-width ratio of the part are given as inputs to the algorithm, the track angle, the duty cycle and the frequency that result in maximum conveying velocity are displayed as outputs.

5 RESULTS AND DISCUSSION

When the program is run, the neural network is trained and its training parameters, the minimum gradient achieved and the performance values displayed. The performance plot of the same is shown in Fig. 7. It can be seen that the best performance of is achieved after 5 epochs.

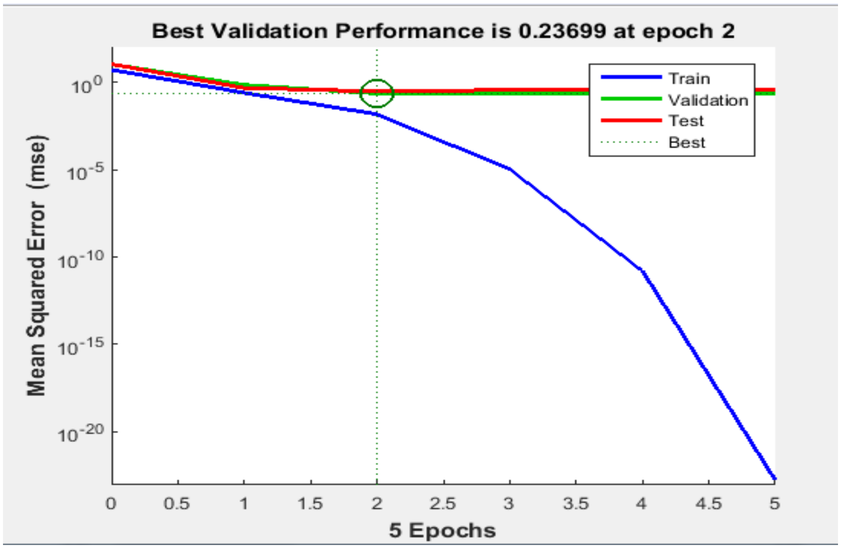

Figure 7: Performance plot of the ANN

The regression plot of the ANN is shown in the Fig. 8 and Fig. 9. The accuracy of the regression fit can be determined using the co-relation co-efficient 'R'. The co-relation coefficient for training and overall fits is 0.982 and 0.907 respectively.

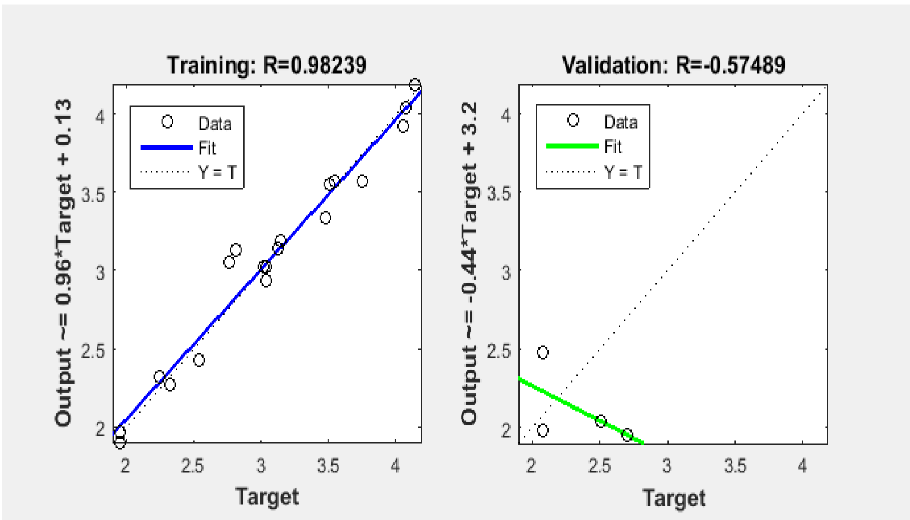

Figure 8: Regression plot of the ANN

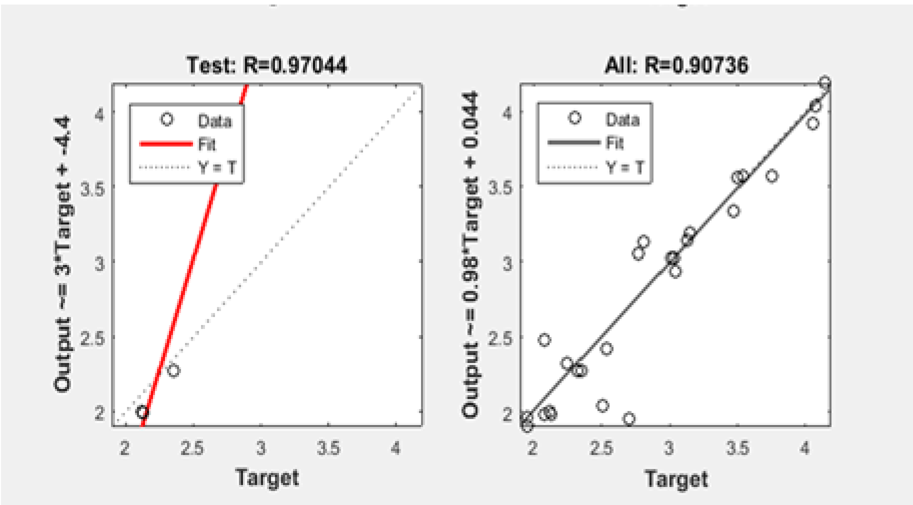

Figure 9: Regression plot of the ANN

Table 4: Feeder and part parameters for testing and validation of ANN, ANFIS

Set No	**μ**	**m (g)**	**l/w**	**θ (˚)**	**Duty Cycle (%)**	**f (Hz)**
1	0.44	50	1.5	7.5	98	39
2	0.44	25	2	8.4	98	38
3	0.28	50	1	8.9	97	50
4	0.33	50	2	8.9	98	50
5	0.28	25	2	8.9	94	50
6	0.33	50	1	8.9	90	25
7	0.28	25	1.5	7.75	98	42
8	0.33	25	1	8.06	95	42
9	0.44	100	1.5	8.06	92	48
10	0.44	50	1	7.75	92	36

After the neural network has been trained, it is used in the adaptive control algorithm to determine the optimal feeder parameters to achieve maximum conveying velocity for a part. The feeder and part parameters considered for testing of ANN and ANFIS is tabulated in Table 4. Thus, for a part which has a μ of 0.33, mass of 0.05 kg and length-to-width (l/w) ratio of 2, the maximum conveying velocity obtained in ANN is 0.0420 m/s. The feeder parameters that give the maximum conveying velocity are track angle of 8.9˚, duty cycle of 98% and frequency of 50 Hz.

The conveying velocity obtained for the tabulated values through ANFIS is 0.03942 m/s. The experimentally obtained conveying velocity for the same combination of parameters is 0.04184 m/s. The percentage deviations of the conveying velocity obtained from ANN and ANFIS with respect to the experimental values, are calculated and are plotted in Fig. 10

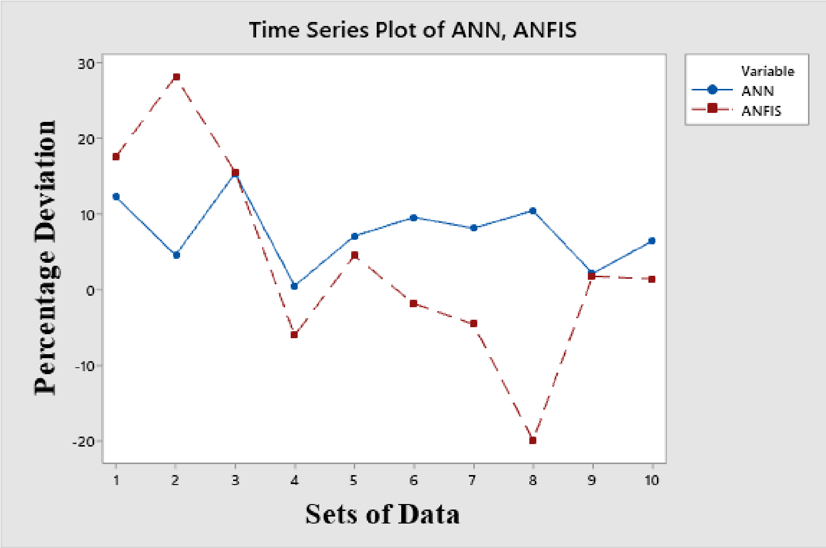

Figure 10: Conveying velocity – Percentage Deviation

The maximum and minimum deviations (%) obtained from the two models - ANN and ANFIS with respect to the experimental values are tabulated in Table 5. ANN shows the least deviation among the algorithms. This means that the ANN models the actual system more accurately than ANFIS.

Table 5: Consolidated results

Models	**% Deviation in velocity**		**Range of deviation (%)**	**Remarks**
	Max.	**Min.**		
ANN	15.37	0.48	14.89	Best fit
ANFIS	28.17	1.40	26.77	Second best fit

CONCLUSION

An experimental setup with provisions to adjust the feeder parameters (angle of vibration, track angle, duty cycle, frequency of excitation, amplitude of vibration), part parameters (l/w ratio of the component, mass of the component) and coefficient of friction between the contact surfaces, was developed and experimental studies were carried out to find the effect of feeder and part parameters on the conveying velocity.

- It was found that the conveying velocity increased with an increase in the frequency, duty cycle and track angle. The conveying velocity decreased with an increase in the length-to-width ratio, mass of the part and the co-efficient of friction between the part and the track.
- It was found that the parameters track angle ($p=0.009$), frequency of the excitation force ($p=0.011$) and duty cycle ($p=0.031$) have a significance level of less than 0.05 and have a crucial effect on the conveying velocity of the parts. Track angle has the lowest significance level of 0.009 and has the most crucial effect on the conveying velocity.
- A linear regression model (1) to fit the experimental data of the conveying velocity was computed. ANN and ANFIS were trained and tested to develop an adaptive control algorithm to determine the optimum values of feeder parameters for maximum conveying velocity of parts.
- The deviation in conveying velocity values for a different set of data, taken for validation, of all three models confirmed that the ANN (Deviation Range = 14.89%) was able to model the actual system more accurately than the ANFIS (Deviation Range = 26.77 %).
- The developed adaptive control algorithm can be used in an automated system where the output values from the adaptive control program can be calibrated to run the driver of the vibratory feeder, thereby making the feeder self-adjusting.

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