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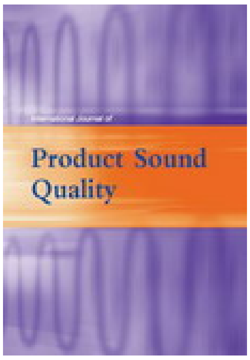

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Mohan Arumugam, Prabukarthi Arumugam, Suresh Mayilswamy, R. Naga Dhatshana

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Investigation on orientation effects of modified rocker arm for vibratory part feeder in assembly automation

Mohan Arumugam* and
Prabukarthi Arumugam

Department of Mechanical Engineering,
PSG College of Technology,
Coimbatore, India
Email: amn.mech@psgtech.ac.in
Email: apk.mech@psgtech.ac.in
*Corresponding author

Suresh Mayilswamy

Department of Robotics and Automation Engineering,
PSG College of Technology,
Coimbatore, India
Email: msh.rae@psgtech.ac.in

R. Naga Dhatshana

Department of Mechanical Engineering,
PSG College of Technology,
Coimbatore, India
Email: nagadhatshana@gmail.com

Abstract: Linear part feeder is used in assembly automation to arrange and orient the parts for assembly, loading, packing, etc. For designing the trap, the natural resting orientation or most probable orientation of the component is to be found initially. The natural resting orientation of the component can be identified by using both theoretical and practical methods. After determining the resting orientation, the trap is designed based on the various gating tool's impact on part transition in motion using the principle of the Markov chain model which is simulated using dynamic simulation software, and part motion time is investigated for the proposed model. In this work, the natural resting orientation of an asymmetric part, the rocker arm is identified, and based on this orientation trap is designed for the linear part feeder. From the study, group C has been identified as the most probable orientation with a probability of 0.62 in the stability method, 0.71 in the centroid solid angle method and 0.61 in an experimental drop test. The dynamic simulation of average part motion time for group A, group B and group C is 14.9 seconds, 11.8 seconds and 8.9 seconds respectively.

Keywords: linear vibratory part feeder; natural resting orientation; assembly automation; rocker arm; orientation; trap module; Markov chain model; dynamic simulation.

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Biographical notes: Mohan Arumugam is an Assistant Professor and PhD research scholar in the Department of Mechanical Engineering, PSG College of Technology, Coimbatore. He has research expertise in low-cost assembly automation, industrial automation, and the internet of things for mechanical applications.

Prabukarthi Arumugam is an Assistant Professor in the Department of Mechanical Engineering, PSG College of Technology, Coimbatore. He published research articles in various reputed international journals in composite materials, machining of Ti alloys, and industrial engineering.

Suresh Mayilswamy is an Associate Professor in the Department of Robotics and Automation Engineering, PSG College of Technology, Coimbatore. He published research articles in various reputed international journals in assembly automation, part feeding systems, and additive manufacturing.

R. Naga Dhatshana is a Postgraduate student who completed a Masters of Engineering in Computer Integrated Manufacturing and has research expertise in the field of robotics and industrial automation.

1 Introduction

A linear vibratory part feeder is a device that is utilised by manufacturing industries to convey the parts to various stages of manufacturing and assembly processes. In vibratory feeders, two major concepts are incorporated: The first one is that vibration helps to transport or move the material from one to another place, and the second relates to gravity as it is used to determine the direction of the material and since vibratory feeders aim to transport a large number of small components, those two concepts highly aid in achieving the desired work. The linear vibratory feeder is used to handle both asymmetrical parts and symmetrical parts as it can translate any orientation of the component to the most preferable resting orientation with the assistance of blades, gates, ledges, barriers, and other parts that help in changing the component to the desired orientation. In this paper, an asymmetric component named a rocker arm is chosen. In the two-wheeler manufacturing sector, rocker arm is a part that is used in the assembly line of an engine, specifically in an internal combustion engine which serves to work as an opening and closing valve. This research work involves the identification of possible orientation and the preferred resting orientation of the chosen asymmetric component by employing both theoretical and practical methods. Theoretical methods are of many types such as stability method, centroid solid angle (CSA) method, critical angle method, and energy barrier method, and the practical method is performed through a drop test. Here, two theoretical methods are compared with the experimental method. Once identified the most possible orientation of the asymmetric component, the development of the trap module was modelled with the aid of the Markov chain model and was fabricated using acrylic material and tested for rocker arm (Suresh et al., 2013). The research work focuses on implementing a part-feeding system to enhance efficiency in the production of the automobile manufacturing industry. Suresh et al. paper describes the implementation of theoretical methods such as the stability method and centroid angle method to discover the favourable orientation of a brake pad. Ngoi et al. (1997) applied both practical and theoretical methods to discover the possible lying orientation of the complex-shaped parts. Udhayakumar et al. (2011) validated the preferred resting orientation of the brake liner with the help of the empirical method and also using different theoretical aspects. Later researchers applied the CSA approach to determine the possibility of favourable resting characteristics of curved surface parts (Ngoi et al., 1995). Berkowitz and Canny (1996) designed a part feeder that changes the component to desire orientation Markov chain model principle was incorporated. The algorithm aided in designing the trap for a feeder in an effective manner and uses simple trap blades to build a successful trap for the feeder. Boothroyd (2006) illustrate the transfer of parts sequentially. By introducing mechanical gating tools in the design of a part feeder, the movement of the components one after another in sequential order for primitive objects is achieved. Boothroyd elaborated on illustrating industrial standardised part feeders and outlined mechanical parts feeders. Chua (2007) have used the Markov chain model algorithm to model the trap for a vibratory feeder in an effective manner and use the simple trap blades to accomplish a successful trap for the feeder. The author has deliberated on the design and development of the part feeders for the orientation of small-scale components in the industry. Suresh et al. (2018) have explained the theoretical approaches used in predicting the most beneficial resting orientation of the brake pad and the usage of the probabilistic model called the Markov chain model which aids in designing and sequencing the mechanical gates for the trap. Researchers also have discussed the reorientation of the polygonal part in the feeder without the need for sensors (Berretty et al., 2001). The sensor-based automation in part feeding played a major role in the handling of asymmetric parts. The sensor presented in the feeder is used to identify the part and its orientations (Sadesh et al., 2015). Handling asymmetric, small and irregular shaped parts in assembly was a glitch for the assembly or packaging industries. A trap module that can handle irregular parts such as park brake lever (Mathew et al., 2021), shock absorbers (Udhayakumar et al., 2021) and lego robot parts (Udhayakumar et al., 2023) were demonstrated by the researchers. The demonstrated trap modules would be a proper replacement for robots or manual labour in industries. Apart from the process parameters such as track angle and vibrational frequency for a linear vibratory feeder, the friction coefficient between the component and the trap module surface plays an important role in the conveying velocity. Researchers have explored the stick-slip phenomenon that occurred during the conveying of parts in vibratory motion (Mayyas, 2021). A study on the dynamics of part motion on linear vibratory feeders is essential aspect in determining the part orientation and design of trap module (Balaji et al., 2022).

The objective of this research is to create a product-based trap module that can be integrated into a linear vibratory feeder. The trap module developed can handle the part feeding of small and complex shaped geometry components. This will pave the way for the handling of many irregularly shaped components, which are currently handled by manual labour or high-cost robots. In industries, the successful design and implementation of this low-cost automation demonstrated using the selected component would replace manual labour or robots.

2 Selection of component and grouping of components based on the orientation

The selected component modified rocker arm is an irregular component and is utilised in a two-wheeler gearbox assembly. To start and close the valve, the component is oscillating up and down lever-type mechanism that converts circular motion from the cam into straight linear motion in the valve. A rotating camshaft lobe directly or indirectly lifts and lowers one end of the component through a tappet and pushrod. When the camshaft lobe advances the exterior of the arm, the interior pulls down on the valve, forcing it to open. The interior of the arm rises when the camshaft forces the outside of the arm to return, allowing the valve spring to close the valve. This valve's intricate construction differs somewhat from the standard rocker arm used in gearbox components. The front and the back view of the selected component are shown in Figures 1 and 2.

Figure 1 Front view of the modified rocker arm (see online version for colours)

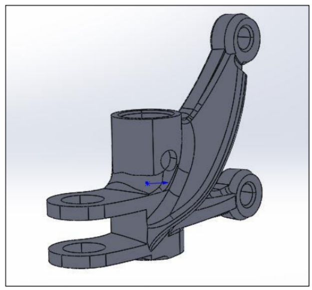
Figure 2 Rear view of the modified rocker arm

Figure 3 Possible orientations of the modified rocker arm

The possible orientations of the modified rocker arm are shown in Figure 3. The number of possible orientations for the selected rocker arm component is six and there exist some non-possible orientations also but they are not considered. Typically orientation of the part is based on the geometry of the part while for the rocker arm; the number of possible orientations is six.

3D geometric model of the selected asymmetric rocker arm component designed using Solid works software which is shown in Figure 4. A CAD model of the component is required to do theoretical analysis such as stability analysis and, the CSA method.

Figure 4 Geometric 3D model of the rocker arm (see online version for colours)



3 Theoretical approaches and experimental method to investigate resting orientation

The possible orientations of rocker arm were grouped based on the component's orientation family for theoretical analysis of the part (Ngoi et al., 1995). So, the part is categorised into four groups such as A-B-C-D. Group D shown in Figure 5 is considered an impossible orientation because it cannot rest in those grouped orientations without any support and is therefore taken as zero. The possible orientation groups are shown in Figure 6.

To discover the preferred resting orientation of the group using theoretical aspects, the stability method and CSA method are used in this research work which is demonstrated as follows:

3.1 Stability method

Stability is the capacity to maintain a component in a certain position. The higher the contacting surface area of the component's orientation with the ground, according to the conclusions of logical analysis. The part's stability would be high in its natural resting position (Suresh et al., 2013). As well, the lesser the centre of gravity of the component, the more steady the part would be high in the natural resting orientation. As a result, stability (S) is determined by the contacting surface area (A) and the distance between the centre of gravity (y). The stability of the orientation (S) is related to the surface area (A) and inversely proportionate to the centre of gravity height (y). The contacting surface area of a particular orientation and centre of gravity distance is found in CAD software as shown in Figure 7.

Figure 5 Grouping for non-possible orientation (see online version for colours)

Figure 6 Grouping for possible orientation

The comprehensive equation for the stability method is given in equation (1).

$$P_i = \frac{N_i A_i / Y_i}{\sum_{i=a}^{d} N_i A_i / Y_i}$$

where

- P_i – the probability of occurrence of the orientation of group i
- N_i – the total number of contacting surface areas of group i
- A_i – the contacting surface area (mm^2) of each orientation of group i
- Y_i – the height of the centre of gravity distance (mm) from the base of group i.

For all three groups' surface area, the number of contact surface areas is found using CAD modelling software and the same is tabulated in Table 1.

Figure 7 Surface area for orientation ‘a’ (see online version for colours)

Table 1 Surface area for each group

	Distance of centre of gravity from the base, Y_i (mm)	*Contacting surface area, A_i (mm^2)*	*Number of contacting surface area, N_i*
Group – A	18.28	71.90	1
Group – B	9.02	49.94	1
Group – C	8.79	139.62	1

The sample result for group A is given below,

- Contact surface area

  $A_a = 71.90\ mm^2$

- Centre of gravity

  $Y_a = 18.28$ mm

- Number of contact surface area

  $N_a = 1$

  $$\sum_{i=a}^{f} \frac{N_i A_i}{Y_i} = 25.4 \text{ mm}$$

  $P_a = 0.155$

Similarly, calculations for group B and group C are performed and the results are obtained.

3.2 CSA method

A solid angle method is described as a one-steradian unit occupied by a part of a spherical surface with an area equal to the square of the sphere’s radius (Suresh et al., 2013). The radius and the surface area (R) For orientation ‘1,’ the apexes of the projected surface are linked to the centre of gravity to form a prism, and with the centre of gravity of the modified rocker arm as the midpoint, a sphere with an arbitrary radius is made, and the probable volume is at the juncture of the prism and the sphere. The surface area and radius are found by using geometric modelling, which is shown in Figure 8.

The CSA of orientation (W_i) is given by,

$$W_i = \frac{A_i}{R^2}$$

The probability of natural resting orientation is,

$$P_i = \frac{W_i / h_i}{\sum_{i=a}^{f} W_i / h_i}$$

where

- A_i – the contacting surface area (mm^2)
- R – Arbitrary radius (mm)
- W_i – CSA of orientation I (Steradian)
- P_i – the probability of the component lying on a specific orientation
- h_i – the distance of the centre of gravity of orientation I from the base (mm).

Figure 8 The contacting surface area and arbitrary radius for orientation '1' (see online version for colours)

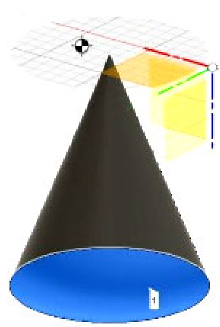


Figure 9 Drop test unit (see online version for colours)

For all three groups contacting surface areas and arbitrary radius for each orientation originate from utilising 3D geometric modelling software which is shown in Table 2.

Figure 10 Cumulative occurrence of dropping orientations (see online version for colours)

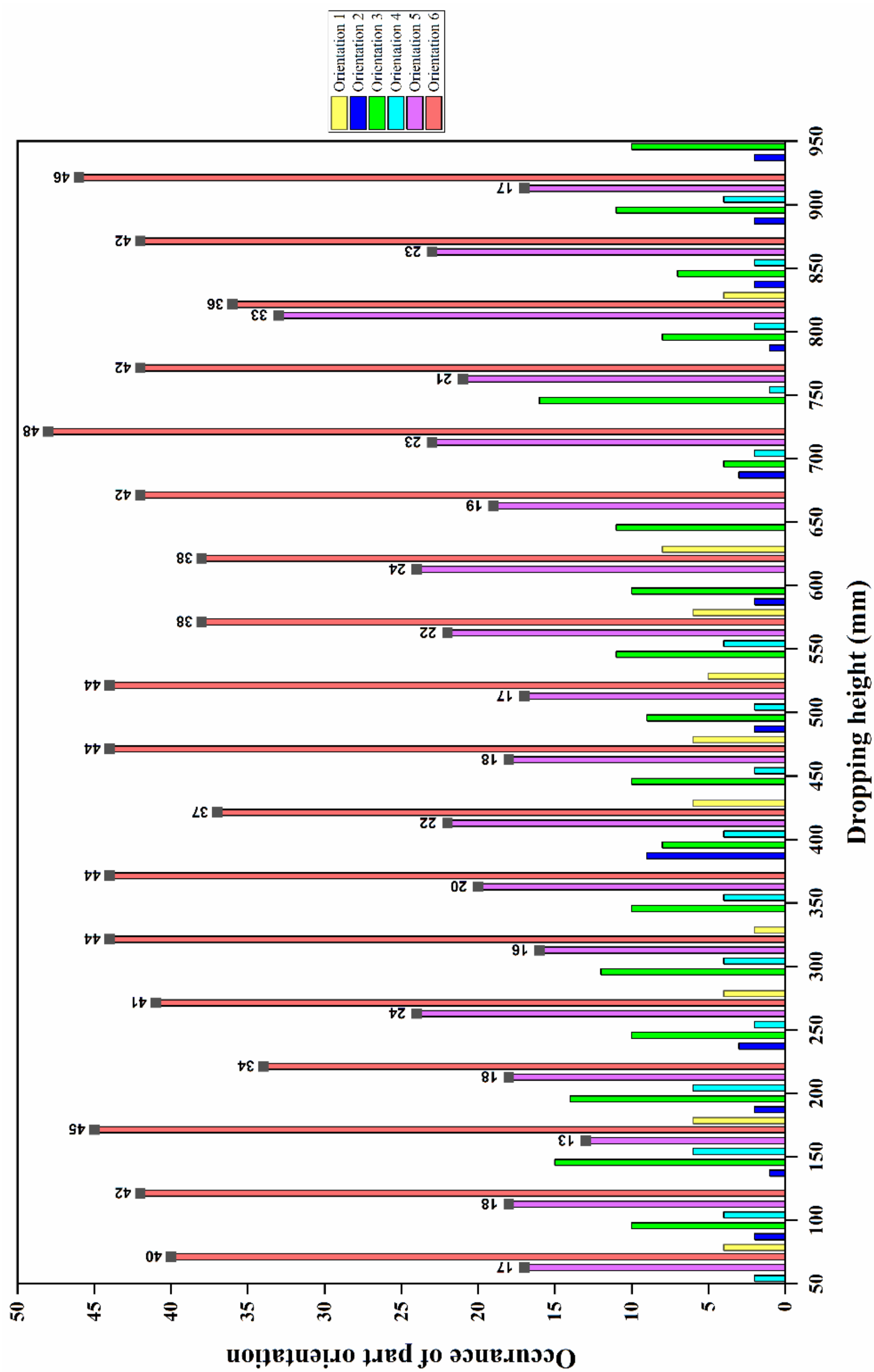


Table 2 Surface area and radius for each group

	Contacting surface area, A_i (mm²)	*Arbitrary radius, R (mm)*	*Centroid solid angle, (St)* $W_i = \frac{A_i}{R^2}$
Group – A	34.10	8.79	0.45
Group – B	47.80	8.79	0.62
Group – C	54.72	8.79	0.71

Sample calculation for group A is given below:

- Contact surface area

  $$A_a = 34.1\, mm^2$$

- Arbitrary radius

  $R = 8.79$ mm

- Centroid solid angle, $W_a = \frac{A_i}{R^2}$

  $$W_a = \frac{34.1}{(8.79)^2} = 0.44$$

- Centre of gravity

  $h_a = 18.28$ mm

  $$P_a = \frac{W_a / h_a}{\sum W_i / h_i} = \frac{0.0241}{0.1734}$$

  $$P_a = 0.14$$

Similarly, calculations for group B and group C are performed and the results are obtained.

3.3 Drop test

A drop test is utilised for predicting the potential possible orientations and preferred resting orientation of the selected component. In a drop test, the component is dropped from various heights at different orientations and resulting orientations are noted and the most preferred resting orientation is identified based on the number of occurrences. The drop test method is performed to discover the preferred orientation of the chosen modified rocker arm component by dropping the component from a height of 100 mm to 950 mm in an interval of 50 mm and noting its repeatability of the same orientation. The height range of 0 to 100 mm is not considered in the study since the potential height difference has a slight influence on the kinetic energy of the component as well as component orientation. The wooden drop test setup has a hard base surface which is carried as a reference for the measurements. The modified rocker arm was dropped from different heights and the setup of the drop test is shown in Figure 9 and from each height, ten samples for all six orientations were dropped and the cumulative values were noted as depicted in Figure 10, and the most favourable orientation was identified. Based on the drop test findings, it is clear that orientations 5 and 6 (group – C) are the most often occurring resting orientations, which is the preferred one.

The experimental probabilities can be calculated using the drop test data. During the drop test, at some height, the dropped component will hit the wooden surface and topple out of the wooden zone. Those probabilities were not considered in the calculation of experimental probabilities.

For the drop height of 700 mm, the component is dropped from each orientation (1–6) with a repetition of 15 numbers.

- Total number of drops (N) = 15 × 6 = 90 No's.
- Resting orientations (Nr) = Orientation 1 (0) + Orientation 2 (3) + Orientation 3 (4) + Orientation 4 (2).
- Orientation 5 (23) + Orientation 6 (48) = 80 No's.
- Orientations not considered due to toppled out of the effective zone (Nt) = 10 No's.

From the calculation, it is noted that orientation 5 and 6 (group C) has 71 No's of occurring orientations out of 90 No's. For group C, the experimental probability of a drop height of 700 mm is 0.78. A similar calculation is used to find the probabilities of remaining dropping heights.

After identifying the probable resting orientation by using the experimental method – drop test and by using the theoretical methods such as the stability method, and CSA method, the next step is to design the trap module using the experimental and theoretical findings.

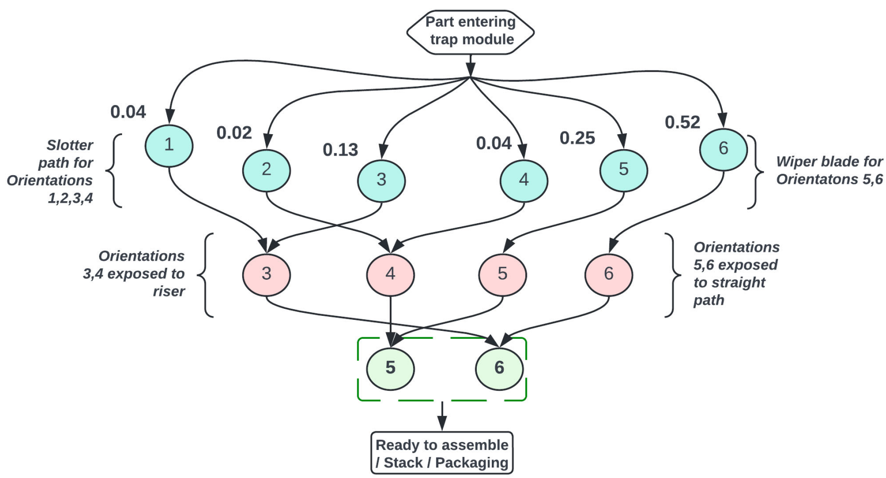
4 Design of a trap module

A vibratory feeder is a device that employs vibration to 'feed' components to a machining or assembly process. Vibratory feeders transport material using both vibration and gravity. Gravity defines the direction, which is either downward or downward and to the side, and the vibration is used to move the material (Suresh et al., 2013). A linear vibratory part feeder with a trap module on top of it is used to orient parts with the aid of vibration and feeds the parts to further process or machine. The design of the trap module starts with the selection of suitable gating tools and the construction of the probabilistic model called the Markov chain model.

4.1 Markov chain model

After selecting the appropriate getting tools (Boothroyd, 2006), the trap module is designed by employing the probabilistic model called the Markov chain model. A component has various potential orientations, and the most preferred resting orientation of the component is determined via a drop test. The Markov model is used to create a feeder trap after identifying the component's favourable orientation. A Markov chain, also known as a Markov process, is a probabilistic type of event prediction model that depicts a series of possible occurrences in which the probability of each incident is determined only by the state established in the preceding incident. The approach is based on a mathematical procedure that evaluates the possibility of transitions from one orientation to another within a finite set of potential orientations. Figure 11 shows how Markov models are employed to estimate the usage of different gating tools for trap modules. The initial state probabilities of each orientation were calculated based on the experimental probabilities arrived through the drop test. The cumulative value of probabilities for each orientation was calculated to bring the initial state probabilities. The subsequent levels of the Markov chain model were decided based on the mechanical gating tools. The possible orientations from 1-6 along with the component geometry were analysed with the various mechanical gating tools. The projected surface in the geometry of the component needs to be considered while selecting mechanical gating tools. The slotter path could accommodate the projected surface for orientations 1, 2, 3, and 4. The subsequent probabilities of the Markov chain model were decided based on the selected gating tools. The selected gating tools decide the re-orientation of the component from initial orientation to subsequent orientations as depicted in the model.

Figure 11 Markov chain model (see online version for colours)

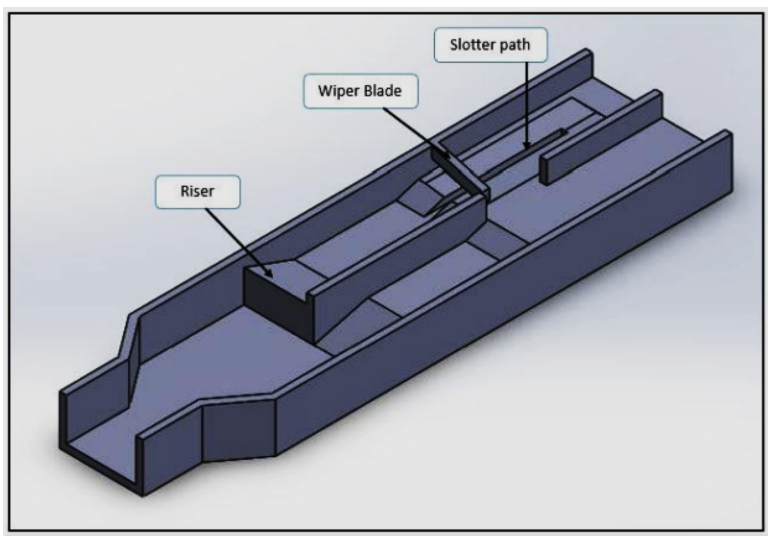


The slotted route is accessible to all dropping orientations after the initial stage of the portion at the trap module. Orientations 1, 2, 3, and 4 travel via the slotted route, whereas orientations 5 and 6 are exposed to the wiper blade due to the component's projected surface. So 5 and 6 orientations travel a different path, while 1, 2, 3, and 4 orientations are exposed to the riser to further shift the orientation to group C orientations.

4.2 Final trap design

The trap for the linear vibratory feeder is designed using the Markov chain concept. The Markov model for each gate was assigned together as a single model to create the definitive trap design as depicted in Figure 12. The results of the Markov chain model guided the process of designing the trap module. The analysis of various mechanical gating tools with possible orientations 1–6 will determine the best gating tools for each orientation. The final gating design module is created by combining the gating tools. The standard gating tool geometry was referred from the benchmark reference (Boothroyd, 2006). This designed trap module's function is to adapt to all possible orientations and process them to obtain the natural resting orientation (group C) of the selected component. The slotter path in the trap module designed to handle resting orientations falls into group B. The component in Group B will traverse through the wiper blade in a straight line and collide with the riser. The riser will topple the component, causing it to rotate to group C. Because of the feeder's constant vibratory motion, the components in groups A and C will collide with the wiper blade and change their path. The sliding path will change the orientations of Group A to a natural resting orientation. Because the trap is a static module, it processes the natural resting orientation (group C). The efficiency of this trap module is based on the process parameters such as vibrational frequency, trap angle and friction coefficient between the component and trap surface. The limitations of this trap module are that all of the mechanical gating systems used in the traps are static and cannot be moved.

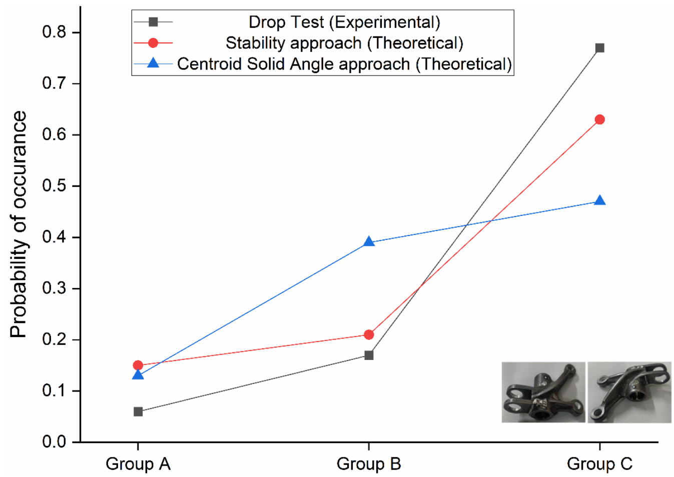
Figure 12 Trap design for linear feeder (see online version for colours)



5 Results and discussion

A drop test and two theoretical approaches were used to discover the preferred resting position of the modified rocker arm. This section goes through the results of these tests in detail. In the experimental technique, the probability of group C is 0.77, and that group is picked as the most likely resting orientation. The stability method's results are also shown in a graph, as seen in Figure 13. The graph shows that under the stability technique, the most likely orientation is selected as group C, while other orientations have less probability than group C. Groups A and B have a lower probability from the CSA approach than group C, which has a probability of 0.709. As a consequence, group C is selected as the most likely orientation.

Figure 13 Comparative plot for theoretical and experimental approaches (see online version for colours)



From the CSA method values are plotted in the graph and the result is shown in Figure 10. In this method also, the most probable orientation is identified as the group C-like stability method. The drop test in different heights from 100 mm to 950 mm in the interval of 50 mm and the probability of occurrence of each group is presented in Figure 10. From the drop test results, group C orientation is identified as the most probable orientation when compared to other orientations.

5.1 *Comparison of theoretical and experimental approaches*

When the drop test technique and theoretical methods results are examined, it is discovered that Group C orientation has the highest likelihood when compared to other orientations. Figure 14 depicts the most likely rocker arm orientation that was discovered.

Figure 14 Final most probable orientation

5.2 *Dynamic simulation – motion study*

After designing the trap, motion analysis is done so that the feasibility of the designed trap can be checked as shown in Figure 15. Rocker arm is dropped in a different orientation and with the assistance of the wiper blade, riser, and gates in the trap, the component orients to the most favourable orientation, i.e., group C orientation.

Figure 15 Simulating result of part dropped in group B orientation (see online version for colours)

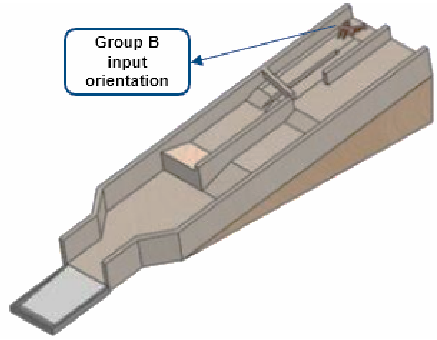
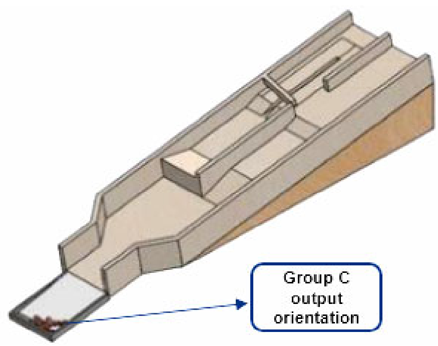
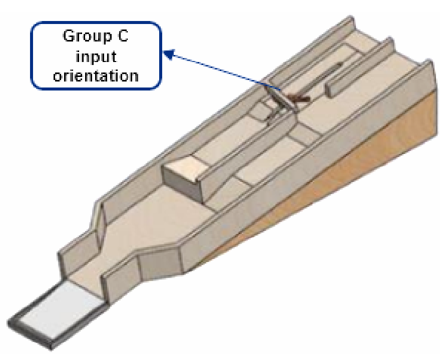


Figure 16 Simulating result of part at the required orientation (see online version for colours)



In the motion analysis process, initially, when the rocker arm is dropped in group A, B, or D orientation (as shown in Figure 16), the rocker arm travels through the slotted path and goes under the wiper blade, after which the rocker arm travels upon riser to change its final orientation to group C which is shown in Figure 17.

Figure 17 Simulating result of part dropped at group C orientation (see online version for colours)



If the rocker arm drops initially in group C orientation (shown in Figure 15), it will move leftward because a protrusion on top of the component will be struck by the wiper blade. The continuous vibration moves and slides the part leftward until reaching its end at the feeder which remains in group C orientation. Table 3 shows the time taken for the part to change its input orientation to group C orientation.

Table 3 Time taken for a change in orientation

Group	*Orientation*	*Time (sec)*
A	1	15.63
	2	14.17
B	3	12.39
	4	11.28
C	5	9.13
	6	8.67

The average time for groups A, B, and C is 14.9 seconds, 11.83 seconds, and 8.9 seconds, respectively. The trap module that was designed is a static module that produces a good result in conveying time compared with similar part handlers (Suresh et al., 2018). As a result, it must process all orientations, even if they are natural resting orientations. The time it takes to process the orientation accounts for group C's average time of 8.9 seconds. To reduce the time required to process the orientation, a separate track for the most likely resting orientation can be included in the trap module. However, the design change will have an impact on the linear vibratory feeder's process parameters. The trap module becomes dynamic by incorporating an image recognition algorithm, an image sensor to process the input orientation, proximity sensors to detect the presence of the component, and mechanical and electrical actuators to re-orient the parts.

6 Conclusions

The purpose of this work is to determine the natural resting position of the modified rocker arm using both practical and theoretical techniques. The trap is intended for the linear part feeder based on the orientations. The stability method and CSA method results reveal that groups A and B have less likelihood than group C. The modified rocker arm is dropped from several heights ranging from 100 mm to 950 mm at 50 mm intervals, and the findings indicate that group C orientation is the most likely. Comparing both the theoretical method and drop test method, group C is obtained as the most probable orientation, and based on this orientation, the feeder path is designed with the aid of different types of gates. Motion analysis is done by using dynamic simulating software for different dropping orientations and checking for the desired output orientation. According to the findings, group C is the most likely orientation, with a probability of 0.62 in the stability method, 0.71 in the CSA method, and 0.61 in an experimental drop test. For groups A, B, and C, the dynamic simulation of average part motion time is 14.9 seconds, 11.8 seconds, and 8.9 seconds, respectively. A similar trap module can be used in any industry to handle small and irregularly shaped parts, especially in linear part feeders. The design of the trap must be modified based on the component to be fed and handled. This type of low-cost automation will pave the way to replace robots or humans to handle part orientation. The design can be further devised by incorporating sensor-based automation, image recognition algorithms, and embedded systems.

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