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A Method to Design Vibratory Bowl Feeder by Using Numerical Simulation Analysis

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Abstract— *In the modern industry, vibratory bowl feeders - VBF have been widely used to feed small and light parts such as USB caps. In this method, the bowl's vibration, which caused by forced vibration and the friction between parts and track, helps convey the parts out of the feeder along the track. However, ensuring that the directional requirements before going out works correctly depends entirely on the sorting bowl. For different types of parts, sorting bowl design is different. This paper presents a digital simulation study, using the multibody dynamics analysis on the Adams View platform, to analyze the movements status of parts on the sorting bowl. And it uses modal analysis on the ANSYS Workbench platform to determine the natural-vibration frequency of the system. With the results, we could identify optimum parameters, bowl's structure, the sorting track, mounting adapter and suspension system for a stable operating system. Then an experiment is conducted to validate the results.*

Keywords— *Vibratory bowl feeders, sorting bowl, USB caps, digital simulation, modal analysis, multibody dynamics analysis.*

I. INTRODUCTION

The capacity of parts feeding depends on the proportion of parts in the right direction coming out of the bowl in a unit of time. During the parts feeding process, the parts move inside the sorting bowl (1a) with the orientated structure and comes out in the required orientation [1]. To accomplish this, an automatic vibratory bowl feeder has been designed as in Fig. 1. The parts are scattered randomly inside the bowl (1a) which is mounted on the upper vibrator (1b). The electromagnetic force between the coil fixed to the upper vibrator (1c) and the other electromagnet (1d) fixed to the lower vibrator (1e) provides vibration to the sorting bowl by rotating movements around the vertical axis and the back and forth movements of the leaf spring (1c), so that the parts are classified and oriented in a specific direction. The interaction force between two components of the electromagnet is controlled by changing the voltage from a controller. Cushion rubber (1f) can deteriorate the system's vibrations that affect other devices.

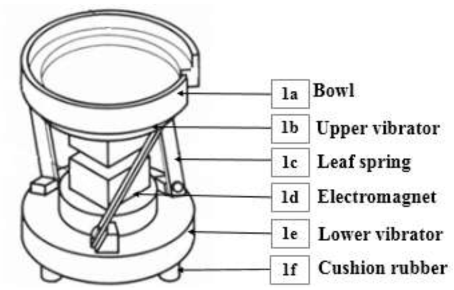

Fig. 1. Automatic vibratory bowl feeder.

However, the process to assure the parts orientation and feeding capacity relies on following factors: frequency, electromagnet's vibration amplitude and sorting bowl structure [2]–[8] For different types of parts, it requires specific sorting bowl designs to feeding parts in aligned direction that was specified. There were researches study on the design of sorting bowls based on computational theory [3], [4]. It also depends on the shapes and dynamics of parts. Thus, verification on dynamic behavior of the parts on bowl feeder is necessary to ensure feeding capacity. In addition, feeding capacity depends on the speed of parts on feeding tracks, which has the tight correlation with the vibration's amplitude of the system as well as other dynamic factors. This amplitude depends on feeding structure, especially suspension system. Suspension's selection is based on the system resonates with the exciting force's frequency [2]. After the selection, the dynamic behavior of the system in relation to natural-vibration frequency should be verified to compatible with the electrical frequency. There were researches on this matter which were conducted by comparing the digital model with experimental results [6].

By using digital simulating analysis, this paper is to propose a method of designing vibratory bowl feeders by identifying whether the mechanical system's natural-vibration frequency is compatible with the frequency of the electromagnet's electric current. The results of the digital model analysis are used to simulate a machine and experimentally analyzed to verify.

II. THE DESIGN OF A USB CAPS FEEDING DEVICE

A. The Sorting Bowl Design

Calculation process is done as in Fig. 2. With the USB caps input parameters as shown in Fig. 3, size: 46.66mm x 16mm x 9.2mm, material is SUS304 and the required capacity; based on calculation the design of the bin with the selected cylindrical shape and the selected material are suitable for the preservation of the subject [2]. For the parts to move along the track, the step and angle of track were calculated, then use to determine the bowl's diameter. According to the expected capacity, the height of the bowl must be calculated to assure the sufficient capacity to accommodate the parts. The calculation of the bowl's parameters is shown in Table I.

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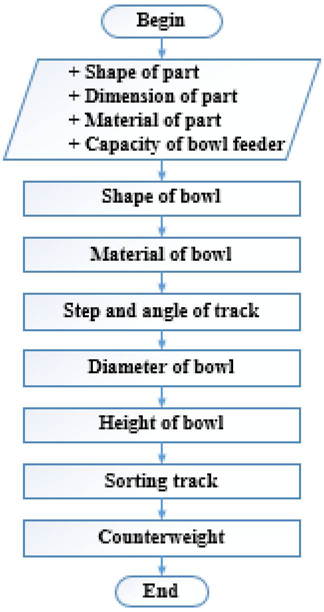

Fig. 2. Process of designing the bowl.

A parts orientation system of vibratory bowl feeders one or more orientation mechanisms set up on explicit positions along the track [2]–[4]. Those orientation mechanisms are used to classify and direct part, as well as reject wrongly oriented parts and put them back to sorting bowl. As the parts move on the track, there are many of the natural state of them are formed as Fig. 3…perpendicular (3a,3e,3f), vertical (3b,3d,3g), stacked (3c).

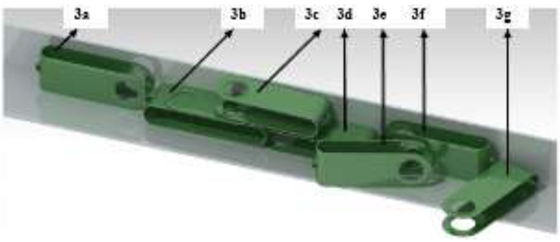

Fig. 3. State of parts on the sorting track.

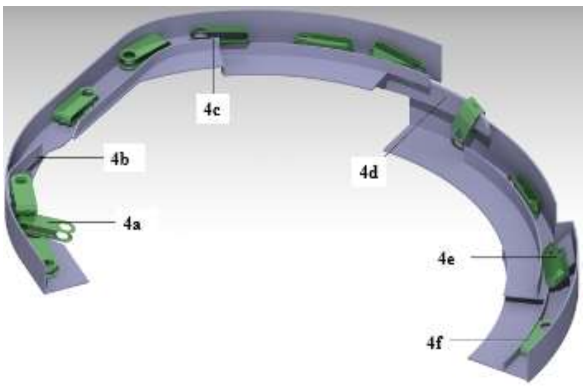

Fig. 4. Sorting track.

Sorting track is designed as Fig. 4 to ensure part is in the required orientation shown in [3], [4]. First, slanting part (3e; 3g) should be removed by creating a narrow path (4a) and by gravity to allow the parts to fall. Use the level on the sorting bowl to remove stacked parts (4b). After these two steps, only the perpendicular parts (3a, 3f) and the vertical ones (3b; 3d) are moving on the track. For vertical (3b; 3d), use the 90^0 flipping classification channel of the parts (4c) to form the perpendicular state (3a; 3f). After the parts settled in the perpendicular state (3a; 3f), the guiding mechanism with the slider (4d) brings the parts to one direction (3f). Finally, use the coulisse with an angle of 45^0 to 90^0 to guide the direction (4e) and deliver the part in the right direction (4f).

To maintain the balance of the system in oscillation, a counterweight system is designed. The result of this oscillation process is that the center of gravity of the sorting bowl lies on the rotating axis of the bowl wall (which coincides with the vertical axis passing through the center of the suspension system) ensuring that the workpieces are uniformly scattered during the vibrating progress. The results of the bowl design are shown in Fig. 5.

B. The Suspension System Design

The size and mass of the USB cap bowl feeder is similar to NTN's Straight wall bowl series [9]. Therefore, the suspension system was selected according to NTN Bowl Feeder [10] and the calculation process was referenced from their manual [2]. Feeders are suspended on three sets of leaf springs; the main specifications of the suspension are shown in Table 1.

The mounting adapter are designed to connect the sorting bowl and suspension system and can be adjusted in size so that the natural-vibration frequency of a vibratory bowl feeder is equal to the frequency of stimulation force and twice the current frequency of the electromagnet.

C. The Technical Parameters of USB Caps Bowl Feeder

Table I shows the calculated parameters of sorting bowl, the selected parameters of suspension system and design of the adapter. Properties of materials used in USB caps bowl feeder are shown in Table II.

TABLE I. The parameters of USB caps bowl feeder.

Component	Material	Size (mm)
Bowl	SUS 304	Diameter: 380 Height: 102 step of track: 40
Mounting adapter	C45 Steel	Outer diameter: 135 Inner diameter: 105 Height: 10
Upper vibrator	Cast iron	Outer diameter: 284 Height: 110
Leaf spring	50MnCrVA Steel	Length: 106 Width: 35 Thickness: 2
Lower vibrator	Cast iron	Diameter: 294 Height: 140

TABLE II. Material properties of mechanical components.

Material	Specific weight (kg/cm^3)	Elastic modulus (x10^11 Pa)	Poisson's ratio
SUS 304	7850	2.1	0.305
Cast iron	8545	1.06	0.324
50CrMnVA & C45 Steel	7800	2.1	0.300

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III. Modeling and Simulation

A. Modeling the Vibratory Bowl Feeder

From the parameters defined in Section II.C, the geometric model of the device consists of three main parts: the sorting bowl, the suspension system and mounting adapter, which are designed as shown in Fig. 5.

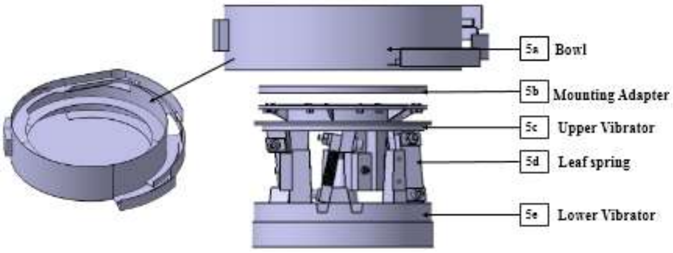

Fig. 5. Geometric model.

B. Simulation Tools

MSC Adams and Ansys Workbench are two commercial software which are used worldwide to analyze and solve scientific and technical problems, including modal analysis. In this research, Adams View module of MSC Adams software is used to simulate and analyze the dynamics of the sorting bowl. Dynamic analysis aims to determine the status of parts on the sorting bowl when being vibrated, thereby refining the bowl design to allocate the workpieces in the required direction. In addition, this study also uses the Modal Analysis module of the ANSYS Workbench software to simulate and analyze the vibration modals at some natural-vibration frequencies of the system. Thus determining the suitable adapter and suspension system design in order to be compatible with the frequency of the current activating the electromagnet of 50Hz to properly operate system [2], [6].

C. Simulation Process

The dynamic simulation process on MSC Adams is done as in Fig. 6 and modal analysis on ANSYS Workbench are shown as in Fig. 7.

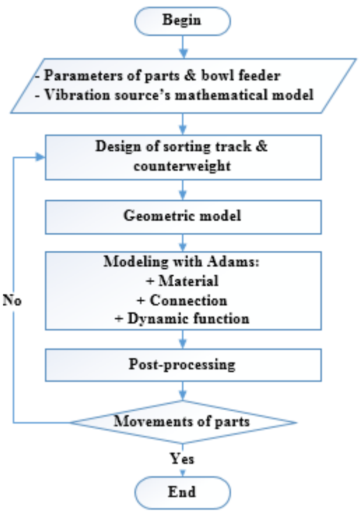

Fig. 6. Process of simulation on MSC Adams.

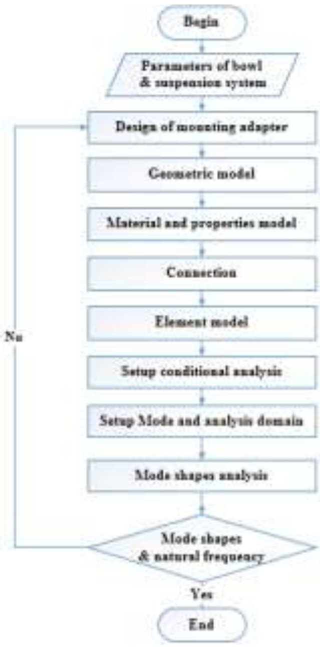

Fig. 7. Process of modal analysis on ansys workbench.

Geometric Models of both processes are done as Fig. 5, with the material used for the components as described in Table I and the material characteristics described in Table II.

In this simulation, vibration source for the bowl is replaced by a prismatic and revolute joint. The two-degree-of-freedom joint was modeled by two sine function with the same phase and frequency. The amplitude and frequency have been measured in experiments. Consequently, the mathematical functions to model the movement of workpiece are:

Prismatic: $x = -a.\sin(2\pi.100.t)$

Revolute: $\theta = b.\sin(2\pi.100.t)$

where:

a: Prismatic amplitude

b: Revolute amplitude

The bowl's model is analyzed using Finite Element Method in Ansys Workbench. The model uses the quadratic elements Solid187 and Contact174, Targe170 for bonded link.

D. Verification on the Digital Model of the Suspension Model

a) Verification on the oscialation frequency of the suspension system

Result shows that the natural-vibration frequency of the suspension system is 196.78 Hz as shown in Fig. 8, which has the form of rotation around the vertical axis.

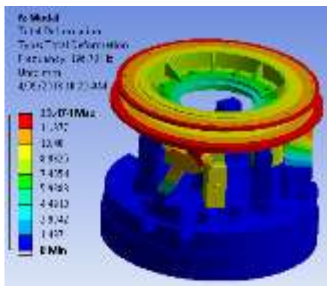

Fig. 8. Natural frequency of suspension system.

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To verify the results and the digital model of the suspension system, VIBROPOST 80- Brüel & Kjær Vibro is used to identify the system's natural oscillation frequency. The device and the measuring instruments are set up as in Fig. 9 – this method is also suitable with the published researches [1], [6], [7], thus identifying the system's natural frequency. The results are the displacement of the caps over time, the response frequency of the system, and the natural oscillation frequency of the machine's components.

b) Experiment's setup and measuring instrument

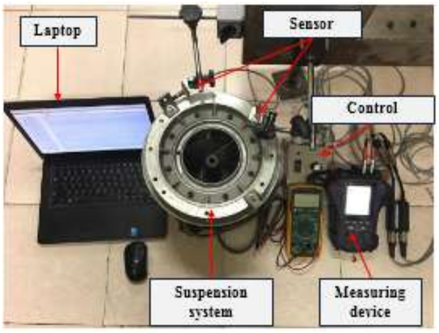

Fig. 9. Experiment's setup and measuring instrument VIBROPOST 80.

The measuring instrument uses two proximity sensors which allow measuring vibration amplitude and frequency without direct contact. VIBROPOST 80 can connect to 4 modules, so it can simultaneously measure both vertical and tangential oscillations. In addition, this instrument can also identify natural frequency of each component of the system. With external memory, VIBROPOST 80 can process the measured data right on the device. The measuring instrument's technical information is included in Table III.

TABLE III. Technical information of VIBROPOST 80 - Brüel & Kjær Vibro

Technical information	Measuring scope
Parameters	Velocity, acceleration, displacement, frequency
Frequency range	0.18Hz-80kHz
Number of modules	4
Screen	VGA/LCD color screen
Screen size	220 x 220 x 71 mm
Signal processing	On screen or on computer
Displayed signal	Simultaneously (vt, gt, cv, ts)
Specific frequency measurement	Yes
External memory	16Gb SD/SDHC
Internal memory	128Mb
Computer connecting software	ReX PC
Security level	IP65

c) Experiment Results and Result Processing

The data of vertical displacement and rotating angles over have been taken over time and processed with ReX software which is specially developed for VP80. After processed, the results include the suspension system's response frequency and amplitude (Figure 10).

From Fig. 10, we can see that the natural oscillation amplitude of the suspension system is 201 Hz. As the voltage varies, the amplitude also varies. However, no matter what the voltage value is, the natural oscillation frequency of the system always remains the same. The results are nearly similar to the numerical modal analysis, thus verify that the suspension model is suitable for evaluating the vibratory bowl feeders.

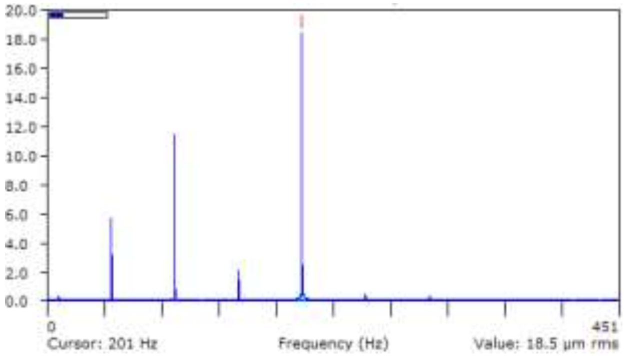

Fig. 10. Specific frequency and oscillation amplitude.

E. Digital Enviroment Results

a) Process of parts transferring

Results of parts dynamic behavior through the sorting bowl are done as in Fig. 11. The simulation shows that the bowl design is accurate to keep USB caps go on the right direction.

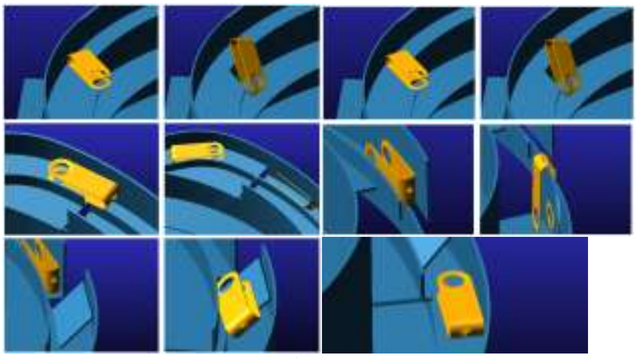

Fig. 11. Behavior of part on the sorting track.

b) System's Oscillation

After verifying the suspension system model by experiment, the authors come to verify the natural oscillation frequency of the vibratory bowl feeder, results as in Fig. 12.

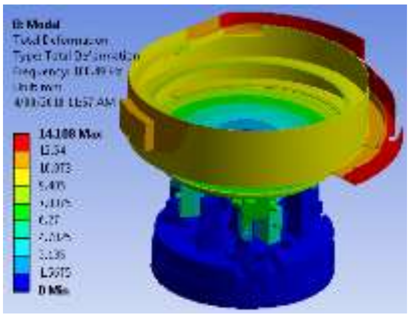

Fig. 12. Natural frequency of vibratory bowl feeder.

At the natural oscillator frequency of 100.49 Hz, the simulated vibrating feeder device has a rotational form of rotation around the vertical axis that coincides that of the real feeder.

And this natural oscillation frequency is two times the stimulated electric frequency (50 Hz) [2], [11] and is within the frequency range that the vibrator can work well [6]. Hence, validating the parameters of the suspension system and the design, as well as the manufacture of feeding bowl and adapter are optimal.

IV. MANUFACTORING AND TESTING

To verify the results of analyzing and designing process, the authors have come to manufacture a USB caps vibratory bowl feeder with the parameters in Section II.C as in Fig. 13. The experiment done (Fig. 14) shows that the parts moved as expected on sorting bowl.

Fig. 13. Experimental setup.

Fig. 14. Testing setup.

V. CONCLUSION

This result shows that the design of sorting track, adapter and the selection of suspension system by simulation is correct at first try. The vibration source for the simulation of dynamic behavior of workpieces on sorting bowl can be perfectly replaced by a two-degrees-of-freedom-joint modeled by two sine function with the same starting phase. Meanwhile, it also proves the feasibility of the recommendation to build a vibratory bowl feeder with a constant frequency current's electromagnet, and the system's structure can be designed to have the natural oscillation frequency concurring with the stimulating force's frequency by modal analysis. This alternative should be used to design vibratory bowl feeder for other sporadic, small and light parts.

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