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MANUFACTURING AUTOMATION FOR HANDLING ASYMMETRIC COMPONENTS

Abstract:

A prominent problem in manufacturing automation is the accurate and reliable presentation of small parts, in a single specified configuration called preferred orientation, to a work cell. This is often referred to as the "part feeding" problem. Low cost automation is employed to develop the part feeding system for brake liner, a typical asymmetric part. Currently handling of such asymmetric parts is done either manually or by using expensive robot and vision systems. These approaches cumulatively increase the production cost. The proposed low cost part feeder system uses sensorless mechanical devices or barriers such as slot, wiper blade, balcony, edge riser etc. to eliminate or reorient the arbitrary orientation into a preferred orientation which facilitates stacking. A complete set of such mechanical devices is called trap. The orientation with highest probability of occurrence is found using drop test, which is the preferred orientation at the exit of the feeder. A trap is designed to get the preferred orientation at the exit of the feeder. Critical dimensions of the trap were identified and experiments were conducted to optimize them.

Keywords:

Part feeders, linear vibratory feeders, traps, brake liners

INTRODUCTION

Automation is generally employed in the field of material handling and orienting in a manufacturing environment. An accepted definition of materials handling is the art and science of moving, positioning, packing and storing substances in any form. The material handling devices are normally designed around standard production machinery and integrated with specially made feeders. Such feeders replace human effort by supplying the material-to-be-worked at the work station. Machinery designers undertake the design of special elements based on the material-to-be-handled, range available in the market, affordability etc. Asymmetric components in the form of circular/cylindrical sectors are few areas unchartered. In the present work, brake liner, a typical asymmetric component has been considered and a feeding system is developed to feed and orient them. With our manufacturing sectors requiring large volume of such a product, automation based processes become essential. In the field of research, automation is not new and there has been substantial amount of literature published in this area. However, the published work is mostly limited to cylindrical and regular prismatic components. The sector shaped parts like brake liners, half bearings have more number of stable poses, which makes the processes of feeding and orienting, complex. Hence, a specialized feeding system has to be designed. Boothroyd [1] has done seminal work on characterizing industrial part feeders. An excellent introduction to mechanical parts feeders can be found in Boothroyd's book .With Poli and Murch[2], he developed taxonomy of industrial parts and feeders for orienting such small industrial parts.Goldberg and Gordon smith [3] discussed a class of mechanical filters that can be described by removing polygonal sections from the track of the feeder; they refer to this class of filters as traps, which eliminate or reorient the parts until they reach the final preffered orientation. These traps do not employ any sensor based devices. Robert-Paul Berretty et al [4]has discussed about design of traps for vibratory bowl feeders . B.K.A.Ngoi et al [5] has analyzed the natural resting aspects of parts in vibratory bowl feeders using 'Drop Test'. The works of Dina R. Berkowitz et al [6] concentrated on a tool based on dynamic simulation for Markov model building of part feeders. This Markov model was used to evaluate the performance of the feeder. Edmondson et al [7] has developed a flexible parts feeding system using flex feeders, pattern matching sensors and PLC. Wee et al [8] developed a flexible belt parts feeder to separate cylindrical parts. Patrick S.K. Chua et al [9] developed an active feeder for handling cylindrical parts having grooves at one end. Omno C Goemans et al [10] discussed about blades for feeding 3D parts on vibratory tracks. He had considered L-type and T-type components for his experiments. In the present paper, an attempt is made to design a simple inexpensive trap to make the asymmetric component (brake liner) fall in the preffered orientation on a moving conveyor without the aid of robots and sensors. The conventional manufacturing of brakeliners segment parts involve the following processes as shown in Table.1 The granules are mixed with chemicals and are preformed into a brakeliner sheet. The brakeliner sheet is cut into samll brakeliner pieces in a slitting machine. The brakeliners are then sent for internal grinding, external grinding, chamfering and final inspection.

Table.1 Manufacturing of brake liners

Operation No	Process
1	Mixing of granules with chemicals
2	Preforming / hot molding
3	Slitting/ cutting to size
4	Internal grinding / finishing
5	Outer grinding/ finishing
6	Chamfering/ edge nosing
7	Inspection of size/ shape

During each stage of operations 3 to 6 (Figure.1), the components have to be segregated and stacked for further processing. In the absence of an appropriate part feeding system, the segregation and stacking between each stages are to be done manually., which consumes more labour time. If a part feeding system is developed for handling these parts, then productivity can be increased by reducing the labour time.

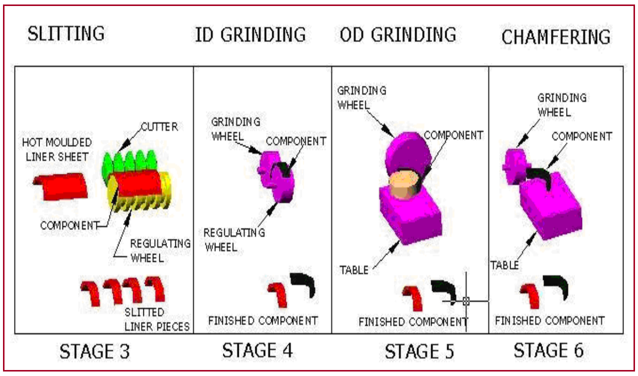


Figure.1 Machining stages of brake liners

OBJECTIVES & METHODOLOGY

The following objectives are addressed to fulfill the above requirements:

- To study the different resting orientations of sector shaped parts and determine the most probable occurring orientation
- To develop a part feeder system using traps to handle sector shaped parts.
- To determine the critical dimensions of the trap.

The methodology of the work is listed below:

- Study of resting orientations of the identified sector part (brake liner) and identification of the most favorable orientation by drop test.
- Design of a part feeding system (trap) for the favorable orientation of the brake liner, without sensors.
- Determination of critical dimensions of the trap, experimentally.

NATURAL RESTING ORIENTATION OF THE BRAKE LINER

The brakeliner considered for the experiments is shown in Figure.2. This brake liner is sector shaped, asymmetric in nature and has less weight of about 8.829 g.

The brakeliner has eight possible resting orientations which are numbered as 1 to 8 as shown in Figure.3.

Out of the eight orientations, the neighbouring orientations are clubbed into same family and are named as orientations 'a', 'b' and 'c' as shown in Figure.4. The orientations 1,2 3 and 4 *which rest on the sector shaped sides are grouped as orientation 'a'. The orientations 6 and 8 which have their open side facing towards sky are grouped as orientation 'b'. The orientations 5 and 7 which have their open side facing towards ground are grouped as orientation 'c'. The orientations a, b and c were considered only for drop tests and for design of traps, orientations 1 to 8 were considered.*

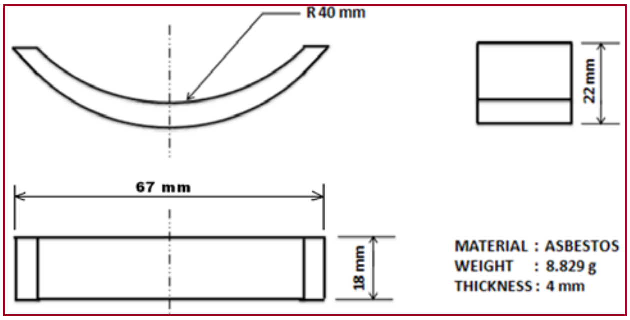


Figure.2 Brake Liner

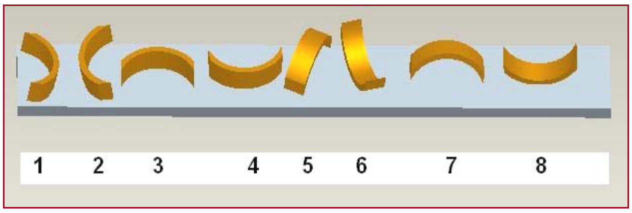


Figure.3 Resting orientations of brakeliner

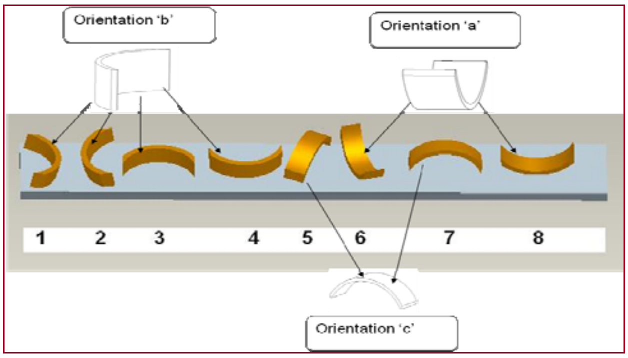


Figure. 4 Clubbing of orientations of brakeliner

DROP TEST

In order to determine the most occurring natural resting orientation of parts, drop test was conducted. The following steps were involved in the drop test [5]

- *A sample size of 30 parts was taken.*
- *Parts were dropped one at a time from a height into a hopper.*
- *When the part came to rest, the orientation was noted.*
- *Steps 1 to 3 were repeated by varying the initial orientation from a, b and c with the height fixed.*
- *Steps 1 to 4 were repeated for varying heights of 10, 12, 14, 16, 18, 20, 22, 24 and 26 cm. (When the part is dropped at any height greater than of 26cm, the part jumps out of the hopper).*
- *The orientation which occurs the most was considered the natural resting orientation or the favorable orientation of that part.*

Figure.5(a) to Figure.5(i) show the result of drop test conducted at different heights (10 cm to 26 cm) with initial orientations as a, b and c.

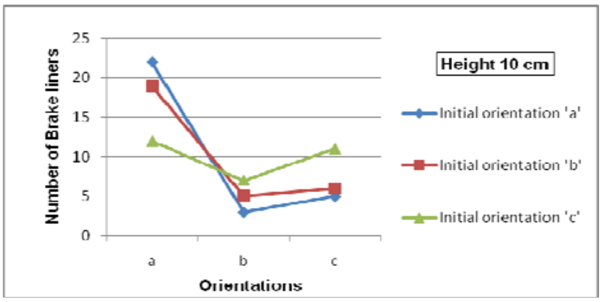


Figure.5(a) Effect of initial orientation when dropped from 10 cm height

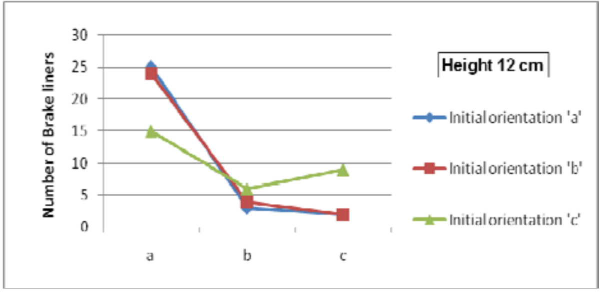


Figure.5(b) Effect of initial orientation when dropped from 12 cm height

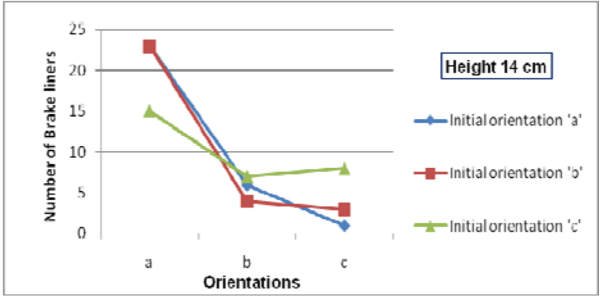


Figure.5(c) Effect of initial orientation when dropped from 14 cm height

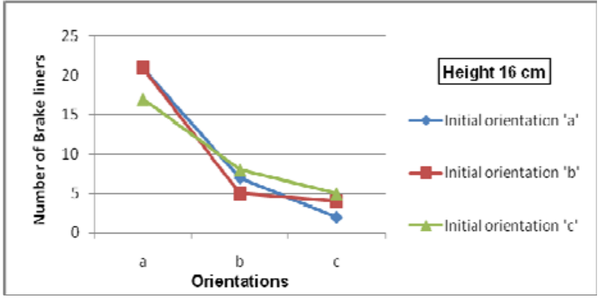


Figure.5(d) Effect of initial orientation when dropped from 16 cm height

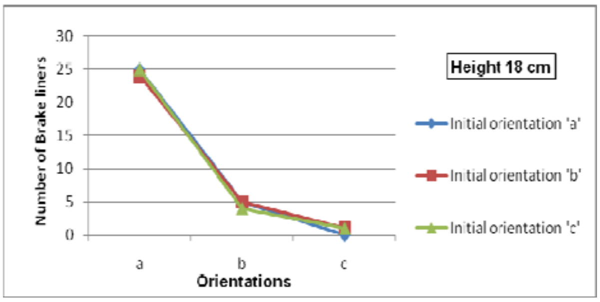


Figure.5(e) Effect of initial orientation when dropped from 18 cm height

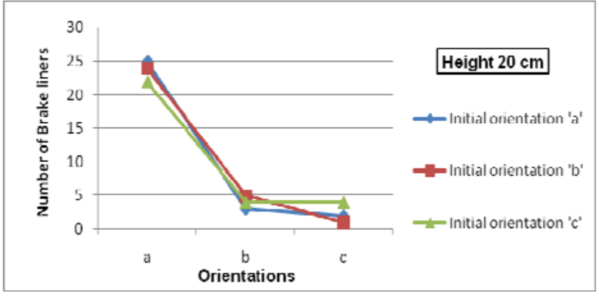


Figure.5(f) Effect of initial orientation when dropped from 20 cm height

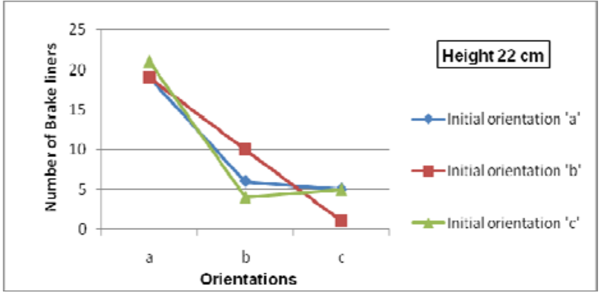


Figure.5(g) Effect of initial orientation when dropped from 22 cm height

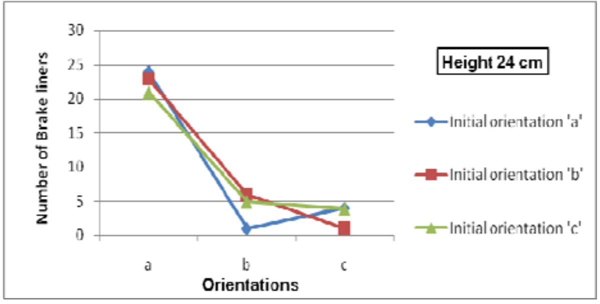


Figure.5(h) Effect of initial orientation when dropped from 24 cm height

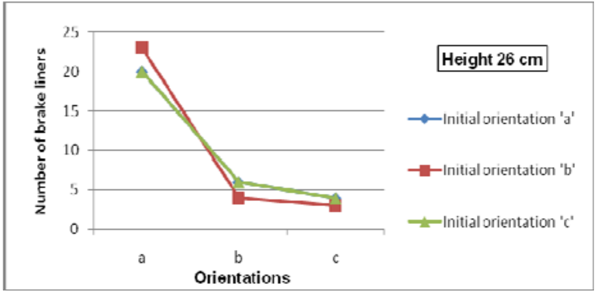


Figure.5(i) Effect of initial orientation when dropped from 26 cm height

It can be observed from the above drop test data that, orientation 'a' was obtained mostly, irrespective of which initial orientation the part was dropped as shown in Figure.5(a) to Figure.5(i). So the trap has to be designed in such a way that output is always orientation 'a', i.e. orientation 6 or 8 as shown in Figure.3. The height was observed to be a factor that changed the probability of occurrence of natural resting orientations due to its impact on potential energy of the part. Thus a proper height has to be maintained to obtain the most probable resting orientation. Initial orientation has no significant effect on the probability of occurrence of natural resting orientations when sector shaped parts were dropped from a height of 18 cm and 20 cm because only at those heights the potential energy was sufficient to facilitate a change in orientation.

DESIGN CONSIDERATION FOR TRAPS

Goldberg and Gordon smith[3] discussed a class of mechanical filters that can be described by removing polygonal sections from the track of the feeder; they refer to this class of filters as traps, which eliminate or reorient the parts until they reach the final preffered orientation. Mechanical traps are proposed to get a single orientation of parts to facilitate stacking. These traps having various combinations of gates (such as slot, balcony, guiding block, edge riser, gap etc), will either reorient or eliminate the disoriented component. Some of the important gates of the trap are discussed in the following sections.

Types of Gates. *The mechanical barriers are classified into two categories, based on their function (i) reorient or (ii) eliminate the disoriented component.*

Active Gates. *These are the gates which reorient the component to preferred orientation without disturbing the preferred orientation.*

Passive Gates. *These are the gates which eliminate the unfavorable orientation without disturbing the preferred orientation.*

Slot. *A slot is a rectangular interruption of the supporting area of the trap.*

Wiper Blade. *A wiper blade is a mechanical barrier, which converges towards the outlet of the trap and ends with a narrow critical path.*

Gap. *A gap is an interruption of the supporting area that spans the entire width of the track. Both of its boundaries are perpendicular to the vertical surface of trap. The shape of a gap can* thus be characterized solely by the distance between these two parallel boundaries. This distance is referred as the gap length.

Guiding Block. The guiding block is a rectangular interruption which could be characterized by the track width it allowed.

Edge Riser. Edge riser is an inclined plane mounted on the track of the feeder which is used to reorient the parts

DESIGN OF TRAP I

The model of a trap I (made of cardboard) developed in this work is shown in Figure.6.The wiper blade was introduced at the entry of the trap to reorient the incoming parts with orientations 1,2,5 and 6 to orientations 3,4,7 and 8 . A slot was introduced in the vertical surface to eliminate parts with orientation 4 and a gap in the horizontal surface to eliminate parts with orientation 7. A balcony was provided to ensure that orientations 1, 2 5 and 6 were eliminated. To ensure that the parts were always in contact with vertical surface, the horizontal surface was slightly inclined.

Markov model for Trap I

Markov model was used to compute the probability that a part in a particular initial orientation will end up in the preferred final orientation. The probability for each pre- and post-orientation, that the gate will convert, was computed. Once Markov model for each gate was obtained, the gate models were chained together to get a model for the entire feeder.

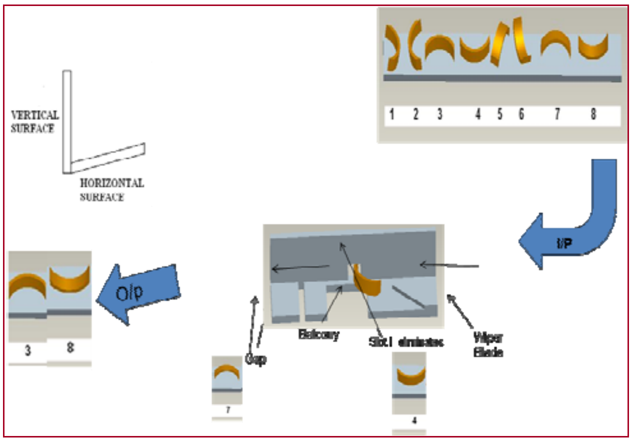
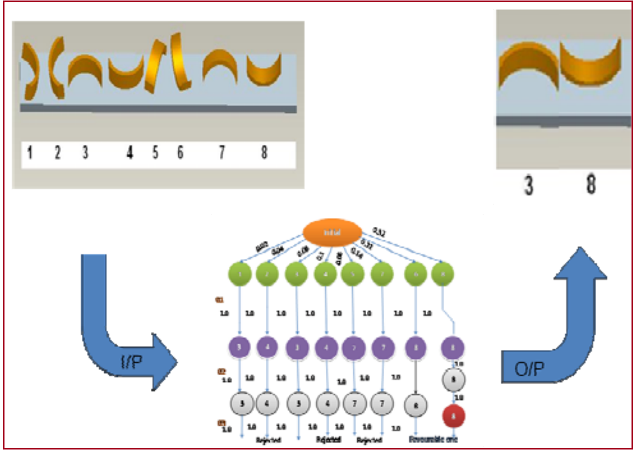


Figure.6 Model of Trap I

Orientations 3 and 8 were the output of the trap I as shown in Figure.6. From Markov model as shown in Figure.7, the efficiency of the trap I was estimated as 54%. Also, it can be seen that the preferred orientation 8 came out with the undesired orientation 3. It has to be eliminated or reoriented to get preferred orientation 8 as the only output.



Probability for Preffered orientation = 0.54
Figure.7 Markov model for Trap I

DESIGN OF TRAP II

The need for trap II was to reject or reorient the orientation 3, without disturbing the preferred orientation 8. An edge riser, an active tool with a guiding block was used to exactly reorient the part in orientation 3 into orientation 8 and allow only orientation 8 without any disturbance, as shown in Figure.8. The guiding block guide the part in orientation 3 to send it to the next gate, edge riser . The part in orientation 8 was unaffected by the edge riser. As the part moves over the edge riser, change of momentum takes place. Because of this change of momentum the part is decelerated. At a particular height, the centre of mass of the part falls out of the projected area of the part, and hence the parts topple and get converted to orientation 8.

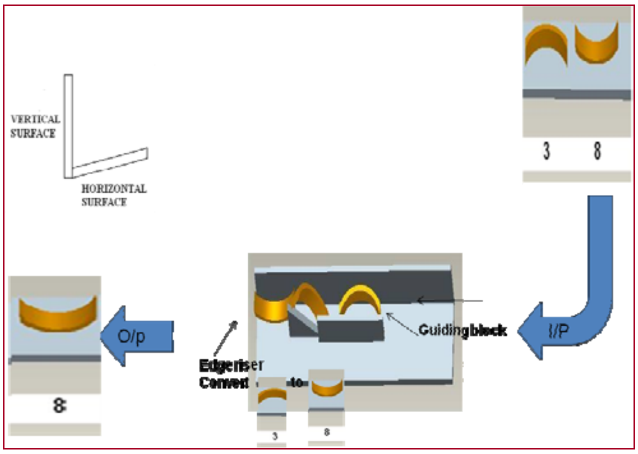
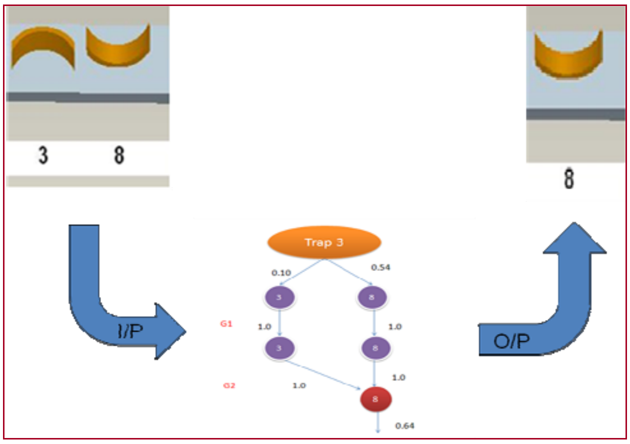


Figure.8 Model of Trap II

Markov model for Trap II

In trap II, the orientation 3 was converted in to orientation 8 which was 10% of the total in coming parts. This provided an advantage of increase in efficiency by 10%. Finally the probability of success for the preffered orientation at the exit of the feeder was found as 64% from Markov model as shown in Figure.9.



Probability for Preffered orientation = 0.64
Figure.9 Markov model for Trap II

DESIGN OF TRAP III

The efficeincy of trap II was 0.64 as discussed in the previous section and the feasibility of increasing the efficiency is discussed in this section. The gates are reordered as shown in Figure.10 to obtain maximum probability of success.

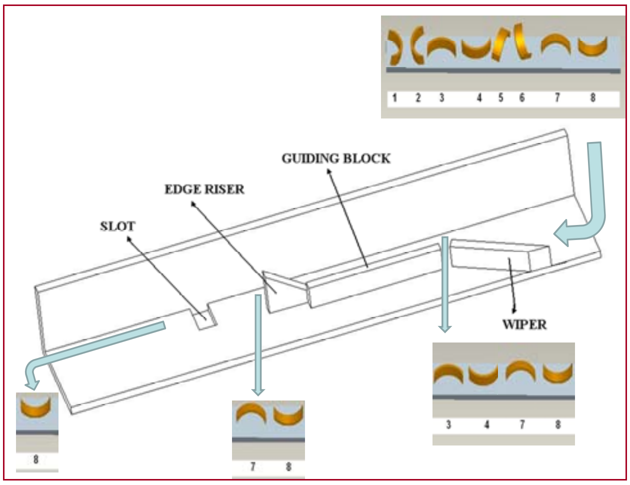


Figure.10 Model of Trap III

The wiper blade was introduced at the entry of the trap to reorient the incoming parts with orientations 1,2,5 and 6 to orientations 3,4,7 and 8 . At guiding block and edge riser, parts of orientation 3 and 4 get reoriented to orientations 8 and 7 respectively. Orientation 7 was removed through the slot, but fell down as orientation 8. So, a conveyor was placed below the slot so that the part of orientation 8 was transported along with the parts at the exit of the trap. Hence, the efficiency of the trap increased to 100%.

DETERMINING THE CRITICAL DIMENSIONS OF THE TRAP AND FABRICATION OF TRAP

The dimensions of the trap were obtained through trial and error method. The critical dimensions are the wiper blade angle (∅) with the vertical surface of trap and the trap inclination angle(θ) with the horizontal surface as shown in Figure.11 and Figure.12 respectively. The trap was made of cardboard to determine the critical dimensions.

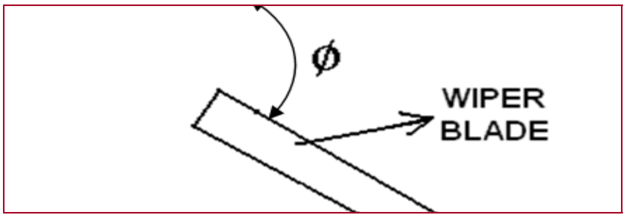


Figure.11 Wiper blade angle

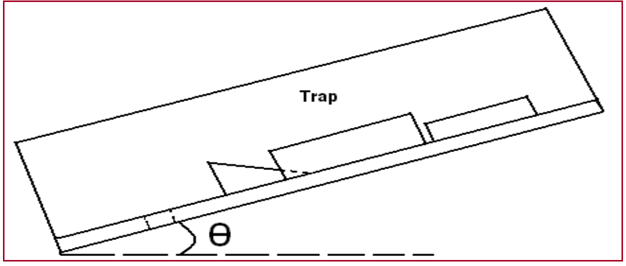


Figure.12 Trap inclination angle

Determining the orientation of wiper blade

The wiper blade angle (∅) was varied from 20° to 40°. This range was fixed because, for wiper blade angle less than 20° the parts tend to nest (cluster), since the path was too narrow for the parts to pass through it. For wiper blade angle greater than 40°, some parts passed without getting in contact with the wiper blade and hence reorientation did not occur and the parts tend to nest at the entry of guiding block. So, the wiper blade angle range was fixed as 20° to 40°.

In order to determine the appropriate wiper blade angle the following steps were followed,

- *A sample size of 30 parts was taken.*
- *The wiper blade angle was fixed to particular angle (∅).*
- *Parts were dropped at random orientations at the entry of the wiper blade.*
- *The number of parts that have successfully exited the wiper blade with or without*

reorientation was noted.

- *Steps 1 to 5 were repeated 5 times (5 trials) so that the results are reliable.*
- *Steps 1 to 6 were repeated by varying the wiper blade angle (Ø) from 20° to 40°.*

From Figure.13, it can be clearly seen that for angles between 25° to 35° almost all parts were re-oriented to preferred orientation. Hence, wiper blade angle was set between 25° to 35°.

Determining the trap inclination angle

The trap inclination angle (θ) was varied from 20° to 40°. This range was fixed because, for inclination angle (θ) less than 15° the parts do not slide on the track, since the excitation force could not overcome the frictional force. For angle greater than 30° the parts slide very fast and then tumble. So, the trap inclination angle was varied between 15° to 30°.

In order to determine the trap inclination angle the following steps were followed,

- *A sample size of 30 parts was taken.*
- *The trap inclination angle was fixed to particular angle (θ).*
- *Parts were dropped at random orientations at the entry of the trap.*
- *The number of parts that have successfully exited the trap with or without reorientation was noted.*
- *Steps 1 to 5 were repeated 5 times (5 trials) so that the results are reliable.*
- *Steps 1 to 6 were repeated by varying the trap inclination angle(θ) from 15° to 35°.*

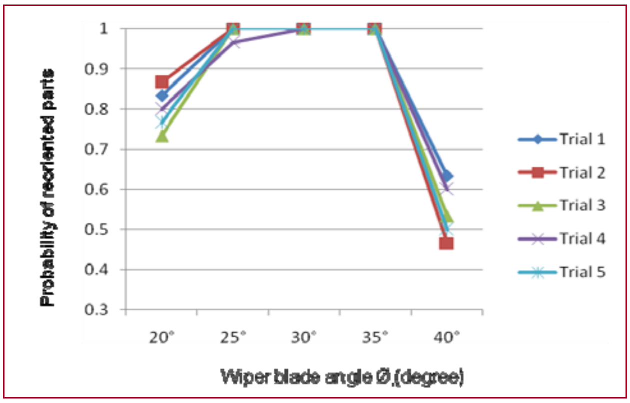


Figure.13 Effect of wiper blade angle on successful orientation of parts

From Figure.14, it can be clearly seen that for angles between 20° to 30° almost all parts pass through the trap and re-orient themselves without nesting. Hence, Trap inclination angle is set between 20° to 30°.

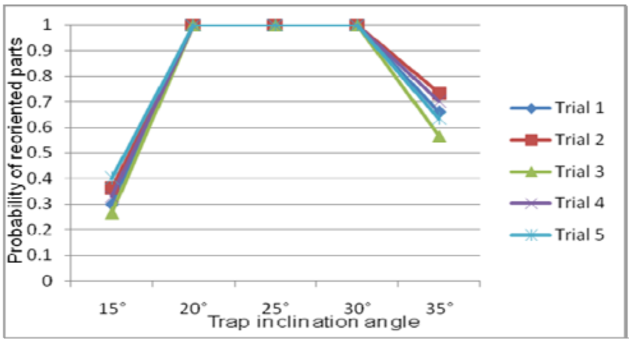


Figure.14 Effect of Trap inclination angle on successful orientation of parts

Fabrication of trap

The trap was fabricated (Figure.15) using acrylic plastic. Acrylic plastic was chosen as it has a fairly low coefficient of friction when compared to other materials, ease of fabrication, low cost and bulk availability. The above discussed experiments were repeated using the acrylic plastic trap and the appropriate wiper blade angle range was found to be between 25° to 35°. Similarly, the appropriate trap inclination angle was found to be between 9^0 and 11^0.

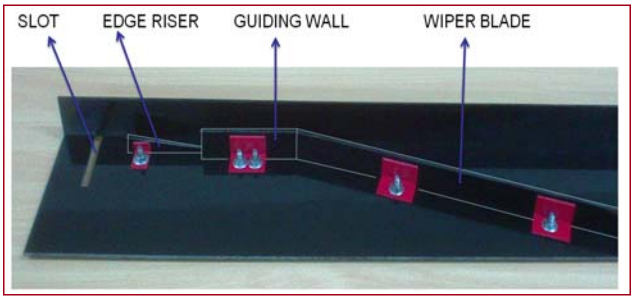


Figure.15 Fabricated trap

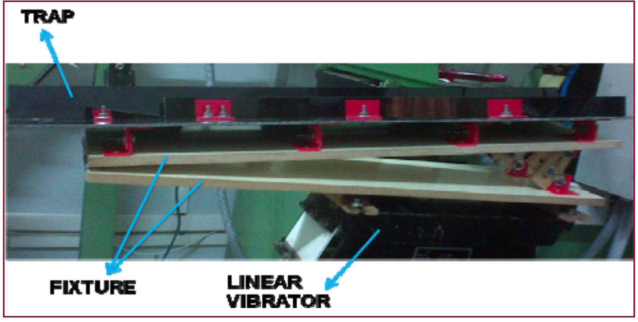


Figure.16 Experimental set-up

OPTIMISATION OF PARAMETERS FOR MAXIMUM CONVEYING VELOCITY

The frequency, amplitude of vibration and the trap inclination angle play a critical role in determining the conveying velocity of the trap assembly. ANOVA (Analysis of Variance) technique was adapted to find the effect of these three factors on conveying velocity of the trap. Figure.16 shows the experimental set-up, i.e. trap *mounted on a linear vibratory feeder. Levels are the limits within which the factors can vary during the experiment. The level was chosen as three. The outcome of these (Factors and Levels) combinations gave 27 experiments (Levels ^{Factors} = 3^3 = 27). Table.2 shows the factors and levels chosen.*

Table.2 Chosen factors and levels

Levels Factors	1	2	3
Vibration amplitude, a (% of supply voltage)	61	63	65
Excitation frequency, f (Hz)	68	69	70
Trap inclination angle, Ɵ (degree)	9°	10°	11°

Experiments were conducted with a sample size of 30 parts per experiment. The parts were dropped at random orientations on the trap. The parts travel a fixed length of 60 cm on the trap. The time taken to cover this distance is observed. Finally the velocity is calculated with the distance and time.

Table.3 Full Factorial array

Factors No.	Vibration amplitude, a (% of input voltage)	Excitation frequency, f (Hz)	Trap angle, Ɵ (theta)	Response (average velocity, x 10^2 m/s)
1	A_1	F_1	T_1	2.30
2	A_1	F_1	T_2	3.28
3	A_1	F_1	T_3	4.95
4	A_1	F_2	T_1	3.14
5	A_1	F_2	T_2	3.97
6	A_1	F_2	T_3	5.98
7	A_1	F_3	T_1	4.19
8	A_1	F_3	T_2	4.82
9	A_1	F_3	T_3	6.87
10	A_2	F_1	T_1	2.68
11	A_2	F_1	T_2	3.47
12	A_2	F_1	T_3	5.41
13	A_2	F_2	T_1	3.39
14	A_2	F_2	T_2	4.43
15	A_2	F_2	T_3	6.34
16	A_2	F_3	T_1	4.33
17	A_2	F_3	T_2	5.05
18	A_2	F_3	T_3	7.18
19	A_3	F_1	T_1	3.20
20	A_3	F_1	T_2	3.74
21	A_3	F_1	T_3	6.17
22	A_3	F_2	T_1	3.79
23	A_3	F_2	T_2	4.78
24	A_3	F_2	T_3	7.10
25	A_3	F_3	T_1	4.33
26	A_3	F_3	T_2	5.73
27	A_3	F_3	T_3	7.86

Legend: $_1$,$_2$ and $_3$ → Levels.

Full factorial array

Orthogonal array gives the possible combinations with minimum number of experiments but, since the number of experiments was low, Full Factorial array was used as shown in Table.3.

The table also shows the average velocity of the parts. From Table.3, it is clearly seen that experiment - 27 (A3 : F3 : T3) with vibration amplitude=65(% of input voltage), excitation frequency=70(Hz) and trap inclination angle = 11° gave the highest conveying velocity of 7.86x10^2m/s. The response considered was the conveying velocity which was preferred to be high. So, the Quality loss function considered was of Larger the Better type. The optimal level of amplitude, frequency and trap inclination angle was found by considering the maximum value of Mean of Means.

Regression Analysis

It is a statistical measure that attempts to determine the strength of the relationship between one dependent variable and a series of other changing variables (known as independent variables). The two basic types of regression are linear regression and multiple linear regression. Multiple linear regression model was attempted in this work since three independent variables (vibration amplitude, excitation frequency and trap inclination angle) were considered to predict one output (conveying velocity, m/s). The regression model was trained using the statistical software Minitab 15 from the results obtained experimentally. Regression equation was developed for the conveying velocity using the statistical software. The regression equation for the conveying velocity is given by the following relation

$$\text{Velocity x } 10^2 \text{ (m/s)} = -80.7 + 0.200\, a \text{ (\% of input voltage)} + 0.842\, f \text{ (Hz)} + 1.47\, \Theta \text{ (deg)}$$

$$\text{with } R^2 = 95.2\ \%$$

R Square (R^2) is the square of the measure of correlation between the observed value and the predicted value and indicates the proportion of the variance in the dependent variable. The regression equation gives fairly good result when compared with the experimental result (Table.3) within the range of the input parameter as shown in Table.4.

Table.4 Comparison of regression results with experimental results

S.No	Vibration amplitude, a (% of supply voltage)	Excitation frequency,f (Hz)	Trap inclination angle (Θ) (Theta)
1	61	69	11
2	61	70	11
3	63	69	9
4	65	69	9
5	65	69	11

S.No	Conveying velocityx10^{-2} (m/s)		Error %
	Experimental results	Regression model results	
1	5.98	5.768	3.55
2	6.87	6.61	3.78
3	3.39	3.228	4.78
4	3.79	3.628	4.27
5	7.1	6.568	7.49

ANOVA

From the results of ANOVA, it was observed that for variation in the response, amplitude has contributed upto 5.11%, frequency has contributed upto 22.29% and trap inclination angle has contributed upto 71.58%. This shows that they had statistical significance on the conveying velocity obtained, especially the trap inclination angle. It is also seen that the error associated to the ANOVA for conveying velocity is approximately 1.02%.

CONCLUSION

The salient conclusions of the work are listed below:

- *By drop test at different heights, it was found that orientation 'a' (i.e. orientations 6 and 8) has the highest probability of occurrence. Hence, orientation 'a' is considered as the natural resting orientation of this part and the part feeder is designed such that orientation 'a' is the only output.*
- *The part feeding system using traps for the favorable orientation of the brake liner was designed and fabricated.*
- *For wiper blade angles between 25° to 35° almost all parts were re-oriented to desired orientation. Hence, wiper blade angle can be set between 25° to 35° for both cardboard & acrylic traps.*
- *For trap inclination angles between 20° to 30°, all parts passed through the trap and reorient themselves without nesting in case of cardboard traps and 9^{0} to 11^{0} in case of acrylic traps.*
- *The optimum level for vibration amplitude is 65(% of input voltage), for excitation frequency is 70(Hz) and for trap inclination angle is 11^{0} for which the trap gave the maximum conveying velocity of 7.86 cm/s, which was determined experimentally.*
- *An expression relating the conveying velocity as a function of vibration amplitude, excitation frequency of vibration and trap inclination angle was obtained through regression analysis. The expression had good correlation with experimental results.*
- *By ANOVA, the trap inclination angle was found to be the most influencing factor with contribution of 71.58%.*

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