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APPLICATION OF PNEUMATIC SUCTION CUP AS A POSITIONING ELEMENT FOR THIN METAL SHEETS IN TECHNOLOGICAL PROCESSES

WYKORZYSTANIE PRZYSSAWKI PNEUMATYCZNEJ JAKO ELEMENTU POZYCJONOWANIA CIENKICH BLACH W PROCESACH TECHNOLOGICZNYCH

Abstract

In the paper an analysis of gripping thin metal sheets in technological process of stamping metal closures is presented. An object made of two suction cups and pneumatic control system of vacuum and pressure inside the suction cup was analyzed. Mathematical model contains differential equations which were solved basing on Matlab/Simulink application. Prepared model provides an opportunity to check different parameters of the system. The paper presents analysis of impact of feed pressure on the course of sucking forces.

Keywords: *pneumatic suction cup*, *modeling of pneumatic systems*, *Matlab/Simulink*

Streszczenie

W artykule podjęto zadanie analizy chwytania cienkich blach w procesie technologicznym tłoczenia zakryć koronowych. Do analizy wybrano układ składający się z dwóch przyssawek i odpowiedniego układu pneumatycznego sterującego podciśnieniem i ciśnieniem w przyssawkach. Przedstawiono model matematyczny w postaci równań różniczkowych i przeprowadzono jego analizę z wykorzystaniem pakietu Matlab/Simulink. Zbudowany model pozwala na zbadanie wpływu różnych parametrów układu. Przedstawiona analiza dotyczy wpływu ciśnienia zasilania, na przebieg wartości sił przyssania.

Słowa kluczowe: *przyssawka pneumatyczna*, *modelowanie układów pneumatycznych*, *Matalab/Simulink*

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Designations

m – computational mass of element above the suction cup (metal sheet)
V – volume of suction cup chamber
x – position of metal sheet above the suction cup (measured from the bottom)
c – friction loss coefficient for suction cup material
k – centering spring stiffness coefficient for suction cup material
F – the force generated by air inside suction cup on metal sheet
G – force of gravity
d – inside diameter of the suction cup
r – split width between suction cup and metal sheet
A – active area of the suction cup
p – pressure inside suction cup chamber
p_{atm} – atmospheric pressure
Q_i – volumetric flow rate at the suction cup input
Q_o – volumetric flow rate at the split between suction cup and metal sheet
B – equivalent volumetric elastic modulus for air
N – pressure ratio of jet pump
p_s – sucking pressure
p_d – jet pump output pressure
p_i – jet pump input pressure
k_{th} – friction loss coefficient for jet pump throat
k_{en} – friction loss coefficient for jet pump throat entry
k_n – friction loss coefficient for jet pump nozzle
b – jet pump area ratio
M – volumetric flow ratio for jet pump Q_2/Q_1
Q_1 – volumetric flow rate at the jet pump input
Q_2 – volumetric flow rate of air sucked by jet pump
h – split height between suction cup and metal sheet
R_1 – suction cup inside radius
R_2 – suction cup outside radius

1. Introduction

Industrial packaging produces cans and bins are made from very thin metal sheets that are less than 0.2 mm thick. Such thin metal sheets have very low stiffness, therefore transporting and feeding to the stamping machine is very problematic. In this paper, the undertaken task is to analyze feeding system of thin metal sheets for stamping press for metal closures. The technology basis on lacquering and lithography printing before stamping process. Printing process is very accurate, the lithography have specified arrangement provide for division of metal sheet. Positioning tolerance in stamping process is less than 0.5 mm. In this case, the way in which metal sheet is grabbed influences the arrangement of the lithography. Pneumatic suction cup with absorber, which gives good distribution of pneumatic force was studied. Analysis was performed by Matlab/Simulink computer software.

2. Object of the study

General view of metal sheet gripping using pneumatic suction cup is shown in Figure 1. It is made of two suction cups consisting of sealing ring 1 and stopping bumper 2. Furthermore, in the gripping system equipment ejector 3, pneumatic valve 4 and air supply 5 can be found.

Metal sheet 6, which is ready to be feed to stamping machine is situated on positioning Table 7.

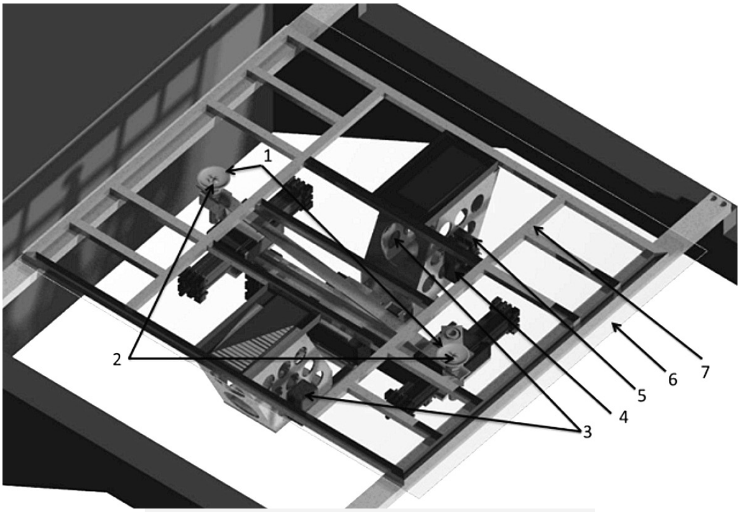

Fig. 1. Schematic diagram of gripping metal sheet using pneumatic suction cup

Rys. 1. Schemat ideowy uchwytu blachy za pomocą przyssawek pneumatycznych

Feeding process starts with taking metal sheet from a bale. In this case, air at the certain pressure is supplied to the ejector, which creates vacuum in the suction cups and at the same time sufficient lift force to grab metal sheet. At the end of positioning process metal sheet is very fast released by redirecting air stream directly to the suction cups.

3. Mathematical model

Schematic diagram of pneumatic system is shown in Figure 2. To generate vacuum the ejector with nominal nozzle value 1 mm was used. Ejector 4 is supplied from main air supplying line via pneumatic valve 3. Switching on the valve 3 produces vacuum into suction cup. Pneumatic valve 5 is responsible for switching between sucking and blow out system. Suction cup grabs metal sheet, holds it during positioning movements and then releases it. Because efficiency of the stamping machine is high, positioning and feeding cycle is very short, roughly few tenth of second, therefore time for grapping metal sheet as well as releasing has to be minimized and those times are based on the analysis performed in this paper.

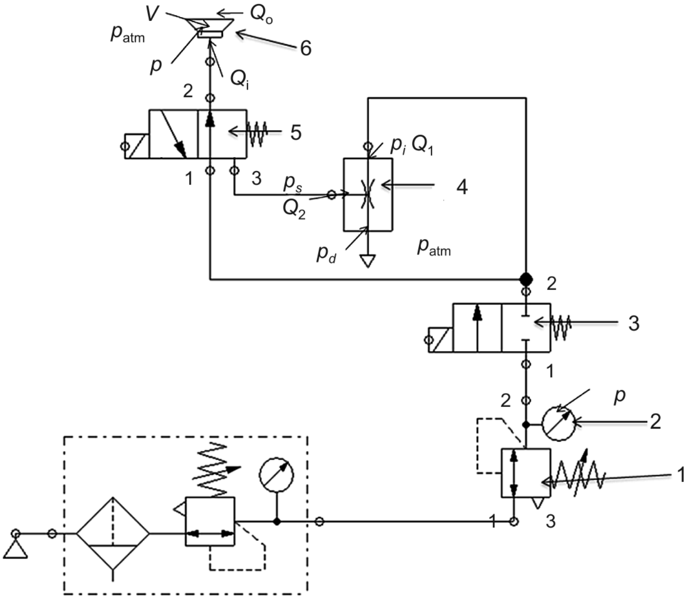

Fig. 2. Pneumatic diagram with marked system parameters

Rys. 2. Schemat pneumatyczny wraz z oznaczeniami parametrów układu

For mathematical modeling, the following assumptions were made: the system is in thermal equilibrium, elastic elements deformation is linear and the metal sheet is not deformed by air pressure. Under these assumptions, the mathematical model will constitute the differential equations for elements movement, flow rate continuity and elements characteristics.

For system modeling, model of one-degree freedom mechanical system (Fig. 3) was used. Motion equation which describes metal sheet – suction cup system:

$$m\ddot{x} = -c\dot{x} + kx + F - G \tag{1}$$

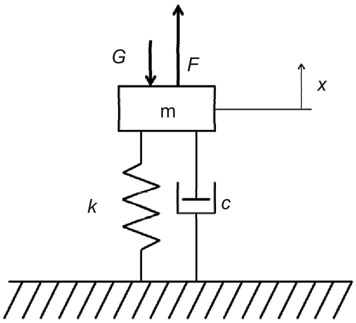

Fig. 3. Schematic diagram of one-degree freedom mechanical system

Rys. 3. Schemat układu o 1 stopniu swobody

Flow rate continuity equation inside suction cup chamber:

$$\dot{p}\frac{V}{B} = Q_i - Q_o \tag{2}$$

In Figure 4 jet pump schematic diagram is shown. The equation describing ejector [3]:

$$N(1-k_n) - 2b = M^2\left(\frac{2b^2}{1-b} - \frac{1+k_{en}}{c^2}\right) - b^2(1-k_{th})(1+M)^2 \tag{3}$$

where:

$$M = \frac{Q_2}{Q_1} \tag{4}$$

$$N = \frac{p_d - p_s}{p_i - p_d} \tag{5}$$

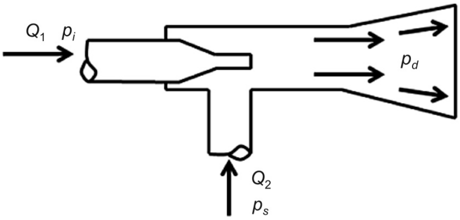

Fig. 4. Schematic diagram of jet pump with marked system parameters

Rys. 4. Schemat ideowy pompy podciśnienia wraz z oznaczonymi parametrami

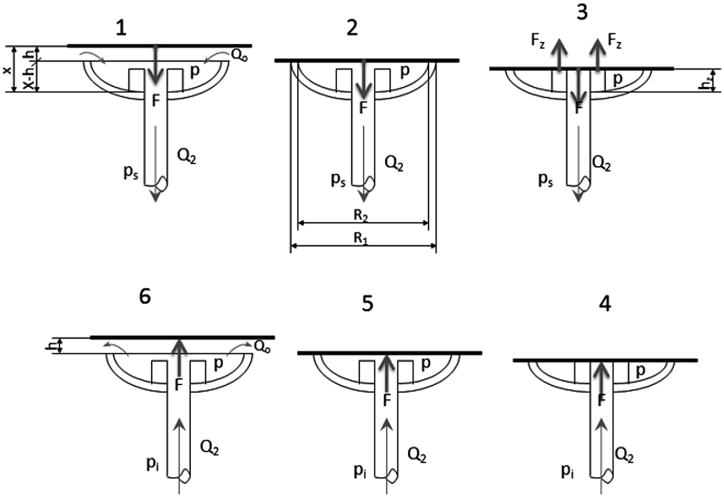

Fig. 5. Schematic diagram of metal sheet griping process

Rys. 5. Schemat układu arkusz blacha-przyssawka w procesie chwytania blachy

Before metal sheet is close enough to seal connection with the suction cup, air comes out through the interspace between metal sheet and the suction cup with height *h*(*x*). In Figure 5 steps of metal sheet griping are shown: 1 – state before grab, 2 – state at the sealing moment, 3 – appropriate metal sheet grab (bottoming of the metal sheet to the absorber), 4 – direction changing from sucking to blowing, 5 – detachment of metal sheet from suction cup, 6 – metal sheet repulsion from the suction cup causes interspace *h*(*x*).

Equation describes flow rate through the interspace *h*(*x*) [2]:

$$Q_0 = \frac{\pi p k^3}{6\eta \ln \frac{R_1}{R_2}} \tag{6}$$

4. Simulation results

Simulation model was based on equations from 1 to 6. All equations were solved using Matlab/Simulink software. Block diagram of used equations (Fig. 6) was prepared, each block represents different parts of the system. Several simulations with unit step function flow rate input with different air pressure were made.

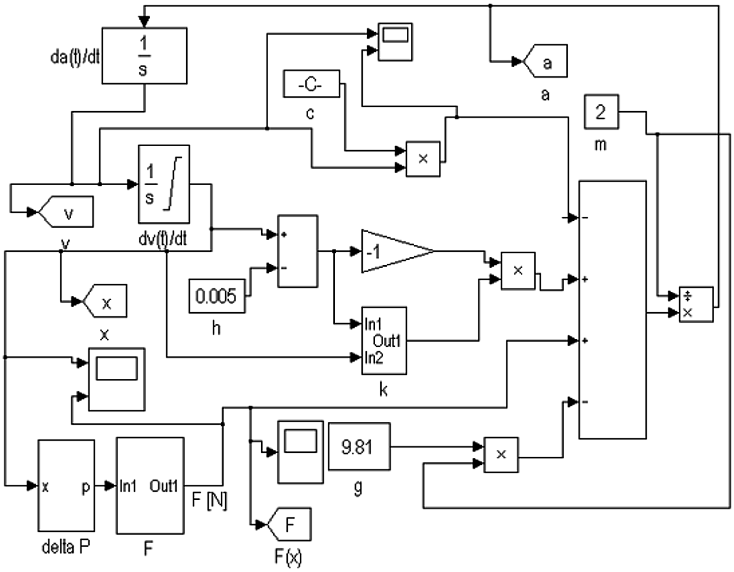

Fig. 6. Block diagram describing the suction cup (Matlab/Simulink software)

Rys. 6. Schemat blokowy opisujący przyssawkę wykonany w programie Matlab/Simulink

Simulation time was 1 [s], the system of equations was solved by fourth-order Runge-Kutta method with 0.0001 [s] time step. Simulation process was started with letting down metal sheet on suction cup. After 0.2 [s] unit step function input vacuum was generated.

It was assumed that correct position for beginning movement of metal sheet is when metal sheet touches the absorber (position x = 0.0046 [m] or lower). After positioning, switching suction to blowing takes place, it is 0.5 [s]. Blow should be sufficient for subtle convection of metal sheet above the suction cup. The result of the simulation is vertical position of the metal sheet and acting force of the pressure from the suction cup.

In the figure 7 diagram with results of the simulation for unit step function input for pressure 0.5 [MPa] is shown. It was observed that reaching maximal suction force 56.5 [N] takes place in 0.2626 [s]. Acquiring position x=0.0046 [m] (touching absorber with metal

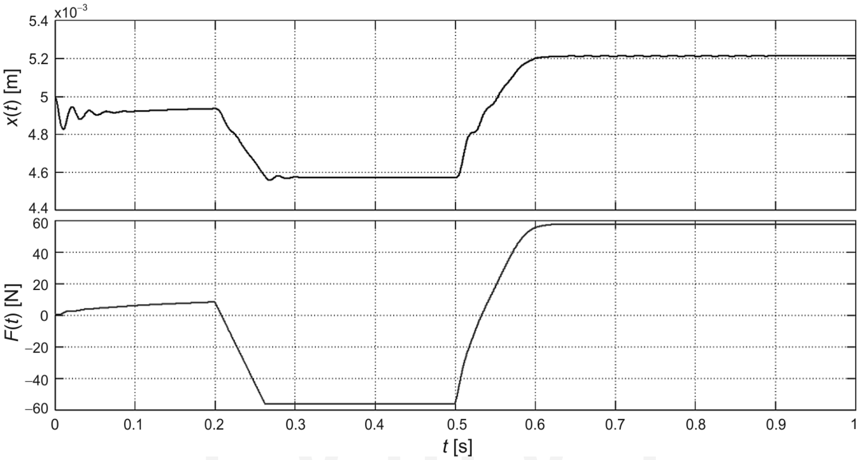

Fig. 7. Simulation results for 0.5 [MPa] pressure

Rys. 7. Wyniki symulacji przy ciśnieniu roboczym 0.5 [MPa]

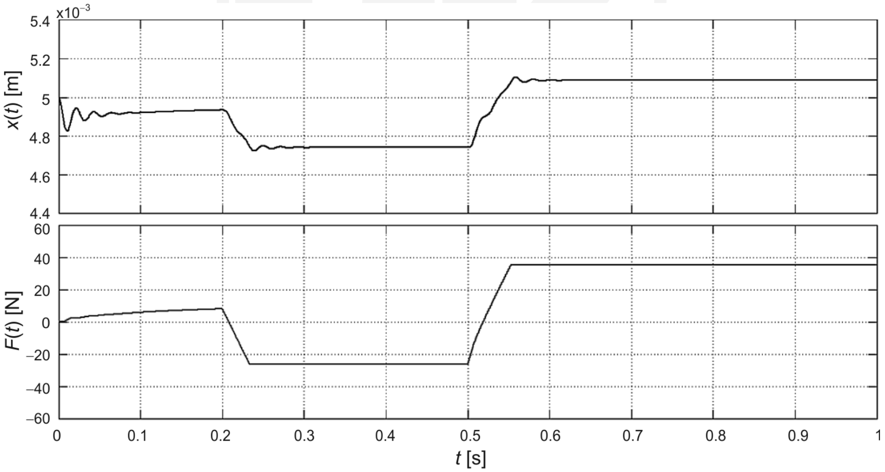

Fig. 8. Simulation results for 0.15 [MPa] pressure

Rys. 8. Wyniki symulacji przy ciśnieniu roboczym 0.15 [MPa] sheet) takes place in 0.2587 [s], after 0.1587 [s] from the start point. Detachment of metal sheet from suction cup took place 0.5535 [s], after 0.0535 from the start point. After stabilization of position, interspace between metal sheet and the suction cup was 0.0002 [m].

Simulations for different pressures 0.4 [MPa], 0.3 [MPa], 0.2 [MPa] were performed. All of the results are close to the obtained for 0.5 [MPa] pressure. Simulations outcome proved, that for pressure lower than 0.2 [MPa] significant differences in force, time and metal sheet position can be observed (Fig.8). Vacuum generated by ejector is too low to pull metal sheet to the absorber. After switching on the vacuum pulling force 26.5 [N] in 0.2335 [s] was obtained, 0.1335 [s] after start point. Detachment of metal sheet from suction cup took place in 0.5372 [s], after 0.0372 [s] from start point. Interspace between metal sheet and the suction cup were 0.000088 [m].

5. Conclusions

Performed simulations proved that the pressures from 0.5 [MPa] to 0.2 [MPa] do not significantly affect maximal sucking force of applied suction cup. Moreover, time for starting metal sheet movement without adhesion loss does not change. It is caused by the ejector oversize comparing to the suction cup. Significant difference was observed for the pressure lower than 0.2 [MPa]. Simulation results proved that pressure 0.2 [MPa] is advantageous in context of minimal air usage and fulfilling functional requirements.

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