

“PART FEEDING SYSTEM FOR FMS”

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

In

Mechanical Engineering

BY

DEBASIS ROYMOHAPATRA

Under the Guidance of

PROF. B.B.BISWAL



Department of Mechanical Engineering
National Institute of Technology
Rourkela



**National Institute of Technology
Rourkela**

CERTIFICATE

This is to certify that the thesis entitled “Part feeding system for FMS” submitted by Debasis Roymohapatra, Roll No. 10503003 in partial fulfillment of the requirements for the award of Bachelor of Technology degree in mechanical Engineering at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

DATE:

Prof B. B. BISWAL

Mechanical Engineering Department

PLACE:

National Institute of Technology

Rourkela-769008



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DEBASIS ROYMOHAPATRA

Roll No- 10503003

8th Semester B. TECH

Mechanical Engineering Department

National Institute of Technology, Rourkela



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ABSTRACT:

This paper describes the development of a flexible and vibratory bowl feeding system which is suitable for use in a flexible manufacturing system. The vibratory bowl feeder for automatic assembly, presents a geometric model of the feeder, and develops force analysis, leading to dynamical modeling of the vibratory feeder. Based on the leaf-spring modeling of the three legs of the symmetrically arranged bowl of the feeder, and equating the vibratory feeder to a three-legged parallel mechanism, the paper reveals the geometric property of the feeder. The effects of the leaf-spring legs are transformed to forces and moments acting on the base and bowl of the feeder. Resultant forces are obtained based upon the coordinate transformation, and the moment analysis is produced based upon the orthogonality of the orientation matrix. This reveals the characteristics of the feeder, that the resultant force is along the z-axis and the resultant moment is about the z direction and further generates the closed-form motion equation. The analysis presents a dynamic model that integrates the angular displacement of the bowl with the displacement of the leaf-spring legs.

CHAPTER-01

INTRODUCTION

A prominent problem in manufacturing automation is the accurate and reliable presentation of small parts, in a desired orientation, to a work cell. This is often referred to as the parts feeding problem. A part feeding system is the proverbial black box with the parts entering the system in arbitrary orientations and exiting the system in a single specified final orientation. These part feeding systems implement a plan: a sequence of filters or gates that push, rotate and even drop parts until they reach the desired orientations. An efficient part feeding planner has the filters sequenced so that most of the entering parts, exit the system in the desired orientation. Methodologies to develop efficient manufacturing assembly lines include sophisticated computer vision based bin picking, manual loading of pallets, trays or magazines and the design of the specialized feeding machines- all seemingly necessary components of the automated manufacturing assembly lines. For many types of automated manufacturing equipment, there is a requirement to supply them with parts which invariably need to be presented in a single orientation. Parts feeders are used for this purpose. A part feeder, which singulate and orient the part prior to packing and insertion, are critical component of an assembly line and one of the biggest obstacles to flexible assembly. The methods and technologies of moving component parts of an assembly into the transfer and insertion station on the assembly machine. While in motion, parts encounter various orienting devices such as wipers, scallops, narrow track, air jets, etc., in a vibratory bowl feeder. Parts that are moving in undesired orientations will be rejected by these orienting devices and re-circulated, whilst those moving in the desired orientation are allowed to reach the output section of the parts feeder. In mass production, when the volume of a particular part is high, the most common method employed is to use vibratory bowl feeders.

CHAPTER-02

LITERATURE REVIEW

- Richard Silversides[1] investigated the vibratory bowl feeder for automatic assembly, presented a geometric model of the feeder, and developed force analysis, leading to dynamical modeling of the vibratory feeder. Based on the leaf-spring modeling of the three legs of the symmetrically arranged bowl of the feeder, and equating the vibratory feeder to a three-legged parallel mechanism, the paper reveals the geometric property of the feeder. The effects of the leaf-spring legs are transformed to forces and moments acting on the base and bowl of the feeder. Resultant forces are obtained based upon the coordinate transformation, and the moment analysis is produced based upon the orthogonality of the orientation matrix. This reveals the characteristics of the feeder, that the resultant force is along the z-axis and the resultant moment is about the z direction and further generates the closed-form motion equation. The analysis presents a dynamic model that integrates the angular displacement of the bowl with the displacement of the leaf-spring legs. Both Newtonian and Lagrangian approaches are used to verify the model, and an industrial case-based simulation is used to demonstrate the results.
- Development of a model for part reorientation in vibratory bowl feeders with active air jet tooling done by Nebojsa I. Jaksic and Gary P. Maul[2] stated that Vibratory bowl feeders (VBFs) are widely used in industry for feeding and reorienting small parts in high volume production. Standard VBF tooling consists of various mechanical barriers inserted in the bowl path which are prone to jamming and limit the feeder to only one type of part. Programmable feeders have been developed to improve the exhibility of these devices, however feed rates are often low. This research describes the development of a model of part behavior required for reorienting a part with an air-jet-based computer controlled orienting system. This system can be used to eliminate jamming and improve feed rates in VBFs. The control algorithm accepts the part's weight, geometry, and its orientation. Sensors then compare the present with the desired orientation and the algorithm determines the appropriate pulse of air to produce the desired orientation. Part

feeders are devices that orient parts for production operations. They can be divided into two major groups: vibratory and non-vibratory. A typical vibratory bowl feeder (VBF) is comprised of a shallow cylindrical bowl supported by several leaf springs attached to a cylindrical base containing an electromagnet. Inside the bowl is an inclined helical track. The cycling of the electromagnet causes the bowl to vibrate and the parts to move along the track either by sliding or by hopping.

- Development of a flexible and programmable parts feeding system M.L. Tay, Patrick S.K. Chua, S.K. Sim and Y. Gao[3] described the development of a flexible and programmable vibratory bowl feeding system which is suitable for use in a flexible manufacturing system. Controlled by computer and driven by electro-pneumatic cylinders and stepper motors, this feeding system is capable of identifying the orientations of non-rotational parts and actively re-orientating them into the desired orientation. Three different neural network modules (ARTMAP, ART2 and Back-propagation) were tested for their suitability for the orientation recognition system. The system developed extends the capability of conventional bowl feeders to include feeding parts with only internal features, and feeding a family of similar parts without costly re-tooling. These features are well suited to applications in flexible manufacturing systems.
- Andrea Edwards [4] described a genetic algorithm approach to the automated design of the vibratory bowl part feeders. This genetic algorithm approach runs on a parallel computer and gives near optimal designs in much less time than previous reported optimal, brute force search methods.

CHAPTER-03

THEORY

3.1 PART FEEDER:

It is a device that receives a number of random oriented parts at its input and delivers them in a desired orientation at its output. The fabricated part arrives at the assembly site in a multitude of ways. A most common condition is to have component arrived at the assembly areas in boxes or other container in bulk disoriented condition. Storage density is usually excellent and shipping cost minimal. Other parts because of fragility, cosmetic considerations, war page or shipping cost are shipped in specific orientation-retention containers, such as trays, tubes or mandrels. It means by which these component are extracted from these storage device and placed in an altitude proper for insertion is the heart of automatic assembly. It should come as no shock, therefore to pinpoint that the most versatile of all part feeder remains the human assembly worker.

3.2 TYPES OF PART FEEDER:

1. BARREL FEEDER.
2. CENTRIFUGALL FEEDER.
3. DRUM FEEDER.
4. SHAKER FEEDER.
5. ROLL FEEDER.
6. REVOLVING PLATE FEEDER.
7. GRAVIMETRIC FEEDER.
8. LINEAR FEEDER.
9. VIBRATORY FEEDER.

Barrel Feeder:

It is similar in appearance to a selector ring feeder, barrel or drum feeder pick up parts from the bulk storage area with scoops or blades fastened to the side of a rotating drum. These parts are discharged by gravity onto orienting ratio. Although the method of elevation is different, the selecting principle of this type of feeder is similar to that of elevator type feeding devices



Fig1. Barrel feeder

Centrifugal Feeder:

Centrifugal feeders are intended to slip parts to the outside of the feeder through the rotation of the centre or bottom plate in the feeder. These feeders are very attractive for high volume application from a theoretical stand point, but have proven disappointing in practices, since debugging is consuming of both time and sample parts, while the pool techniques, for such development is extremely limited. When the centre plate is rotated more slowly, these feeders are often used as reservoirs.

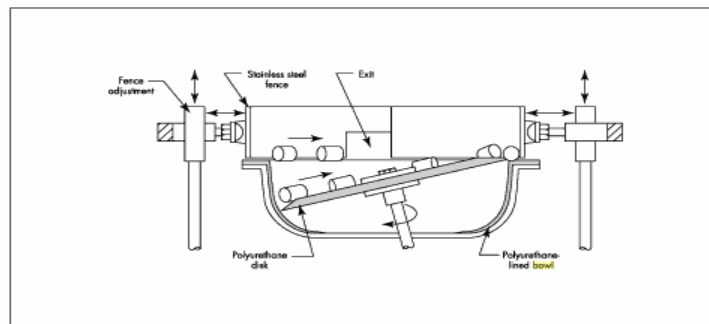


Fig2. Centrifugal feeder

Drum Feeder:

A drum feeder is distinguished from a barrel feeder only in the shape of its rotational bin. For feeding certain part particularly washers, rivets, pin, screws, they were efficient, quiet and inexpensive.



Fig3. Drum feeder

Shaker Feeder:

The shaker feeder consists of a shaker pan beneath the hopper. The back end of the shaker pan is supported by hanger rods. The front end is carried on wheels and is moved by a crank as the pan oscillates; the material is moved forward and dropped into the feed chute. In most units, the number of shaking strokes is kept constant while the length of the stroke is varied. The angle of inclination varies from about 8° for freely flowing solids to 20° for sticky particles. If arching is expected then agitator plates are installed in the hopper to break up the arches. The shaker feeder is rugged and self cleaning, and it can handle most type of solids regardless of particle size and condition.



Fig4. Shaker feeder

Roll Feeder:

Roll feeder are low capacity devices used for handling dry granules and powders. The feeder consists of a feed hopper, two feed rolls, and a drive unit. Guide vane in the hopper distributes the material and provide agitation by oscillation. The feed rolls from the material into a uniform ribbon, and feed rate is controlled either by means of a slide that varies he width of the ribbon or by a variable-speed drive. The range is typically 6:1 when using feed slide and 10:1 when variable speed drives are used. For materials that tend to cake or bridge in the hopper, agitators can be provided to maintain the material in a free flowing state.



Fig5. Roll feeder

Revolving –Plate Feeders:

Revolving-plate feeder consists of a rotating disk or table, which is located beneath the hopper outlet. The table is rotated and, as it rotates; fresh material is drawn from the hopper while the solids that the feeder discharges are scrapped off by skirt boards. The feed is controlled by adjusting the height of the gate or positioning the skirt board. Revolving plate feeders handle both coarse and fine materials. Sticky materials are also handled satisfactorily, because the skirt boards are able to push them into the chute. This type of unit cannot handle materials that tend to

flood. A variation of the revolving plate feeder utilizes rotating fingers to draw feed material from the bin. Revolving-plate feeders can also be equipped with arch-breaker agitators in the conical throat section of the hopper.

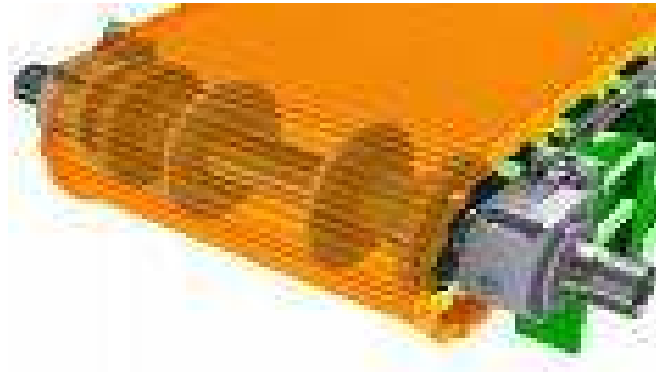


Fig6. Plate feeder

Gravimetric Feeder:

Belt-feeders are compact factory-assembled devices that use belts to transport the material across a weight-sensing mechanism. In the case of solid flow meters, the flow of solid is uncontrolled, and the load on the constant speed belt is measured as an indication of the solid flow rate. The flow rates of solids on a simple gravimetric feeder can be regulated by a vertical or rotary gate, screw or other volumetric control device. More accurate control methods are based on varying the belt speed or adjusting both the belt speed and belt loading.

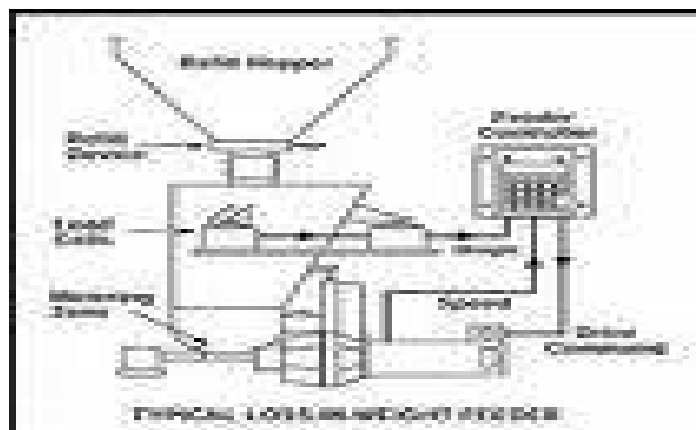


Fig7. Gravimetric feeder

Linear Feeder:

A linear feeder provides a positive means for taking oriented parts from the exit of a bowl feeder or other orienting device, moving them in a positive manner across space up to 20ft per single feeder, and maintaining all the time. Using

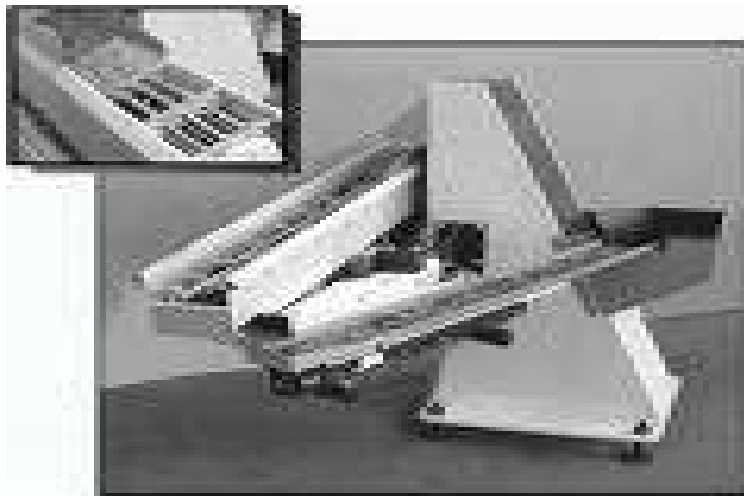


Fig8. Linear feeder

VIBRATORY FEEDER:

A vibratory feeder is a device that uses vibration to “feed” material to a process or machine. Vibratory feeders use both vibration and gravity to move material. Gravity is used to determine the direction, either down, or down and to a side, and then vibration is used to move the material. The material is almost always a dry material that unlike a liquid may not move down an incline without some assistance from the vibration effect. A common vibratory feeder is cone shaped. The material bulk is delivered in an uncontrolled fashion into the top of the feeder and a controlled delivery of the material comes from the bottom of the feeder. An example would be a pill bottling system. A large batch of pills is dumped into the top of the vibratory feeder. Gravity

will pull the pills toward the bottom of the feeder where they can exit one at a time so that they can be counted. Once the correct number is in the container, the feed is stopped until a new bottle is placed in position. In this way bottles can be filled automatically by machine with the correct number of pills in each bottle.



Fig9. VIBRATORY FEEDER

The vibration in the vibratory feeder ensures that pills keep moving towards the exit into the bottle without becoming congested. The vibratory feeder comes in many shapes and sizes but all use the same principle, which is to feed bulk material in at the top in an uncontrolled fashion and take material out at the bottom at a controlled and steady rate. It is designed to be flexible, programmable and intelligent.

It is compound of three sub-systems:

- i. The vibratory bowl feeder sub-system.
- ii. Computer sub-system.
- iii. Programmable logic controller (PLC) sub-system.

CHAPTER-04

VIBRATORY BOWL FEEDER

4.1 Introduction:

The vibratory bowl feeder is the most common mechanism for feeding industrial parts. The bowl has a helical track climbing the inside wall. By giving the bowl a circular vibratory motion, parts dumped into the bowl will climb the helical track in single file. As parts climb the track, they encounter a sequence of obstacles which either re-orient the parts, or deflect disoriented parts back into the center of the bowl. Instead of welded passive orienting devices such as wiper blades and permanently constructed orienting devices on the track, stepper motor controlled wiper blades and adjustable track width are incorporated into the bowl feeder to make it flexible and programmable to suit parts of different sizes.

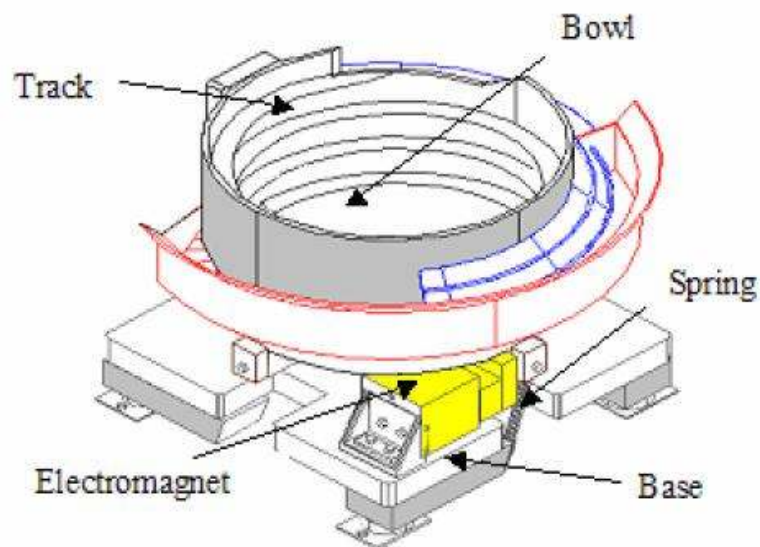


Fig10. VIBRATOR BOWL FEEDER

The vibratory bowl feeder consists of nine specially designed stations along its track for feeding of non-rotational parts. These stations are controlled by both the computer sub-system and the PLC sub-system.

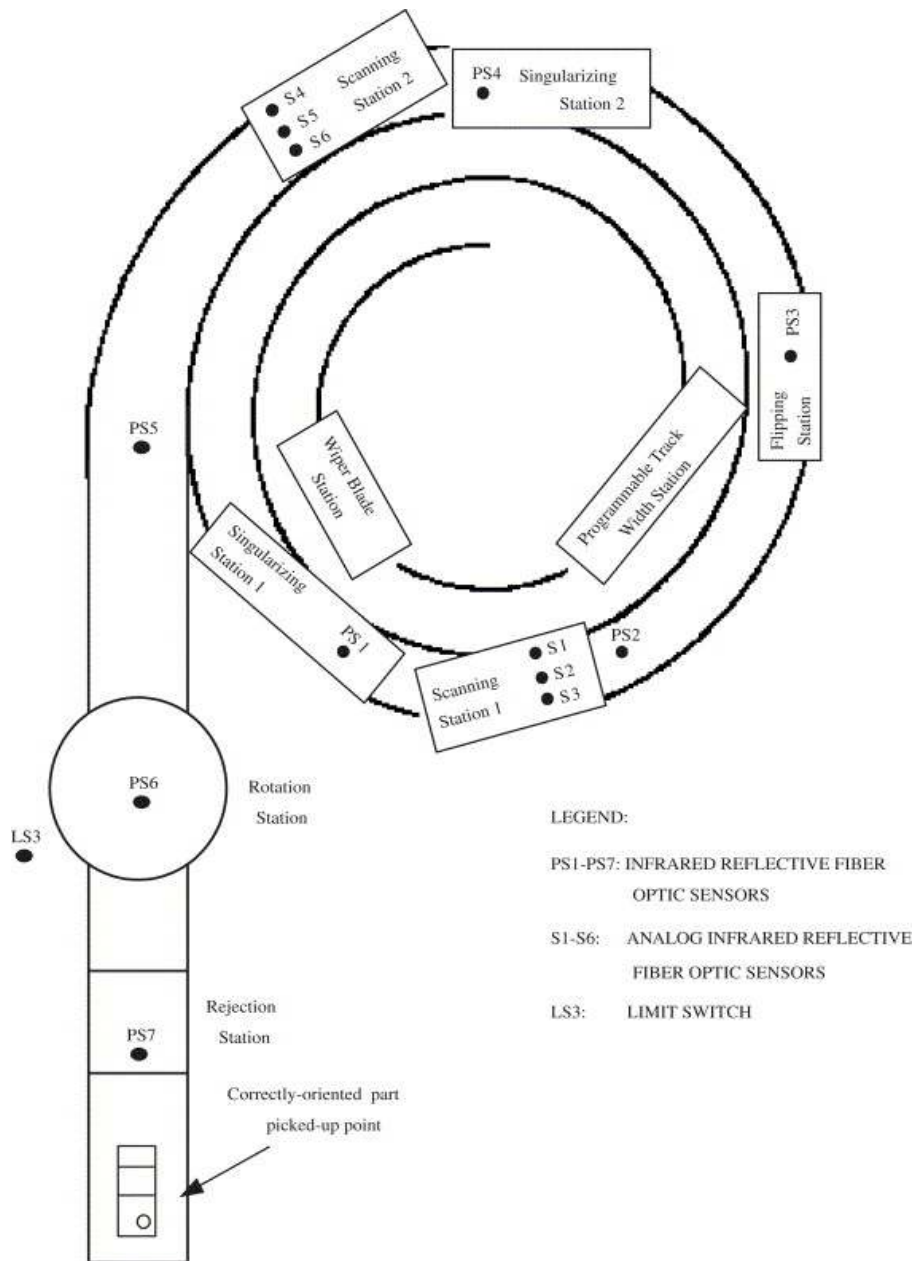


Fig11. SYMMETRIC DIAGRAM OF FEEDING SYSTEM

Wiper blade station:

It is a passive orienting device commonly used in the vibratory bowl feeder to reject or wipe off parts that are stacked on top of one another and also those parts that are higher than the set height limit of the wiper blade. In this feeder, the wiper blade is attached to a ball-screw assembly that is driven by a stepper motor controlled by the computer, so that the height of the wiper blade can be programmed, thus parts with different heights can be fed in this feeder.

Programmable track width station:

This is also a passive orienting device commonly used in the vibratory bowl feeder to ensure that all the parts would travel in single file longitudinally on the track, rejecting parts that are traveling abreast to another part. In this feeder, the programmability of the track width is achieved by constructing a hinged wall pair that guides the parts into a narrowing track. The hinge will open up to widen the track and vice versa. A stepper motor that is similar to the one used in the wiper blade controls the width of track. Since the width of the track is controlled by the stepper motor, parts with different widths can be fed in this system.

Singularizing station 1:

Singularizing station 1 is used to control the flow of the part into the scanner. It consists of a door hinge that is integrated into the wall of the bowl feeder, a pneumatic cylinder which will control the hinge to extend to block a feeding part or retract to release a feeding part, an infrared reflective fiber optic sensor PS1 which is used to detect that a part is present. When a feeding part blocks the path of the infrared light from the sensor PS1, the presence of the part is acknowledged by the PLC. Then the initially closed hinge, which is controlled by the PLC, will open to block the next feeding part that comes along. Hence, only one part at a time is allowed to proceed to scanning station 1 for scanning.

Scanning station 1:

This station serves to determine the orientation of a feeding part with three analog infrared reflective fiber optic sensors. Each of the optical fiber sensors is connected to a sensor block, which will transform the light signals into the voltage signals and amplify the voltage signals. The output of the sensor block is connected to an A/D converter card, which will convert the voltage signals into the digital signals for the computer to process. The scanning station 1 is used to scan the surface profile of the part and send the data to the computer, so that the orientation of the part can be identified. The part identification process and the operation of the subsequent station are controlled by neural network software in the computer.

When the orientation of the feeding part has been determined, the computer would decide on one of the following:

- (1) No action if the part is in the desired orientation or 180° reversed.
- (2) Request flipping operation if the part is upside-down.

Flipping station:

This station is designed to flip the part which is identified to be upside-down by the scanning station 1. The orienting device consists of a 90° vee-track, and air-jet and a reflective fiber optic sensor PS3. The flipping operation is activated upon request by the computer, after determining that the part is upside-down. Therefore, as the feeding part arrived and is sensed by PS3, the air-jet would blow the part to rest on the other side of the vee-track, and thereby flipping it 180°.

Singularizing station 2:

This station is used to control the flow of the part into the scanning station 2. The structure of singularizing station 2 and its working principle are exactly the same as that of singularizing station 1. They all ensure that just one feeding part at a time can pass through to the next scanning station. The reflective fiber optic sensor PS2 is used to detect that a part is proceeding to singularizing station 2, therefore open the singularizing station 2 to let the part pass through.

Scanning station 2:

This station would make a second identification to determine the orientation of the feeding part. The structure and the function of the scanning station 2 are the same as that of the scanning station 1. After the scanning, the computer would decide the appropriate actions to be taken after scanning such as:

- (1) No action if the part is in the desired orientation.
- (2) Request rotating operation if the part is 180° reversed.
- (3) Reject the part if a poor scan or identification was encountered.
- (4) Reject an upside-down part.

In addition, as a precautionary measure, it would compare the scanning result with that of the first scanning station and would also attempt to use the successful first scanning result whenever possible if a poor scan or identification is encountered.

Rotation station:

This station is the final station to orientate the parts to the desired orientation and is used to re-orientate a part that is 180° reversed. It consists of a 180° pneumatic rotary actuator which rotates a short chute by 180°, two pneumatic rotary actuator acting as stoppers at the entrance and exit of the chute, two reflective fiber optic sensors PS5 and PS6 which are used for detecting the presence of the part and a limit switch LS3 which can detect if the rotating station has turned 180°. The overall sequencing of the rotation is controlled by PLC.

The computer would signal the PLC to perform a rotation operation when required. The exit of the rotation station would first be closed by the pneumatic actuator to catch the part. Upon sensing of feeding part in the rotation station, the entrance would be closed by another pneumatic actuator and the rotary actuator would perform a 180° rotation before releasing the part from the rotation station. The feeding part would then slide out and activate another reflective fiber optic

sensor (PS7) to signal “end of rotation” and return the rotation station to its initial condition. If the part is in the desired orientation, no signal would be generated by the computer and it would be allowed to slide through the station as it moves down the chute.

Rejection station:

This is the last station of the whole system, it would reject any part upon sensing it when a “reject” signal is given by the computer. This is to ensure that only parts determined to be in the desired orientation will be picked up. The rejection station consists of a diverting chute that is connected to a pneumatic cylinder. Upon sensing of feeding part by the fiber optic sensor (PS7), the chute would be lowered by the cylinder to reject the part if a “reject” signal is received, or be inhibited when the part is moving in the desired orientation.

THE COMPUTER SUB-SYSTEM:

The main functions of the computer sub-system include:

- (1) Controlling the stepper motor, so that the wiper blade station and the narrow track station can be programmed.
- (2) Receiving the analog data from the scanning station 1 and scanning station 2, and converting the analog data to digital data.
- (3) Using neural network software to recognize the orientation of the parts.
- (4) Sending the activation signal based on the orientation it has recognized to activate the orienting devices.

Most functions mentioned above were achieved with the help of the data acquisition card and the motor control card installed in the computer.

PROGRAMMABLE LOGIC CONTROLLER (PLC) SUB-SYSTEM:

In the feeding system, all the outputs of the sensors are connected to the input of the PLC. The activation signal sent by the computer is also connected to the input of the PLC. The outputs of the PLC are connected to the solenoid, which in turn controls the orienting devices to act accordingly.

There are two types of vibratory bowl feeder drives in general use are:-

- a) Electromagnetic bowl feeder drives.
- b) Free-piston pneumatic drives.

Even though they each convey parts with a vibratory action, there are distinct differences in performance.

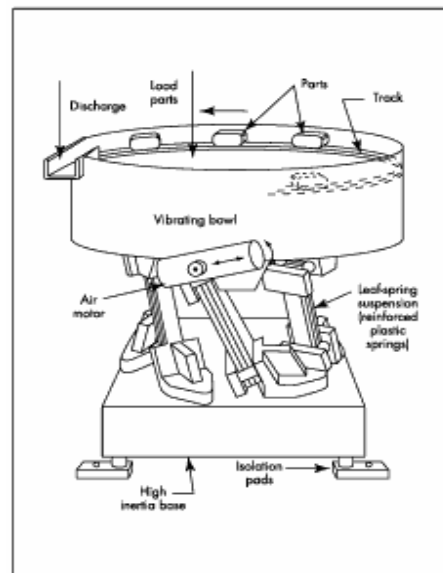
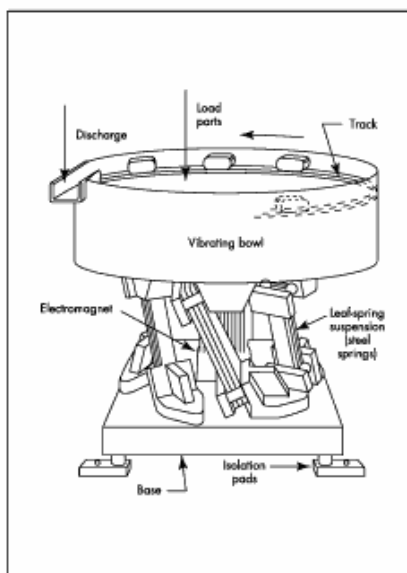


Fig12. Electromagnetic bowl feeder drives

Fig13. Free-piston pneumatic bowl feeder drives

A vibratory bowl feeder is commonly found in many assembly operations. The bowl sizes vary from 4inch in diameter to 4 or 5ft in width. The alternating vibrations produce a motion that will in practice because the product to proceed up the spiral ramp on the inside curved surface of the bowl. The upward spiral path has custom fiducials either attached to it or machined into it, so as to only allow parts in the predetermined orientation to make it to the top. Parts that are not

correct are dumped back into the bowl. So any particular part may make several short-circuited trips before reaching the top properly aligned. The product's motion up the spiral seems to defy gravity. This is not actually true, since the vibrational energy is causing the part to go up the spiral each cycle more than it goes down. The force balances at rest, upward and downward. Parts do get shaken tremendously before they reach the top.

The key to the net upwards motion is a combination of the frictional coefficients, bowl incline and the angle of bowl vibratory motion, vibrational frequency and amplitude. Figure16. Show how the inertial force at the peak of the upward cycle need to be higher than the frictional force to move, and yet in the inertial forces need to be smaller than the frictional forces to not slip backwards.

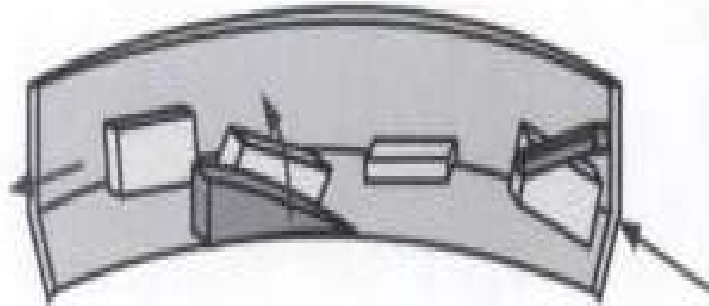


Fig14. Customized fiducials along inclined slope

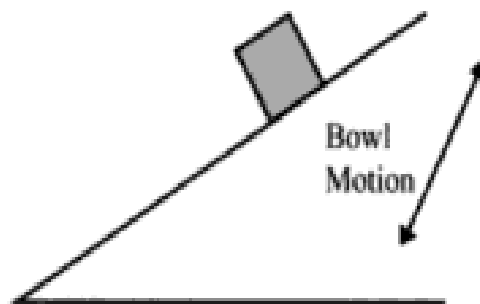


Fig15. Part on incline

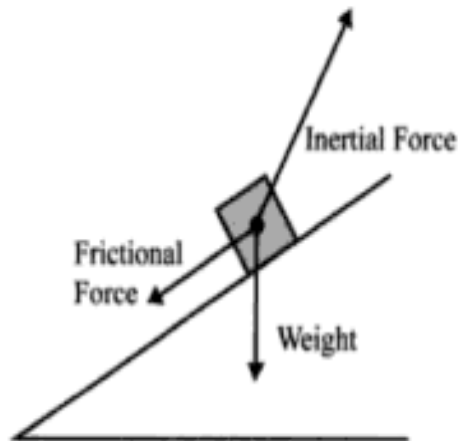


Fig16. Forces at peak of upwards vibration

Bowl feeders can be coupled to keep the product flowing. A bowl cannot hold too many minutes worth of product without getting clogged. And the clogging of parts can be a nightmare if the parts geometry allow for interlocking. Bowls can be stirred often manually or mechanically to keep in production. It usually boils down to cost, timeframe, and the long-term economic outlook.

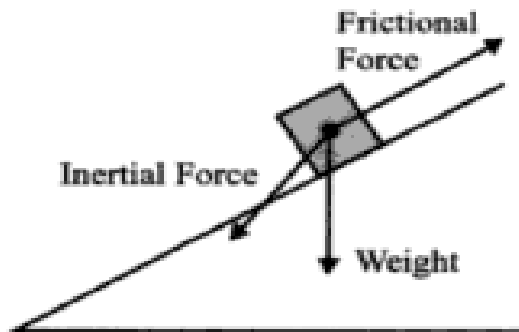


Fig17. Forces at peak of downwards vibration

4.2 Vibratory feeder operation

The electromagnetic parts feeder is a two-mass system. Mass one consists of the heavy base and rubber isolator feet, as well as the electromagnet. Mass two consists of the bowl mounting plate (often called the cross arm), the armature, and the bowl. The two masses are connected through four sets of leaf springs.

When the magnet receives power, vibration occurs because a pulsating magnetic field is established between the armature and the magnet. The springs permit the armature to move toward and away from the magnet, which imparts the vibration into bowl that ultimately moves the parts. The leaf springs are mounted at an angle, causing the parts to left off the bowl surface as they convey forward.

In many countries using 60-hz power, part feeder normally vibrates at a frequency of either 3,600 or 7,200 vibration cycles per minute. To get a closer estimate of feeder speed, use the following:

$$F_x = F \times A \times K$$

Where;

F_x = feeder speed

F = frequency (cycle or vibration per minute)

A = amplitude (length per cycle, for example, inch per cycle)

K = constant (factor is 1.3)

For example:

$$F = 3,600$$

$$A = 0.06\text{in./cycle}$$

$$K = 1.3$$

Then:

$$3,600\text{cycle/min} \times 0.06\text{in./cycle} \times 1.3$$

The estimated feeder speed or part travel = 281in. /min (119mm/sec)

Due to the effects of gravity, friction, and other factor, the maximum rate of part travel actually achievable is reduced. The 7,200 vibrations/min parts feeder is generally used when handling parts that are difficult to orient and sensitive to vibration. In this feeder, the parts are not moved as far per cycle, but are moved twice as many times as the 3,600 vibrations/min unit. This lower stroke at higher frequency results in better control of the part as it moves through the orientation devices.

Vibratory parts feeder turning

Proper turning is important not only to develop maximum spring energy level, but to keep the coil assembly cool. When a drive unit is under tuned, the spring tension is not great enough to allow the feeder mass to return to its neutral position before the next magnetic pulse takes over. Therefore, the mass remains in a state that never allows it to return to its starting or neutral position, and thus restricts the full motion each 1/20sec. A normal 60 Hz current produces 120 magnetic cycle/sec and transmits 120 mechanical cycle/sec to the bowl. Also, when the unit is under spring, the magnetic energy developed the coil assembly is not being and is dissipated in the form of heat. The heat, if prolonged could shorten the life of the coil or cause it to be badly burned.

Over springing (overturning) the drive unit would demand more energy from the coil assembly than is available. While this may not cause harm to the coil, it will result in minimizing spring development. A good balance between coil assembly energy development and spring tension is very important for a smooth and efficient feed system. At this balance point, the parts will feed at maximum frequency with minimum current requirements. The addition or removal of springs on the base drive may be necessary to obtain the balance needed. Coil clatter is a warning sound that indicates the coil gap should be checked and reset.

The driving force used to actuate the bowl feeder is accomplished by using two or three electromagnetic coils. The coil act upon and pull face plates that are constrained by leaf springs attached to the cross arms, causing and translating a tensional vibration in a vertical direction. When the drive base moves the parts at maximum efficiency with minimum current requirements, the unit is said to be tuned. The mass of the feeder bowl is the determining factor in turning the unit. The rubber feet placed at each corner of the base drive play an important part in turning and must be of the proper urometer (hardness) measurement.

APPLICATIONS:

Vibrators are used in different industrial application both as component and individual pieces of equipment. Many vibrators are used to help move bulk materials or small component parts. The application of vibration working with the force of gravity can often move materials though a process more effectively than other methods. Vibration is often used to position small component so that they can be gripped mechanically by automated equipment as required for assembly. Vibratory feeder are used extensively in the food, pharmaceutical and chemical industries, vibratory screens are used to separate bulk material in a mixture of different sized particles. For example sand, gravel, river rock, crushed rock and other aggregates are often separated by using vibratory screens. Vibratory compactors are used for soil compaction e.g. in foundation for roads, railway or building.

Vibratory feeders offer a cost-effective alternative to manual labor, saving manufacturer's time and labor cost. Concrete vibrators are used to consolidate fresh concrete so that entrapped air and excess water are released and the concrete settles firmly in the place in form work. Improper consolidation of concrete can cause product defects, compromise the concrete strength and produce surface blemishes such as bug holes and honey combing. An internal concrete vibrator is a steel cylinder about the size of a handle of a base ball bat with a hose or electrical cord attached to one end. The vibrator head is immersed in the wet concrete.

External concrete vibrators attach, via a bracket or clamp system to the concrete forms. There is wide variety of external concrete vibrator available and some vibrator manufacturers have bracket or clamp system designed to fit the major brands of the concrete forms. External concrete vibrators are available in hydraulic, pneumatic or electric power.

Selection of components

The vital components of the feeder can be:

- 1) Plastic caps.
- 2) Spouts.
- 3) Capsules.
- 4) Electrical connector.
- 5) Bearing.

As well as heavy parts are:

- 1) Anchor bolt.
- 2) Baring races.
- 3) Metal socket.

CHAPTER-05

DESIGN OF VIBRATORY BOWL FEEDER

5.1 Force Analysis:

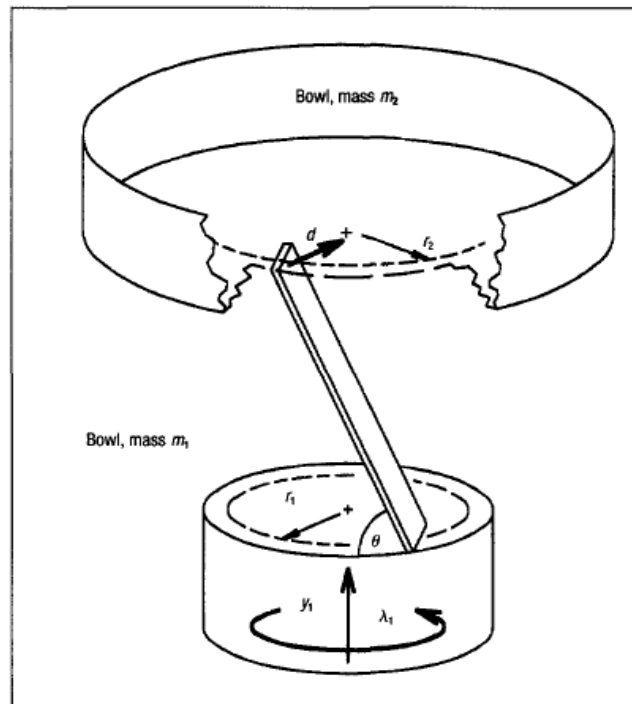


Fig18. Degrees of freedom (only one spring shown)

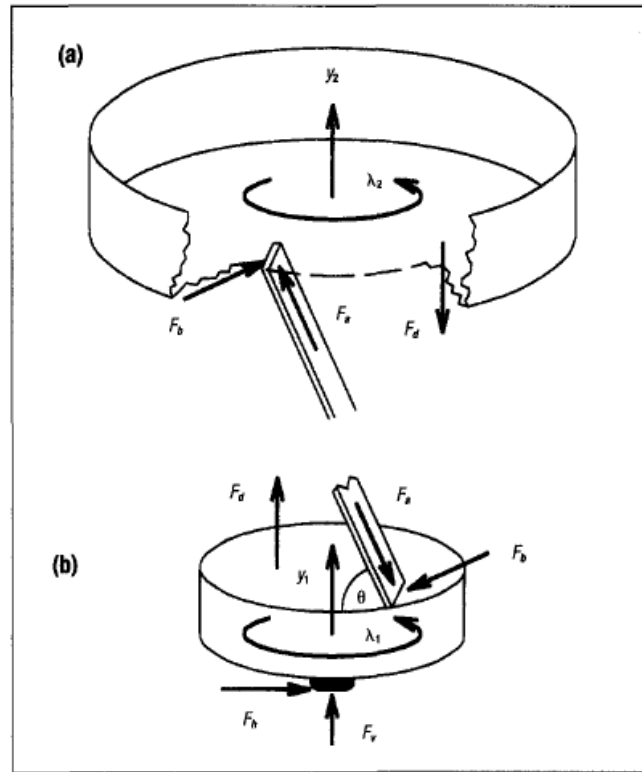


Fig19. Feeder free-body diagram (a) bowl, (b) base

The state equation that models a vibratory bowl feeder assumes that the bowl and base are perfectly rigid bodies and that all components of the bowl feeder behave in a linear fashion. The motion of the bowl and base are constrained to vertical displacement and twisting about a vertical axis, with all other motions being neglected. The leaf springs are assumed to be massless, and in this model the mass of the springs is distributed between the bowl and the base. Finally, the leaf springs are assumed to deflect in bending but not in tension or compression. These constraints allow for motion along three degrees of freedom: the vertical deflection of the base y_1 , the twisting of the base (λ_1), and the deflection of the leaf springs (d), as seen in Figure 18. The vertical and twisting deflections of the bowl y_2 and λ_2 will be expressed in terms of y_1 , λ_1 , and d . Figure 19a shows the free-body diagram of the feeder bowl. The leaf springs exert an axial force, F_a , and a bending force, F_b , on the bowl at a radius of r_2 . The electromagnet also exerts an attractive force, F_d , on the bowl. The following equations apply to the motion of the bowl:

$$m_2 \ddot{y}_2 = F_a \sin\theta + F_b \cos\theta - F_d \quad (1)$$

$$J_2 \ddot{\lambda}_2 = -r_2 F_a \cos\theta + r_2 F_b \sin\theta \quad (2)$$

Similarly, a free-body diagram may be used to find the equations of motion for the feeder base (*Figure 19b*). The leaf spring attachments have a radius of r_1 at the base. In addition, the rubber feet provide a support force (F_v) and a force to counteract twisting (F_h) at a radius of r_0 .

$$m_1 \ddot{y}_1 = -F_a \sin\theta - F_b \cos\theta + F_d + F_v \quad (3)$$

$$J_1 \ddot{\lambda}_1 = r_1 F_a \cos\theta - r_1 F_b \sin\theta + r_0 F_h \quad (4)$$

The position of the bowl (y_2 and λ_2) may be expressed as a function of the position of the base and the leaf spring displacement (y_1 , λ_1 , and d).

$$y_2 = y_1 + d \cos\theta \quad (5)$$

$$\lambda_2 = \lambda_1 + \left(\frac{d}{r_2} \right) \sin\theta \quad (6)$$

Substituting 5 and 6 in 1 and 2 we get:

$$m_2(\ddot{y}_1 + \ddot{d} \cos\theta) = F_a \sin\theta + F_b \cos\theta - F_d \quad (7)$$

$$J_2 \left(\ddot{\lambda}_1 + \frac{\ddot{d}}{r_2} \sin\theta \right) = -r_2 F_a \cos\theta + r_2 F_b \sin\theta \quad (8)$$

Equation 3, 4, 7 and 8 are expressed in matrix:

$$\begin{bmatrix} m_1 & 0 & 0 \\ 0 & J_1 & 0 \\ m_2 & 0 & m_2 \cos \theta \\ 0 & J_2 & \frac{J_2}{r_2} \sin \theta \end{bmatrix} \begin{bmatrix} \ddot{y}_1 \\ \ddot{\lambda}_1 \\ \ddot{d} \end{bmatrix} = \begin{bmatrix} -\sin \theta & -\cos \theta & 0 & 1 \\ r_1 \cos \theta & -r_1 \sin \theta & r_0 & 0 \\ \sin \theta & \cos \theta & 0 & 0 \\ -r_2 \cos \theta & r_2 \sin \theta & 0 & 0 \end{bmatrix} \begin{bmatrix} F_a \\ F_b \\ F_h \\ F_v \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \\ -1 \\ 0 \end{bmatrix} F_d \quad (9)$$

This matrix equation, representing a system having three unknowns and four constraints, is over-constrained. One constraint (F_a) may be eliminated through the appropriate substitution, resulting in the following equation:

$$\begin{bmatrix} m_1+m_2 & 0 & m_1 \cos \theta \\ 0 & \frac{J_1}{r_1} + \frac{J_2}{r_2} & \frac{J_2}{r_2} \sin \theta \\ m_1 \cos \theta & \frac{J_1}{r_1} \cos \theta & 0 \end{bmatrix} \begin{bmatrix} \ddot{y}_1 \\ \ddot{\lambda}_1 \\ \ddot{d} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 \\ 0 & \frac{r_0}{r_1} & 0 \\ -1 & \frac{r_0}{r_1} \sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} F_b \\ F_h \\ F_v \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \cos \theta \end{bmatrix} F_d \quad (10)$$

Forces F_b , F_h , and F_v may be expressed in terms of the deflections y_1 , λ_1 , and d through the following matrix equation:

$$\begin{bmatrix} F_b \\ F_h \\ F_v \end{bmatrix} = \begin{bmatrix} 0 & 0 & -k_s \\ 0 & -r_0 k_h & 0 \\ -k_v & 0 & 0 \end{bmatrix} \mathbf{Y} + \begin{bmatrix} 0 & 0 & 0 \\ 0 & -r_0 b_h & 0 \\ -b_v & 0 & 0 \end{bmatrix} \dot{\mathbf{Y}} \quad (11)$$

Where the vector \mathbf{Y} is defined as:

$$\mathbf{Y} = \begin{bmatrix} y_1 \\ \lambda_1 \\ d \end{bmatrix} \quad (12)$$

Substituting Eq. (11) into Eq. (10) yields a second-order differential equation that describes the motion of the bowl feeder model in terms of Y and the forcing function F_d .

$$\mathbf{M}\ddot{\mathbf{Y}} = -\mathbf{K}\mathbf{Y} - \mathbf{B}\dot{\mathbf{Y}} + \mathbf{U}F_d \quad (13)$$

Where:

$$\mathbf{M} = \begin{bmatrix} m_1+m_2 & 0 & m_2\cos\theta \\ 0 & \frac{J_1}{r_1} + \frac{J_2}{r_2} & \frac{J_2}{r_2^2}\sin\theta \\ m_1\cos\theta & \frac{J_1}{r_1}\sin\theta & 0 \end{bmatrix} \quad (14)$$

$$\mathbf{K} = \begin{bmatrix} k_v & 0 & 0 \\ 0 & k_h \frac{r_0^2}{r_1} & 0 \\ k_v\cos\theta & k_h \frac{r_0^2}{r_1}\sin\theta & -k_s \end{bmatrix} \quad (15)$$

$$\mathbf{B} = \begin{bmatrix} b_v & 0 & 0 \\ 0 & b_h \frac{r_0^2}{r_1} & 0 \\ b_v\cos\theta & b_h \frac{r_0^2}{r_1}\sin\theta & 0 \end{bmatrix} \quad (16)$$

$$\mathbf{U} = \begin{bmatrix} 0 \\ 0 \\ \cos\theta \end{bmatrix} \quad (17)$$

If the vector \mathbf{X} is defined as:

$$\mathbf{X} = \begin{bmatrix} \mathbf{Y} \\ \dot{\mathbf{Y}} \end{bmatrix} \quad (18)$$

In the bowl, Parts are in motion in translation and rotation, and may be in contact with the bowl feeder's wall, track, or with other parts in the feeder. This work considers the effects of only a single part traveling in the bowl feeder. It assumes that the part is small enough to be considered a point mass when compared to the bowl. This work also assumes that the part weighs significantly less than the bowl, and its weight does not affect the motion of the bowl. The part may be in contact with the track and undergoing static friction, in which case the part moves with the track. The part may be in contact with the track but moving relative to the track, undergoing kinetic friction. If the track has sufficient downward acceleration, the part will experience free-fall during part of the drive cycle. A perfectly elastic collision is assumed to occur when the part impacts the bowl.

The feeder bowl wall exerts forces on a moving part, and centripetal force keeps the part traveling along a circular path. The resulting frictional force acts to oppose motion between part and bowl. By considering a part moving along the inside perimeter of a hollow cylinder, a comparison between the wall friction and friction between the part and track may be made. Assuming equal friction coefficients along the part wall and part track surfaces and normal operating conditions, the wall friction is on the order of 1% of the track friction and may be omitted from the model. For analysis of part motion, a local coordinate system is developed (*Figure 20*). The direction parallel to the ramp surface is u , and the perpendicular direction is v . The part is located within the bowl at a radius of r_p . The position of the bowl is given by Y , but this vector must be transformed to a $u_2 - v_2$ system through the following equations:

$$u_2 = \lambda_2 r_p \cos\phi + y_2 \sin\phi \quad (19)$$

$$v_2 = -\lambda_2 r_p \sin\phi + y_2 \cos\phi \quad (20)$$

The bowl coordinates y_2 and λ_2 are expressed as functions of \mathbf{Y} in Esq. (5) and (6). Substitution yields:

$$\begin{bmatrix} u_2 \\ v_2 \end{bmatrix} = \begin{bmatrix} \sin \phi r_P \cos \phi \left(\frac{r_P}{r_2} \sin \theta \cos \phi + \cos \theta \sin \phi \right) \\ \cos \phi r_P \sin \phi \left(\frac{r_P}{r_2} \sin \theta \sin \phi + \cos \theta \cos \phi \right) \end{bmatrix} \mathbf{Y} \quad (21)$$

Parts in a bowl feeder may travel in contact with the bowl undergoing static or kinetic friction or in free-fall if the bowl's downward acceleration is greater than the acceleration of gravity. Table 1 lists the equations of motion that govern the motion of the part, derived from free-body diagrams of the parts. For a part to be in the static friction mode, the part and track must have equal velocities, and the normal force between the two must be sufficient to generate the needed friction.

$$\dot{u}_p = \dot{u}_2 \quad (22)$$

$$\mu_s (\ddot{v}_2 + g \cos \phi) \geq -(\ddot{u}_2 + g \sin \phi) \quad (23)$$

(For track acceleration in the positive u direction)

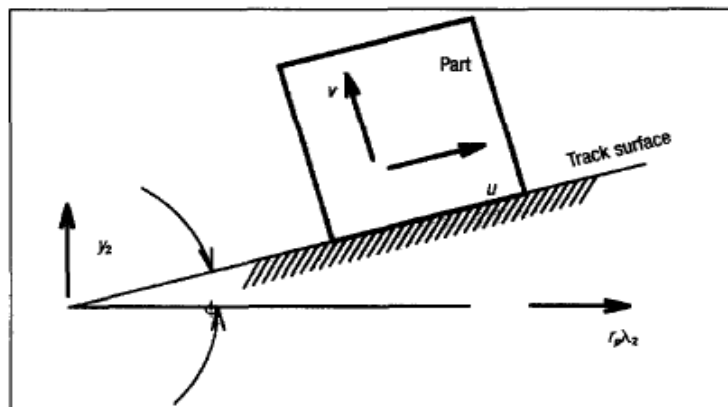


Fig20. Part motion coordinates

$$\mu_s (\ddot{v}_2 + g \cos \phi) \geq \ddot{u}_2 + g \sin \phi \quad (24)$$

Free-fall begins when acceleration of the track in the v direction exceeds the v component of gravity, and ends when the part contacts with the track. Otherwise, the part undergoes kinetic friction. The direction of the friction force depends on the relative velocity between the part and the track.

Table 1
Equations of motion for part in a bowl feeder

Motion Type	Equations of Motion
Static friction	$\ddot{u}_p = \ddot{u}_2$ $\ddot{v}_p = \ddot{v}_2$
Kinetic friction, part sliding forward relative to track	$\ddot{u}_p = -\mu_k (\ddot{v}_2 + g \cos \phi) - g \sin \phi$ $\ddot{v}_p = \ddot{v}_2$
Kinetic friction, part sliding backward relative to track	$\ddot{u}_p = \mu_k (\ddot{v}_2 + g \cos \phi) - g \sin \phi$ $\ddot{v}_p = \ddot{v}_2$
Free-fall	$\ddot{u}_p = -g \sin \phi$ $\ddot{u}_p = -g \cos \phi$

The motion of the bowl is found out using Taylor's series. The parameters of bowl are taken as given below.

$$x(t + \delta t) \approx x(t) + \dot{x}(t)\delta t + \frac{1}{2}\ddot{x}(t)\delta t^2 \quad (25)$$

The feeder has three sections of track having a constant radius. Theft characteristics are given in *Table 3*. A time step will be used in the simulation. The force input to the bowl will be approximated based on observations of the feeder's electromagnet. The force developed by the electromagnet will be a function of both the current running through the coils as well as the gap height between the magnet and the bowl. By using a dc power supply and adjusting the gap height on the feeder, a profile of the driving force as a function of current and the gap height, $F_d(I, h_g)$, will be developed. The current in the coils of the electromagnet will be observed with an oscilloscope. Because the gap height changes with the motion of the base and bowl, the gap height is calculated at each step in the simulation to determine the driving force.

Table 2

Bowl feeder parameters

PARAMETERS	VALUE
1. Base Mass. (m_1)	0.146 lb-sec ² /in.
2. Bowl Mass. (m_2)	0.0571 lb-sec ² /in.
3. Base Mass Moment of Inertia. (I_1)	1.96 lb-in.-sec ²
4. Bowl Mass Moment of Inertia. (I_2)	1.50 lb-in.-sec ²
5. Leaf Spring Angle. (θ)	65 deg.
6. Life spring stiffness (k_s)	12200 lb/in.
7. Radius of Leaf Spring Connection at Base. (r_1)	4.18 in.
8. Radius of Leaf Spring Connection at Bowl. (r_2)	3.392 in.
9. Radius of Rubber Feet. (r_0)	4.474 in.
10. Rubber Foot Horizontal Stiffness. (k_h)	2000 lb/in.
11. Rubber Foot Vertical Stiffness. (k_v)	8090 lb/in.
12. Rubber Foot Horizontal Damping Coefficient. (b_h)	18.1 lb-sec/in.
13. Rubber Foot Vertical Damping Coefficient. (b_v)	24.3 lb-sec/in.
14. Friction Coefficient between Part and the Track. (μ)	0.3

Table 3

Track parameters

Track radius	6-1/8 inch	7-1/4 inch	8-1/4 inch
Length	12 inch	15 inch	18 inch
Angle of inclination	0°	2.4°	2.2°
Coefficient of static friction	0.95	0.95	0.95
Coefficient of dynamic friction	0.90	0.90	0.90

CHAPTER-06

CONCLUSION

Vibration bowl feeder has been overviewed. Its components and various parts are studied. The force analysis of the bowl feeder has been done. The motion of the bowl and part are analyzed. Equations of motions have been written for the motion of bowl and analysis has been done on that basis. The behavior of feeder has been adequately represented. The simulation model can be framed out of the force analysis given based on the various bowl parameters and the equations of motion.

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