Impact of Vacuum Gripping System Oscillation on Product Holding Force

Mykola Iakymchuk , Oleksandr Gavva

***Abstract:**:This article discusses a possible use of vacuum gripping systems to perform process operations with multi-unit packaging equipment. A mathematical model was developed to determine a holding force for structural elements of a multi-unit package and the level of vacuum in such systems taking into account additional dynamic loads, as well as physical and mechanical properties of packages that will allow to ensure reliable holdup of structural elements of a multi-unit package and retain their marketable condition. A comparative analysis of holding force produced by standard suction cups and corrugated suction cups was conducted. The obtained results can be used to develop new types of vacuum gripping systems for multi-unit packaging.*

***Key words:** multi-unit package, holding force, vacuum gripping systems, multi-unit packaging equipment.*

INTRODUCTION

The packaging industry today is developing and using a wide variety of packages of different forms, sizes, weights, and with different physical and mechanical properties of manufacturing materials, and unique customer-oriented auxiliary packaging elements. To make shipment of packages from manufacturers to customers easier, shipment units in the form of multi-unit packages are created. [1].

Systems that are most frequently used to form a multi-unit package are gripping systems. Gripping systems are designed to grip and hold packages in a certain position as they are moved around.

A gripping system is one of the commonly used functional components of multi-unit packaging equipment. Depending on a type of contact between working arms and package elements, all gripping systems can be grouped into the following categories: mechanical, cell, vacuum, magnetic, and combined. Vacuum gripping systems are most suitable for the needs because they ensure package integrity during the multi-unit packaging operations.

STATEMENT

One of the disadvantages of these systems is that they can get disconnected from structural elements of a multi-unit package due to unreliable contact and additional external dynamic loads. The latter factor is important for highly efficient multi-unit packaging equipment. A vacuum gripping system along with the elements of a multi-unit package during their movement in transfer modes can be considered as an oscillating system with elastic elements (Fig.1).

A number of elastic elements and their rigidity have a significant impact on harmonic system oscillation with an effect on the holding force. The largest amplitudes of harmonic oscillations are registered during the use of corrugated suction cups that have special rings providing a capability for adjusting height and gripping surface angle within a wide range, as well as for minimizing the impact of bending moments, etc. Suction cups can be 1.5- and 3.5-corrugated depending on the number of corrugations.

Traditionally, the most effective way to reduce elastic oscillations has been to install special dampers that create additional resistance force [2, 3, 4]. However, when vacuum gripping systems are utilized, the use of dampers becomes extremely problematic. It was found that known dampers had a number of disadvantages when used with these systems, including their large size, complex configuration, and low effectiveness in case of increased loads and speed of moving process parts.

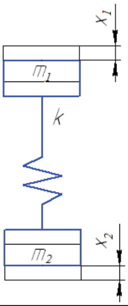
Vacuum gripping arm with 3.5-corrugated suction cups	Oscillating system model
	

Fig. 1. Oscillating system model for a vacuum gripping system

The goal of this research was to develop a mathematical model to determine a holding force for multi-unit package structural elements taking into account parameters of the oscillating system during gripping and transfer of packages.

This type of an oscillating system is represented as a two-mass model consisting of the driving mass – actuator components with a gripping arm - m_1, and the driven mass – structural elements of a multi-unit package - m_2, connected by an elastic link (corrugated suction cup) characterized by rigidity *k* (Fig. 1).

Analysis of the moving process operations showed that the first stage of the movement is executed at the max speed of ϑ. Let us consider the most complex movement process when the size of multi-unit package structural elements is much bigger than a diameter of a vacuum gripping system $L>10d$ [5]. If we ignore transfer processes at the beginning of movement of mass m_1, and assume that the time of the first stage t_1 is short, and the motion is uniformly accelerated, then the average acceleration is equal to $\ddot{x}_1 = \vartheta / t_1$.

We should keep in mind that when a package moves at a high speed, environment creates resistance that adds up to the resistance force whose value is proportional to the squared speed of the package movement [6, 7]. In this case, if the motion is uniformly accelerated, then motion equations for a two-mass system will be as follows:

$$\begin{cases} x_1 = \dfrac{\vartheta t^2}{2t_1}; \\ m_2\ddot{x}_2 - (x_1 - x_2)k = -a(\dot{x}_2)^2 - m_2 g \end{cases} , \qquad (1)$$

where x_1, x_2 are coordinates of mass m_1 and mass m_2; ϑ is the max given acceleration speed; t_1 is the time of acceleration; and a is a coefficient that takes into account the form and the area of a multi-unit package structural element projected to the horizontal area and the specific mass of the environment [3].

If we replace x_1 in the second system equation (1) and perform the appropriate transformations, we will receive:

$$\ddot{x}_2 + \frac{k}{m_2}x_2 = \frac{\vartheta k t^2}{2t_1 m_2} - \frac{a}{m_2}(\dot{x}_2)^2 - g \qquad (2)$$

where t is an instant time that does not exceed the time of acceleration.

In case of uniformly acceleration movement of mass m_1, system oscillations produce very little effect on the way the external load is changing, therefore the speed equation for the system can be written as:

$$\ddot{x}_2 + \frac{k}{m_2}x_2 = \frac{\vartheta}{t_1 m_2}\left(\frac{k}{2} - \frac{a\vartheta}{t_1}\right)t^2 - g \tag{3}$$

Initial requirements for the movement are $t = 0; x_2 = 0; \dot{x}_2 = 0$. Considering the initial requirements, equation (3) can be solved as follows:

$$x_2 = -\frac{2m_2\vartheta}{k^2 t_1}\left(\frac{k}{2} - \frac{a\vartheta}{t_1}\right)\left(1 - \cos\sqrt{\frac{k}{m_2}}t\right) + \frac{at^2}{2t_1^2} - \frac{a\vartheta^2 t^2}{kt_1^2} \tag{4}$$

Elastic link deformation is:

, (5)

and its dynamic load is:

$$F_{dyn} = xk = \frac{2m_2\vartheta}{kt_1}\left(\frac{k}{2} - \frac{a\vartheta}{t_1}\right)\left(1 - \cos\sqrt{\frac{k}{m_2}}t\right) + \frac{a\vartheta^2 t^2}{t_1^2}. \tag{6}$$

By the time the first stage of movement is completed $(t = t_1)$ (system acceleration), expression in equation (6) equals $\cos\sqrt{\frac{k}{m_2}}t = -1$. Having entered the obtained value into equation (6), we receive the max value of the dynamic load:

$$F_{dyn}^{\max} = \frac{4m_2\vartheta}{kt_1}\left(\frac{k}{2} - \frac{a\vartheta}{t_1}\right) + a\vartheta^2 \tag{7}$$

A schematic diagram of forces applied while a corrugated suction cup is holding a package made of porous material is provided in Fig. 2.

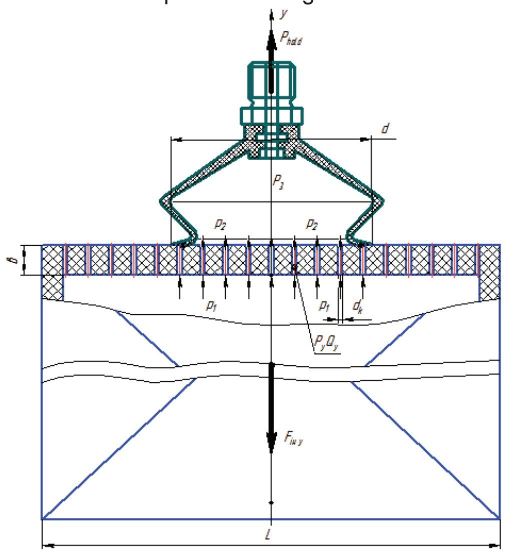


Fig. 2 Forces applied during holdup of porous package material by a corrugated suction cup

According to the above diagram, static holding of the multi-unit package structural elements during their dwell time at intermediate points between movements taking into account their oscillations (Fig. 2) is:

$$P_{hold} = F_{dyn}^{\max} \tag{8}$$

where G is gravity.

The level of vacuum in the corrugated vacuum cup that will ensure holding force P_{hold} during lifting of multi-unit package structural elements taking into account physical and mechanical properties of the package material (Fig.2) is:

$$\Delta P = P_1 - P_2 + P_3 = F_{dyn} / S \tag{9}$$

where P_1, and P_2 are atmospheric and absolute values of air pressure inside the suction cup volume, respectively; P_3 is an absolute air pressure at the exit from the volume limited by an elementary area of contact of the suction cup; and S is an active area of the suction cup.

The results of analytical observations based on the developed model are shown on a chart below. It compares holding forces produced by standard and corrugated suction cups (Fig. 3).

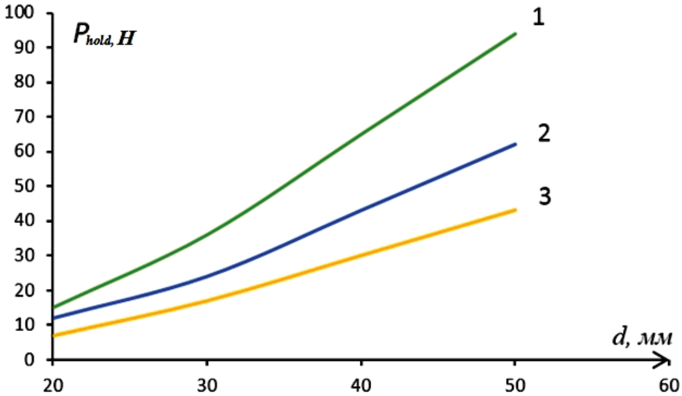


Fig.3 Change of package holding force by standard and corrugated suction cups depending on their diameters taking into account oscillation processes during the operations of lifting the structural elements of a multi-unit package (motion law – linear with steady acceleration $\ddot{x}_M = 2.5 m/s^2$; vacuum level: - 0.7 bar): 1 – standard suction cup; 2 – 1.5-corrugated suction; and 3 – 3.5-corrugated suction cup.

CONCLUSIONS

Based on the conducted research, it was established that corrugated suction cups provide additional technical capabilities for holding packages with complex configuration of surface texture; however they also are an additional source of oscillation processes that significantly reduce package holding force up to 50% compared to standard suction cups with the identical values of vacuum, kinematic and dynamic loads. In order to reach a given force of holding multi-unit package structural elements by corrugated suction cups, either vacuum level has to be increased that will lead to significant energy costs, or the impact of oscillation processes has to be decreased by limiting kinematic parameters of their motion..

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