UNILATERAL GRIPPING WITH ACTIVE VACUUM SUCTION CUP: CALCULATE OF FLOW RATES

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Abstract

This article deals with the problems of the need for the required volume and flow rate in the circuit with underpressure in the design of the gripping effector with active suction cups. It presents a process of designing a vacuum generator which is required to power such effector so that it guarantees a quick and secure fixation of handling objects (OM) at handling it with a robot. The article displays a means of determining so-called evacuation times in the process of gripping of OM during the handling tasks.

Key words: vacuum, end effector, ejector, evacuation time, unilateral gripping

INTRODUCTION

When ensuring an adequate and safe fixation of OM throughout the duration of the handling task space and quality of vacuum suction cups under their membrane are the decisive criterion, flow rate of vacuum suction cups channels connected to the vacuum generator is the determining factor at starting handling task (at the start of fixing OM by suction cup of the gripper).

At this stage of design of the vacuum circuit it is necessary to provide a sufficient volume of high quality vacuum in a relatively short time. We must concern:

- selection of suitable vacuum generator;
- specify volumes in the circuit with vacuum;
- determine evacuation times for a secure fitting of OM.

SOLUTION OF CONDITIONS FOR THE SELECTION OF THE VACUUM GENERATOR

When applying vacuum handling in automated plants an ejector is used as a generator of vacuum in most cases. Compared with the volume generator (vacuum pump) ejector significantly better fulfills the energy intensity of the preparation and especially in distribution of underpressure. Its use thus ultimately represents a significant savings of overall operating costs for vacuum mechanisms.

Advantage of using ejector mainly results in shortening of the channel to be routed underpressure under the suction cups membrane, Fig. 1.

The ideal solution is to use an integrated form of ejector with suction cup, Fig. 2 When proper sizing of integrated circuit with compressed air the energy requirements ratios are much more manageable than it is in the distribution of the vacuum.

It is known that the rate of flow of the compressed air in ducts of the distributor valve, which provides powering of the drive, affects the speed of the drive. Well, in solving the tasks of vacuum is necessary to choose suitable ejector. This means that type of ejector which will be able to provide such decrease in pressure when the suction force of the gripper is sufficient to fix and start movements of OM (taking into account the conditions of handling dynamic motions of equipment - the robot). Such decrease must be made in short time and in all the circuit.

Proposal represents an appropriate ejector solution of the dilemma between the value of quality of underpressure (effect on the gripping force of effector) and the size of the suction power Q of ejector. Mentioned parameters interact, Fig. 3.
For ensuring a high quality underpressure there will be low flow rate and vice versa.

As the speed of activation of suction cup is provided just by the power of the ejector \( Q \), it is necessary to pay sufficient attention to this phenomenon. If the time needed to create a gripping force between the suction cup and \( O_M \) is very long, there will be extending of the times when handling tasks, and thus its effectiveness decreases.

The diameter of the inlet nozzle and the diffuser in ejector influences the ratios between the volume flows and the quality of the vacuum, Fig. 3, in a single-stage ejector. Finding an optimal ejector, which fulfills both parameters of sufficient quality is in some cases nearly impossible.

Therefore, for tasks requiring fulfilling higher quality of vacuum with enough suction power a two-step, Fig. 4, or three-to-four-stage ejectors are used. Increase of an ejector in suction power can be up to 240% (three-stage ejectors) while maintaining the necessary quality of vacuum.

Two- and multi-stage ejectors are manufactured in a compact design, Fig. 4, which is integrated into the body of ejector and the two control valves (mostly version 2/2 NC), reverse valve for sealing underpressure in the circuit and the flow control valve to adjust the speed of the air flow determined to the release of \( O_M \) from the suction cup. Since each ejector is quite sensitive to pollution, a filter is integrated in the assembly. Most manufacturers added an underpressure indicator (sensor combined with a switching circuit).

Whereas channels between the ejector and suction cup are filled with atmospheric air after the ejector stops operating, the flow resistance needs special attention (the consequent length of tubing) and the size of the exhaust volumes (determined by their inside diameter tubes, suction cups and other volumes of the components), Fig. 5.

The ejector is supplied with compressed air from an operational network. Reaching high suction power of ejector it is necessary to ensure the adequate flow at the inlet of ejector. To minimize resistance it is required to use larger diameters of sections (larger inner diameter) of tubes

Identical criteria in terms of the necessary flows are also valid in the tube between the ejector
and suction cup. Since we need a large flow, we use large diameter tubes. However, large diameter tube results in an increase in volume flow at each activation of ejector and suction cup and it is necessary to create a vacuum. This means that there should be a hose of the necessary length between the suction cup and ejector.

Activation of ejector requires certain time. Therefore, when selecting an ejector it is necessary to calculate to determine timing parameters especially in cases of high operating frequencies of handling task.

It is therefore necessary to determine the value of the time which is needed to achieve the desired vacuum level in the effector circuit.

This time $T$ depends both on the volume of exhaust air $Q_{\text{max}}$, which underpressure generator (ejector) needs to achieve the desired quality vacuum $p_v$ [kPa] in the circuit, and second, the volume $V$ representing the total summary of volume corresponding to all components in the circuit that are connected to the output generator (tube, filters, etc.) including ejector connected to the suction cups, Fig. 5.

Calculation of ejector [69] consists of determining the times $T_1$ and $T_2$ for the desired level of vacuum in the circuit behind the ejector, Fig. 6.

From the diagram in Fig. 6, it is clear that in a relatively short period of time ($T_1$) from the switching on of the control valve 63% of ejector maximum value must be achieved. E.g. for single-stage ejector a 63% level of its maximum value of vacuum equals to 84 kPa (at an inlet pressure of 0.5 MPa), thus -52.92 kPa.

As Fig. 6 shows, to obtain a safe 95% level of the maximum underpressure (the rate at which it is safe to handle with $Q_{\text{max}}$) requires approximately 3 times longer time ($T_2$).

Time $T_1$ is calculated from the relationship

$$T_1 = \frac{V \cdot 60}{Q} \quad [s]$$

and therefore

$$T_2 = 3 \cdot T_1 \quad [s]$$

where $T_1$ [s] is the time required to achieve 63% of maximum vacuum $p_v$ [kPa], $T_2$ [s] is the time required to reach the target of 95% of the maximum vacuum $p_v$ [kPa] and $V$ [dm$^3$] is the volume of the channel between the suction cup and resources vacuum. In equation (1) given parameter $Q$ represents the smaller values of flow-volume ($Q_1$ or $Q_2$ [l/min$^{-1}$]), therefore

$$Q = \min\{Q_1, Q_2\} \quad [l/min^{-1}]$$

Lower value corresponds to the actual flow-through volume, respectively suction performance and determine precisely the time required to achieve the necessary level of vacuum.

The circuit with underpressure has a value of $Q_1$ takes 1/3 to 1/2 of the maximum flow rate on the performance of ejector output (ie 1/3 to 1/2 of its maximum suction power) according to the relation

$$Q_1 = \frac{1}{3} Q_{\text{max}} \quad [l/min^{-1}]$$

where $Q_{\text{max}}$ [l/min$^{-1}$] is the maximum ejector suction. Value 1/3 is used for suction cup with a diameter over 40 mm, or for lifting objects of a porous material, the value of 1/2 is used for suction cup with a diameter of to 40 mm.

Value $Q_2$ can be determined from the relation

$$Q_2 = 11.1 \cdot S \quad [l/min^{-1}]$$

where $Q_2$ [l/min$^{-1}$] is the flow-volume of tubing, $S$ [mm$^2$] is proportional cross-section of plastic tubes (pipes) and 11.1 its the gear ratio.

Values of the relative cross-section equal plastic tubes can be determined from the diagram, Fig. 4b), where it is necessary to consider the inner diameter of the tubes (in the diagram in bold numerals over the curve). This should be borne in mind, because ordering tubes are made mostly by outside diameter.

As the with increase in the length of tube significantly reduces the value of the proportional cross-section, it is necessary to keep a rule that the ejector and suction should be used as little as possible and as quickly as tubes with an inner diameter sufficient.

From this determine the relative cross-section used tubes we determine the maximum air flow in these tubing.

For the calculation of $T_1$ and $T_2$ in equation (1) it is still need to add the volume in the hose between the suction cup and vacuum source. This volume is determined as the sum of the volumes of the sections tubes, that according to Fig. 4, true

$$V = \sum_{i=1}^{n} V_{Hi} \quad [dm^3]$$

while
\[ V_{Hi} = \frac{\pi}{4} d_{Hi}^2 L_{Hi} \quad [\text{dm}^3] \quad (7) \]

where \( V_{Hi} \) - volume lines (tubes, pipes) \([\text{dm}^3]\)
\( d_{Hi} \) - internal tube diameter \([\text{mm}]\)
\( L_{Hi} \) - length of tube \([\text{m}]\)

For high-precision calculations, it is possible to balance the total volume of the extract include the other components used (filters, connectors, etc.). Fig. 4 Sometimes it is more convenient to consider directly with the relative cross-section or a defined flow of these elements.

As is the estimated time to achieve the necessary level of underpressure is too long, you can either increase the suction power (change in diameter of the nozzle in the ejector diffuser, must choose another ejector) or decrease the volume tubes (decreasing inner diameter of the tube - but watch out for changes in relative cross section), or shorten the length of tubes between the suction cup and vacuum source.

Another option is to increase the diameter of suction cup so that when reaching 63% of vacuum (time \( T_1 \)) it has already developed a sucker force of required level.

It should be noted that the above calculations are valid only for non-porous materials. When handling porous materials these times must be set by an experiment.

If the calculated time to achieve the necessary levels of underpressure is significantly shorter than it should be, it is advisable to use a source with a smaller suction performance.

This fact strongly affects circuit economy, as with the suction power the consumption of compressed air to ejector is exponentially increasing, Fig. 7. In such case, it is necessary to repeat the calculation for weaker ejector.

**CONCLUSION**

The use of underpressure as one of the tools for implementing unilateral gripping effector requires perfect knowledge of conditions which are valid for the area of using pneumatic circuits.

Ignorance of the laws governing the preparation of underpressure often leads to inappropriate solutions and circuit designs, or in upsetting such addressing grasping. In many cases it leads to careless disposal of compressed air, giving rise to very high operating costs.

However, optimization of vacuum circuits, and proper sizing of components for unilateral gripper effectors with active suction cups brings very efficient and in many cases unique solutions to this problem.

**References**


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