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Study of Part Feeding System for Optimization in Fms & Force Analysis Using Matrix Method

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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.*

Keywords: *Part feeders, Matrix equation, PLC Sub-System, Force analysis*

I. INTRODUCTION

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 feeing 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. 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.

A feeder may have below features :
Coating: Bowl feeder coatings Minimize wear and tear, reduces noise and damage to parts.
Sound enclosure/cover: A foam-lined structure that absorbs the noise created by the vibratory feeder. Reduce noise and protects against dust and contamination.
Base plates: Enable easy mounting of the drive unit to the machine bed.
Sensors: Minimum/maximum level control on a linear track.
Hopper: Large, bulk container that stores material and regulates parts flow into the vibratory feeder system

Types
It should come as no shock, therefore to pinpoint that the most versatile of all part feeder remains the human assembly worker.
Below are the types of Part feeder.
1. Barrel Feeder
2. Centrifugal Feeder
3. Drum Feeder
4. Shaker Feeder

5. Roll Feeder
6. Revolving plate feeder
7. Gravimetric feeder
8. Linear feeder
9. Vibratory feeder

FEEDING SYSTEM DIAGRAM

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.

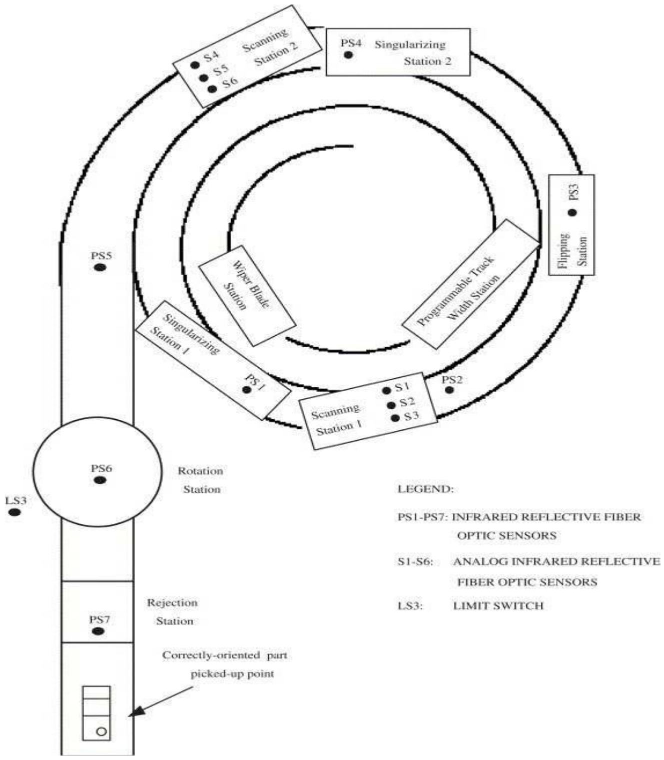

Fig 1. Symmetric diagram of feeding system

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.

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.

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

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.

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.

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.

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.

Rotation station:
This station is the final station to orientate the parts to the desired orientation and is used to reorientation a part that is 180° reversed.

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.

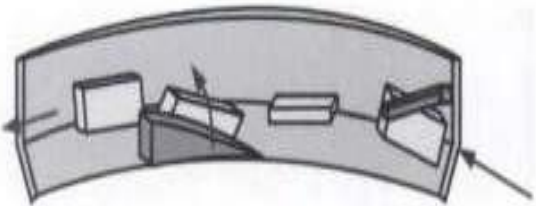

Fig 2. Customized fiducials along inclined slope

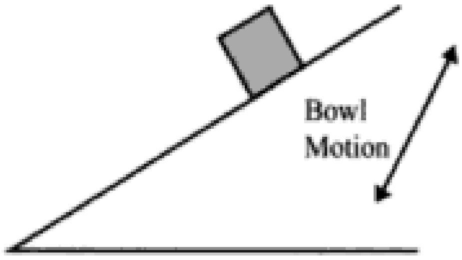

Fig 3. Part on incline

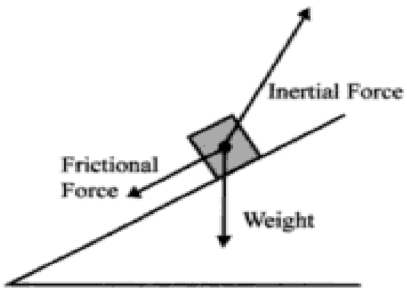

Fig 4. Forces at peak of upwards vibration

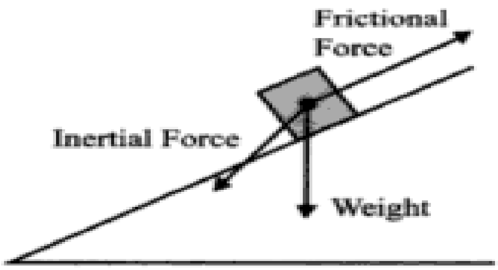

Fig 5. Forces at peak of downwards vibration

To get a closer estimate of feeder speed, use the following:
Fx= F × A × K

Where;
FX = 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)

2.Force Analysis:

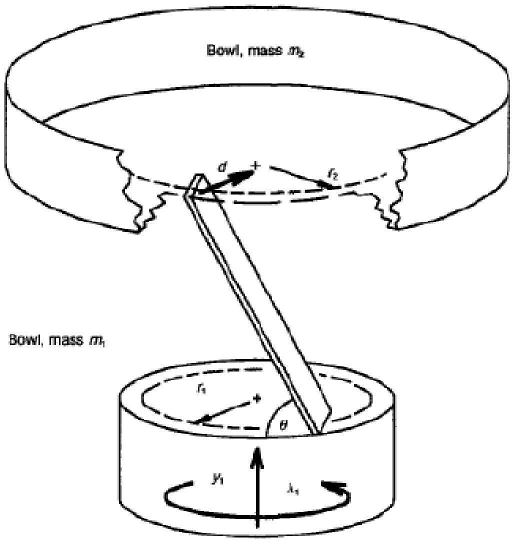

Fig 6. Degrees of freedom (only one spring shown)

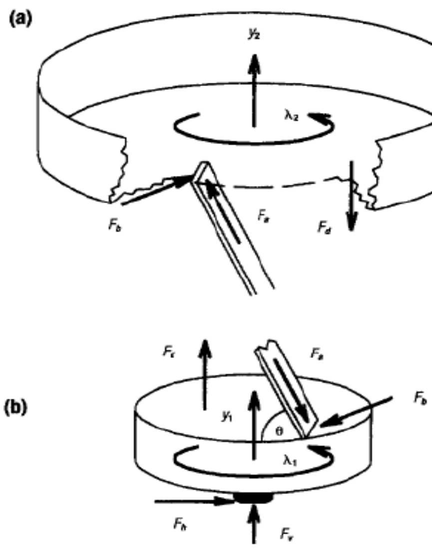

Fig7. Feeder free-body diagram (a) bowl, (b) base

The following equations apply to the motion of the bowl:

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

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

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 r1 at the base. In addition, the rubber feet provide a support force (F,) and a force to counteract twisting (Fh) at a radius of r0.

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

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

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

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

Substituting 5 and 6 in 1 and 2 we get:

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

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

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

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

This matrix equation, representing a system having three unknowns and four constraints, is over constrained.

One constraint (Fa) may be eliminated through the appropriate substitution,
resulting in the following equation:

$$\begin{bmatrix} m_1+m_2 & 0 & m_1\cos\theta \\ 0 & \frac{J_1}{r_1}+\frac{J_2}{r_2} & \frac{J_2}{r_2^2}\sin\theta \\ m_1\cos\theta & \frac{J_1}{r_1}\cos\theta & 0 \end{bmatrix} \begin{bmatrix} \ddot{y}_1 \\ \ddot{\lambda}_1 \\ \ddot{d} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 \\ 0 & \frac{r_0}{r_1} & 0 \\ -1 & \frac{r_0}{r_1}\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} F_b \\ F_h \\ F_v \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \cos\theta \end{bmatrix} F_d \qquad (10)$$

Forces Fb, Fh, and Fv may be expressed in terms of the deflections y1, λ1, and d through the following matrix equation:

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

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

Where the vector Y is defined as:

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 Fd.

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

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

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

Where:

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

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

If the vector X is defined as:

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

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	$\ddot{u}_p = -g\sin\phi$ $\ddot{u}_p = -g\cos\phi$

EXPERIMENTAL SET UP

BOWL FEEDER PARAMETER

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

PARAMETER

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 deg	2.4 deg	2.2 deg
Coefficient of static friction	0.95	0.95	0.95
Coefficient of dynamic friction	0.90	0.90	0.90

Here we have taken example of experiment of a Tip assly m/c of writing instruments.
Parts engaged to complete the experiments are as below:

1.Nozzle
2.Tip
3.Part Feeder set Up Unit

Now nozzle is poured into the hopper and process starts to continue the assembly of Nozzle and Tip together. When M/c is on then nozzle due to vibration raised inside hopper starts travelling towards downward along with track and reaches to punching station where Tip is pressed inside and locking done.

Data Collection

Mode	Part feeder
Operation	Tip Punching
Man Power Utilized	01Nos
Shift Length	8Hrs
Part produced	15000
Breaks	15 Minutes(2 Time)
Rej Part produced	50
Cycle Time	1.92 Sec/Piece

II. EXPERIMENTAL RESULT

1. Cycle Time Reduction

Cycle time is the total time from beginning to the end of the process as defined. It includes process time during which a unit is acted upon to bring it closer to an output and delay time during which a unit of work is spent waiting to take the next action.
For less cycle time , productivity is large while for large cycle time ,productivity will be less .Every industry which needs to produce large quantity will keen to have process with less cycle time.

By establishing Part feeding systems to any process will help to reduce time for part feeding to the working station which helps to reduce cycle time.

2. OEE Improvement

OEE (overall equipment effectiveness) is gold standard for measuring manufacturing productivity. It identifies the percentage of manufacturing that is truly productive.
It is single best metric for identifying losses, benchmarking progress and improving the productivity of manufacturing equipments.

5.Advantages of Part Feeding Systems

1.Flexible solutions can be easily reconfigured to accommodate production changes. With the Part feeding System, this can be done quickly and inexpensively.
2. Products with complex geometries can be handled without problem as well. In addition,
3.The performance and efficiency of Part feeding System remains constant and does not decrease over time.
4.It require less assistance and maintenance over time.
5.Part feeding System reduces potential risks when new projects are evaluated.
6.Part feeding System entails lower costs when changing from one part to another, which improves capital utilization.

III. 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. It helps to reduce cycle time & increase productivity of assly process.

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