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Automated Part Feeding: A Review of Current Practices and Future Directions

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Abstract

The purpose of this review article is to offer a thorough overview of part feeders, which are automated devices used in manufacturing to feed and position components for subsequent processing. The article begins by presenting component feeders and detailing their important tasks in the manufacturing industry. It then describes the many types of component feeders available, such as vibratory, centrifugal, and pneumatic feeders, as well as their advantages and drawbacks. The study also discusses part feeder design factors such as part properties, feeding rate, and orientation precision. It also examines the difficulties connected with component feeding, such as part jams, misalignments, and handling fragile parts, as well as the solutions utilised to solve these difficulties. Lastly, the report provides a review of the important findings as well as recommendations for future research in the topic of part feeders. Overall, this review article is a helpful resource for academics, engineers, and manufacturers interested in learning about the present status of component feeding technology and its potential to improve production processes.

Keywords: Part feeders • Singularisation unit • Orienting unit • Design of traps • Part orientation • Current practices • Future recommendations

Introduction

Part feeders are essential devices in modern manufacturing and assembly lines for improving productivity by reducing manufacturing lead time. Vibratory feeders, which use vibrations and gravity to move and direct materials, are commonly used to transfer large quantities of small objects.

However, irregularly shaped components, such as brake pads, pose a challenge for orientation as they have multiple stable configurations. To address this issue, a trap system is used to change the possible orientations to a natural resting orientation. The trap is designed based on the favorable orientation of the component, which is determined through drop tests. This paper discusses the use of dynamic simulation and physical experiments to design and prototype part feeders for asymmetric parts like brake pads. The study shows that dynamic simulation can hasten the design process and produce similar results to physical experiments. Overall, this work highlights the importance of part feeders and the potential benefits of incorporating dynamic simulation in their design.

Literature Review

Singularization unit

Singularizing units are used to individualize or separate parts from clusters in an industry where volume production occurs. Deflator blades are non-vibrating blades which help for separating cylindrical parts. The working parameters of the singularizing unit are the blade angle and belt speed, while vibrational nodes help the motion of particles at a frequency level set. Part orientation changes to the speed of frequency and where it is provided. The singularizing operation is performed and then a change of orientation operation to follow. This can be reversed and the singularizing operation can be done later [1].

Design and testing of singularizing unit

Markov analysis: The singularizing unit is a mechanism used to transfer or move an object from one specific location to another within a specific duration of time period. It was designed by Markov analysis, a mathematical system that undergoes transitions of part from one state to another, between a finite or countable number of possible states. The part has eight possible orientations which were

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identified through drop test. The hopper feeder should be designed to get the orientation 5 and 6 as the output, with wiper blade (gate I) introduced at the entry of the hopper to change orientation 1, 2, 3, 4, 7 and 8. Barrier (gate II) is introduced to send parts one by one to next stage. The final hopper unit was designed by combining the stages I and II (Figure 1).

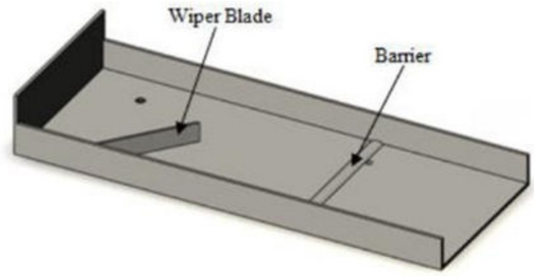

Figure 1. Hopper.

Experimental testing: The hopper is placed over the vibrator to increase the performance of the feeding system. Base plates of various thicknesses were placed between the hopper and the vibrator, varying the parameters of base plate thickness and frequency. An accelerometer is connected to the bottom of the hopper system, the accelerometer output is connected to a DAQ Card, and the system is also connected through a display system. The acceleration response was obtained using lab view software, and the time taken for the passing of the brake pad was recorded using a stop watch. Experiments were conducted by varying the heights of the hopper and changing the frequency of vibration to convert possible orientations into favorable orientations.

ADAMS vibration analysis: A functional virtual prototype of the singularizing unit is built using ADAMS/view and ADAMS/vibration to analyse the vibration behaviour. Input channels and output channels are created to vibrate the system and measure the response. A vibration actuator applies force input or a displacement, velocity, or acceleration. The model was tested and evaluated by running vibration analysis for different input ranges (Figure 2). Animation and frequency response helps to improve the system performance [2].

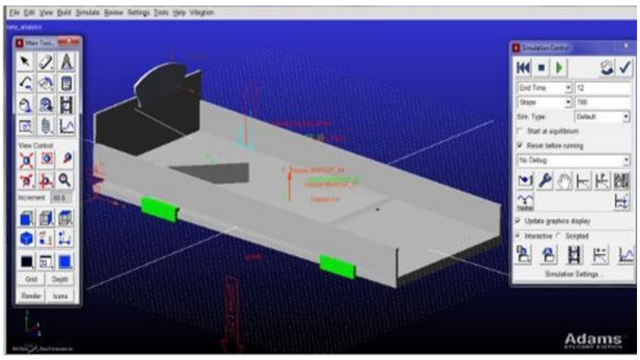

Figure 2. Feeder design using ADAMS software.

Methodology

The methodology for the system adapted. It is used for analysing the optimum parameters for the efficient functioning of the system. Frequency and the trap angle are the two parameters taken into consideration.

Static simulation: Static simulation for the motion of the part on a developed trap is performed using solid works simulation to visualize the process. Gravity is applied in the negative y-direction, and solid-body contact is provided between the part and the trap. Linear motors are used to create the vibratory motion. The frequency of the vibrator applied can be varied based on the requirement. An optimum level of frequency is needed for optimal part motion on the trap [3].

Dynamic simulation: The modelling of trap is done and the behaviour of the respective part is checked with the help of dynamic simulation using ADAMS view program. Various operation points, which are obtained, are used by the system to analyse the trap's vibratory behaviour. The dynamic motion of the part in the trap developed in ADAMS view software is created to obtain time data.

Design of experiments: DOE can be used for various purposes, such as variable screening, transfer function explorations, system optimization and system robustness. It is used for variable screening, where two parameters such as track angle and frequency have to be analysed. Common designs used for variable screening are 2-level factorial design and Taguchi orthogonal array. The main aim of DOE is to put into effect efficient experiments to produce results for sound decision-making.

Factorial design: Factorial experiments are designed with factors such as frequency and trap angle, and two-level full factorial designs are used to represent effects. Pareto analysis and regression are used to analyze collected data where dependence of two variables is observed.

Taguchi method: The Taguchi method is a simple and efficient way to optimize system design for performance by using orthogonal arrays to study parameters with least number of results from experiment. Results from experiments are transformed into SNR, which is used to measure parameters deviating from desired values. SNR is categorized into three, lower better, higher better and nominal better. The classical method of approach requires a number of experiments, but by using the Taguchi method the number of experiments can be reduced for the analysis of the output parameters.

Orienting unit

The unit helps to change the pose of the part to desire one different kinds of units are shown in the Figure 3.

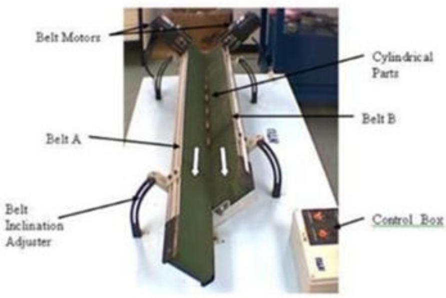

Figure 3. The orienting unit.

The orienting unit shown in Figure 3 is a V shaped conveyor belt used to orient cylindrical parts of various dimensions. It has a different belt roughness and moves at different speeds. Other orientations include fence orientation, blade horizontally mounted, feederwall attached with metal plate, and sensor less system. These orientations and rejection take place while obtaining the desired pose [4].

Geometrical structure change of projections for orienting units can be used to orient other objects like rectangular blocks traps. The three supports used are wiper blade, edge raiser, narrowed track and the wall projection. Infrared reflective sensors are used at the scanning station to determine the orientation and to send the date to the computer. Software is used to design vibratory bowl feed and air jet is used to prevent part jamming. This helps to overcome such issues in the way mentioned below (Figure 4).

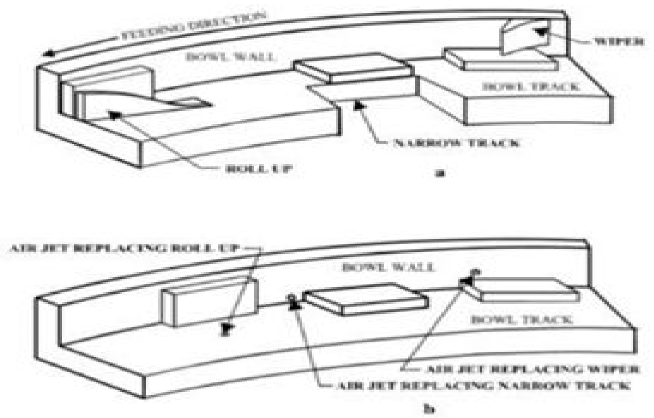

Figure 4. Air jet equivalence.

The air jet is used as an active tool to align products in the path of the feeder.

Conveying velocity

Vibratory conveyors increase vibration amplitude to help part motion when parts are stationary due to parallel inertia of force. The parallel and normal components of force are $m_pa_0\omega^2\cos\psi$ and $m_pa_0\omega^2\sin\psi$ respectively

Where:

$F=\mu$

$_sN=\mu_s (m_pg\cos\theta - m_pa_0\omega^2\sin\psi)$ and

μ_s is the coefficient of static function between part and the track.

A vibrator controller attached to the vibrator is used to control the vibration frequency. The cables from an accelerometer mounted to the trap are connected to a DAC (NI USB-6009). The DAC is then connected to a personal computer. The computer system keeps track of the output acceleration. A user interface was designed with a waveform chart indicator, a numeric control for the nominal voltage output at zero g acceleration, and a numeric control for the sensitivity setting of the accelerometer. Figure 5 displays a block diagram for lab view.

The DAQ assistant is used to feed the data into this block diagram as input. The nominal zero-g voltage offset is subtracted as directed after reading the numbers. On the front panel, an input signal for the nominal zero g voltage can be entered. The voltage value is then multiplied by the sensitivity in V/g to obtain the acceleration value. To the front panel, this sensitivity is provided as input. The result is the acceleration in g, ranging from -1.5 g to +1.5 g, and this number may be seen on a waveform chart on the front panel.

Design of traps

This section discusses the design of traps. It starts with colorful collections of rectilinear traps and ends with general polygonal traps. The thing is to find a trap in the collection that satisfies the feeding property, *i.e.,* that allows the part to be fed in only one exposure. To do this, we subdivide the parameter space of all possible trap shapes into shapes that feed P in exposure σ, and shapes that reject P. On the boundaries of the different regions of the branch, we find critical trap shapes, which feed the part but have critical placements. Combining the services of the trap shapes for different exposures will lead to trap shapes for which only one exposure is fed.

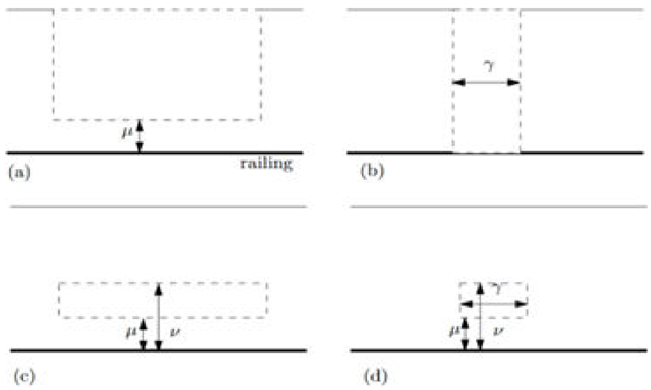

Figure 5. The four rectilinear traps of this section: (a): A balcony; (b): A gap; (c): A canyon and (d): A slot.

Balconies: A balcony is a trap that rows the supporting surface of a track. It is rectilinear and the distance from c to the railing is the radius of the part in the orientation it is traveling in. The critical balcony-width for a given orientation is the radius, and the bowl feeder can select the orientation with the smallest radius. The railing of the track always touches the part at the convex hull, so the given analysis holds for both convex and non-convex parts. The only parts we cannot feed using a balcony are parts for which the minimal radius is not unique [5].

Gaps: This text discusses the problem of moving a part along a gap of arbitrary width. The part is safe if and only if there is a supported triangle around the center of mass. If the gap is small enough, then the part remains safe throughout the motion, and there are no critical poses. The critical gap-width is the part passes safely over this gap but is rejected for gap-widths +, for any >0. The part can only be supported by one side of the gap, either the left or the right side, or both sides of the gap. There are two types of rejected poses of the part:

- The part is only supported to the left (or the right) of the center.

- The supports are contained in a half-plane below (or above) the center (Figure 6).

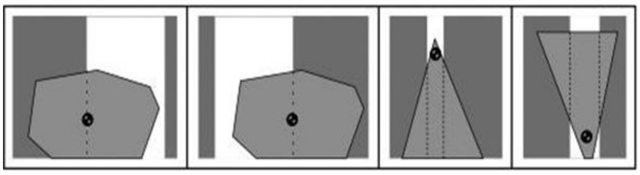

Figure 6. The types of rejected poses.

The critical gap-widths related to the first type of poses are relatively easy to compute by considering the radius of the part at and radius of the center of mass. The gap-width for the second type of critical poses is a bit harder to compute, but the line defining the half-plane plays a crucial role in the analysis. Figure 5 shows an example of a critical pose of a convex part, where the gap-width is the horizontal distance between the intersection points of the line and the edges of the (upper hull of the) part. During the sweep, a linear number of pairs of edges are intersected by the line, and for each such pair of edges of the upper hull of the part we compute the smallest gap-width such that there is a critical pose during the motion.

Canyons: A canyon is a rectangular gap in the track's supporting area, with lower and upper boundaries (el and eu) parallel to the railing, and starting and closing boundaries (es and ec) perpendicular to the railing. To find critical canyons, we assume that the part is in a fixed stable orientation and aim to characterize unsafe and critical placements of the canyon.

Slots: A slot is a rectangular gap in the supporting area of the track, with lower and upper boundaries (el and eu) parallel to the railing, and starting and closing boundaries (es and ec) perpendicular to the railing. The distances between the lower and upper boundaries and the railing are specified by μ and ν, respectively, and the length of the gap is γ.

Parameterized traps: The previous two sections discussed simple traps such as gaps and balconies that can be described with only one parameter. One way to look at the problem of designing a trap which is specified by k parameters is to consider it as an arrangement of algebraic surfaces which divides a higher dimensional space into cells for which the part is safe and cells for which it is rejected. The algebraic surfaces are derived from the higher dimensional boundaries of the convex hull of the part and the trap in different configurations. Computation and processing the cells can be done by Collins' cylindrical algebraic decomposition, which is doubly exponential in k.

Current designs

The parts feeders in the current design use multiple conveyors to deliver a wide variety of parts to the workcell with minimal mechanical alteration. Figure 7 shows two views of the feeding system, with LEGO blocks going up the inclined conveyor and dropping from the return conveyor into the hopper. Figure 8 shows a schematic view [6].

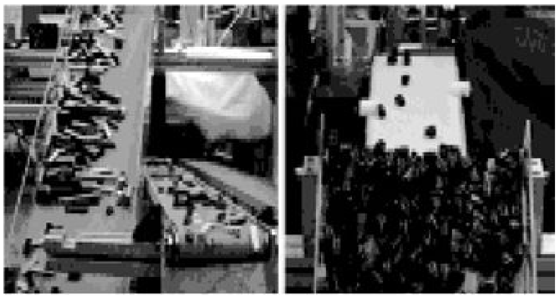

Figure 7. Flexible part feeders.

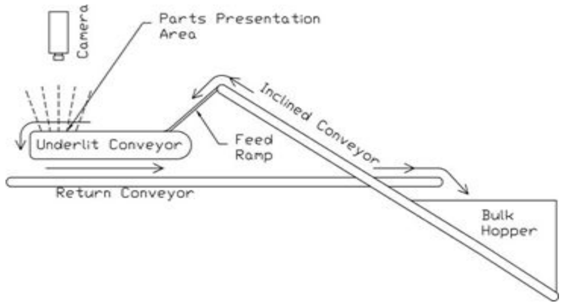

Figure 8. Part feeding system.

Conveyors: Three conveyors work together to present parts to the workcell for assembly. The first conveyor, under servo control, is mounted at an inclined angle and is used to lift parts from a bulk hopper. The second conveyor is a 12" wide, 72" long QC 125 series conveyor, and the third conveyor is an 8" wide, 36" long Dorner 3100 series conveyor. Lights are installed in a window, under the translucent conveyor belt, to provide backlighting for binary vision. Parts which are not in useful orientations or are overlapping are dropped from the end of the horizontal conveyor onto the return conveyor, which transports the parts back to the bulk hopper for re-feeding.

Servo control: The most important details in this text are the use of servo control for the inclined and horizontal conveyors. A Galil 1500 standalone motion controller is used to drive the horizontal and inclined conveyors. Inline transmissions are used to match the output speed range of each motor to the desired speed range of each conveyor. The use of a closed loop system allows for more precise control of the conveyors, such as rapidly shaking the horizontal conveyor back and forth to help singulate parts or move them into a more desirable pose. The return conveyor runs continuously and is driven by a fixed speed AC motor, which only needs to be turned on and off by the controller at system start-up and shutdown. This is accomplished by a relay attached to a single digital output from the Galil controller.

Backlighting/overhead binary vision: Part recognition is performed using CCD cameras mounted over the vision window in the horizontal conveyor. Backlighting was chosen due to its easier to produce uniform backlighting than overhead or oblique lighting, conveyors lend themselves to backlighting, reliable binary images are easily produced, and backlighting is less part specific than other lighting methods. Binary images were chosen because grayscale images are more difficult to work with and require more complicated algorithms to determine the pose of a component. Binary images are faster to process and should not be hindered by the vision system.

Lighting subsystem: The lighting system used in horizontal conveyors has undergone several iterations due to size constraints, uniformity of light, frequency spectrum, and cost. In the first design, three standard incandescent light sockets with compact fluorescent adapters, utilizing electronic ballasts, were mounted in the conveyor. However, the center of the window was found to be much brighter than the edges, and adapter life was also a problem. In an attempt to improve the uniformity of the backlighting, a second iteration of the design was initiated using slimmer mounting adapters and standard fluorescent ballasts. However, heat was still a problem, and two pancake fans were placed inside the conveyor to force air over the bulbs and out vent holes (Figure 9).

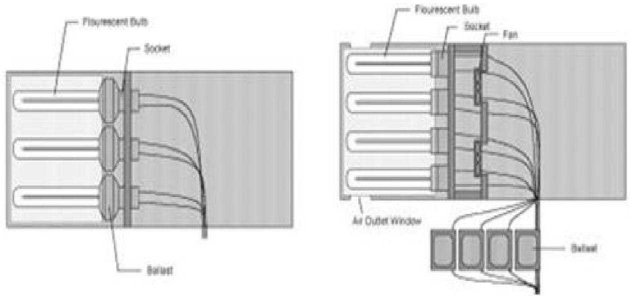

Figure 9. Lightening design evolution.

Figure 9 is a drawing of the 1st and 3rd generation designs. Several options are being explored, including ultra-thin cool-cathode florescent bulbs or the use of an array of LEDs. Although the price of such a system would be much greater than the current setup, it may be necessary to achieve the desired results.

Conveyor belt selection: The selection of the conveyor belt can have a major impact on the function of both the inclined and horizontal conveyors. The inclined conveyor needs a high coefficient of friction and a durable surface, while the horizontal conveyor needs to be translucent and have a homogeneous construction to allow uniform lighting. Black anti-static fibers can interfere with the vision system and degrade the uniformity of the lighting (Figure 10).

Figure 10. Inclined conveyor.

Design for feeding

Designing parts for use in a flexible feeder can have a significant impact on the overall effectiveness of the system. General guidelines have been determined to facilitate the design of parts for flexible feeding. Two distinct areas affect throughput of the feeder: Features to enhance static stability and features to enhance vision recognition. We have developed several guidelines which enhance vision recognition, some of which contradict guidelines for assembly listed by others. An exaggeration of an asymmetric feature is not necessary for a vision system, as a slight asymmetry is all that is needed for the vision system to determine the pose of the part.

Physical guidelines: When designing parts, it is important to consider the feeding system when designing them. The first guideline is to minimize the number of stable poses of a part, which increases the probability that a part will land in a suitable orientation. The second guideline is to design parts to have stable orientations which are consistent with the given assembly, such as if a part needs to be inserted into an assembly with side A down. In some situations, it is impossible to satisfy the above criterion, such as long, slender parts needing to be inserted lengthwise from above.

The most important details in this text are the four guidelines for designing parts to prevent tangling and nesting. Rotary jaw grippers can be used to grasp the part in its stable orientation and rotate it for assembly. The fourth guideline is to design parts which are not easily damaged by the feeder. Parts with transparent areas, such as display covers for automotive dashboards, could be scratched, and heavy parts with sharp corners could damage the belts of the conveyors when being fed.

Vision recognition guidelines: The most important details in this text are that the vision system must be able to identify the pose of the part and determine whether it is graspable. This is done in the context of backlit, binary vision, where the information to the vision system is a silhouette of the given part. The first principle is to design parts with rotational invariance, which means that they can be assembled in more than one rotational orientation. Sometimes, it is not possible for the part to be designed with rotational symmetry, so it is important to design it with an asymmetry such that its pose may be uniquely determined. Examples of such design features include three nubs placed on the inner circumference of a ring or on the outside diameter of a nut.

Vision processing can be used to determine the up/down orientation of a part by examining the length of each shoulder relative to the location of the end of the base. Two "shoulders" of a part may have slightly different lengths to create an asymmetry, which can be determined by examining the distance to the edge of the part to the left and right of the axis. To avoid translucent parts, it is possible to place a opaque band around the exterior of the part without affecting its performance. Sandblasting the relevant area of the mold, for example, will produce a frosted area which can be seen by the vision system. This can be done without adding a step to the part's manufacture [7].

Discussion

The results presented in the above section show that the algorithm automatically finds feeder configurations that orient the three parts used as cases, but the quality of these feeder configurations also relies on behavioural data. Finding better solutions for orienting the three parts would require either the traps being tuned to optimal performance or more trap principles capable of reorienting the parts to other orientations. The margin for considering a part fully oriented, mc, should ideally be set to 1, but for the test it was set mc=0.95. Setting this parameter for the algorithm should be governed by some knowledge on the optimality of the traps used in the search and the closer the traps are to being optimal the smaller the need will be for decreasing mc. The current state of the algorithm for generating data is unable to identify stacking parts, which should be taken into account when designing the feeder.

Future work on part feeders

Future work should focus on improving the algorithm by looking for heuristics guiding the search towards good feeder configurations faster, as well as other, more aggressive, branch termination strategies. Additionally, future work should be directed at efficiently simulating multiple parts interacting with each other as well as the feeder, and validating the designs found using the algorithm with real world tests.

Despite their limitations, part feeders are an essential component of many manufacturing processes, and there are still areas for improvement and innovation. Here are some potential areas for future work:

Improved part handling: One area for improvement is in the handling of a wider variety of parts. Research into new materials and designs for part feeders could help to expand their capabilities and make them more adaptable.

Smart sensors and control systems: The use of smart sensors and control systems could help to improve the accuracy and reliability of part feeders. This could include real-time monitoring of the feeding process and automated adjustments to prevent jamming or misfeeding.

Integration with other automation systems: Part feeders could be integrated with other automation systems, such as robotic arms or vision systems, to create a fully automated manufacturing process. This could help to further increase efficiency and reduce the need for manual intervention.

Maintenance free designs: Finally, there is potential for the development of maintenance free part feeders. This could include new designs that require less maintenance, or the use of materials and coatings that are more resistant to wear and tear.

Conclusion

In conclusion, part feeders have become an integral part of modern automated manufacturing systems due to their reliability, accuracy, and cost effectiveness. By automating the process of part feeding, manufacturers can significantly increase their production rates, reduce errors, and improve product quality. Moreover, part feeders can be easily integrated into existing manufacturing systems, which makes them an attractive option for many manufacturers. Part feeders provide consistent and reliable feeding of parts, which reduces downtime and waste, and ultimately leads to increased profitability. To select the best part feeder for their application, manufacturers need to carefully consider the design requirements and total cost of ownership. They should evaluate the feeder's feeding rate, accuracy, and compatibility with their existing system. In addition, this paper has identified potential areas for future work on part feeders, including the development of smart sensors and control systems, the integration with other automation systems, and the exploration of maintenance free designs. These innovations can further improve the efficiency, accuracy, and adaptability of part feeders, creating more reliable and automated manufacturing processes. Additionally, they should consider the cost of maintenance and repair, as well as the initial purchase price. Overall, the benefits of using part feeders in manufacturing are clear, and their continued adoption is expected to drive further growth and innovation in the industry. By leveraging the latest advancements in technology and design, manufacturers can improve their production processes, reduce costs, and enhance product quality, ultimately resulting in greater customer satisfaction and profitability

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