ISSN (online): 2250-141X
Vol. 6 Issue 4, October 2016

DESIGN CONSTRAINTS OF VACUUM GRIPPER OF ROBOTS – AS A PICK AND PLACE OPERATING TOOL

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ABSTRACT

A substantial part of automated material handling and assembly is the interface between machine and work piece. Most of the robots grippers are not easily applicable for material handling such as the food products are often delicate, easily marked or bruised, adhesive and slippery. This study is an innovative approach of a gripper for handling variable size, shape and weight of unpacked food products i.e. 'Vacuum Gripper of Robot'. This gripper operates using Bernoulli Principle of generating a high-speed flow between the gripper plate and product surface thereby creating vacuum which lifted the product. Feasibility observations are studied in this paper to demonstrate and obtain an overall understanding on the capability and limitations of the vacuum gripper. The main objective of this report is to highlights the importance of Vacuum Gripper in industrial robot applications that will deal exclusively with gripping of different variety of materials/parts by using vacuum gripper. The design parameter of the vacuum gripper has been stated for industrial operations. The end effectors must typically be designed for the specific application.

This paper describes a gripping technology with vacuum gripper design system consideration for related components, such as two dimensional modules and three-dimensional modules. The system comprises of the gripping mechanism itself as well as its supporting items with different environmental aspects to be considered for design. In this approach, the different functions and the performance of the projected components are investigated and analyzed.

Key Words: *Vacuum Gripper, Design Constraints, Technology, Materials, Mechanism, environmental factors.*

1. INTORDUCTION

A vacuum gripper is an essential component of a robotic manipulator. It serves as the robot's hand and allows the robot to manipulate objects for proper gripping safely. Recently robotic grippers are widely used for different kinds of material handling system in various fields. Varieties of robotic grippers are developed with high flexibility and multi-functional approaches. Vacuum grippers are those devices that actually grip an object for moving or placing it within the working range with vacuum type gripping system.

The objectives of the paper is to study the design constrains of robotic grippers and explain the importance of vacuum gripper to achieve simple grasping tasks in the different industrial applications.

The main aspect of our study is to development reliable solution for vacuum type grasping which would be beneficial for industrial applications. [1]Some existing vacuum grippers and feasible mechanism with solutions in the literatures review have been described. End-effectors are usually specifically designed for their particular task,

ISSN (online): 2250-141X
Vol. 6 Issue 4, October 2016

because the highest workload of on-site construction consists of handling and assembly operations, the vacuum gripper is most interesting in this area for the fulfillment of the task.[2][3] The robotics industry was originally developed to supplement or replace humans by doing dull, dirty, or dangerous work which needs care and safety for handling the component.[5][6] They are used in applications like automated assembly lines. Modern vacuum type industrial robotic arms excel over humans in many tasks. [7] They are capable of lifting 5000 kg which are repeatable to 10 m or more.

The vacuum gripper is composed of two servomotors that allow the movement of the wrist and the movement of the vacuum grippers. [4] First step will be the design consideration factors of the vacuum gripper. Second step will be consideration of factors which is very influencing factors for reducing errors and decreasing cycle times. [8][9]Well designed grippers can increase throughput, improve system reliability, compensate for robot inaccuracy, and perform value added functions to the assembly. [13][15] A proper gripper design can simplify the overall assembly, increases the safety of work and human beings.

2. WORKING OF VACUUM GRIPPER

The working face of the suction cup is made of elastic, flexible material and has a curved surface. When the center of the suction cup is pressed against a flat, non-porous surface, the volume of the space between the suction cup and the flat surface is reduced, which causes the air or water between the cup and the surface to be expelled past the rim of the circular cup.[3][7] The cavity which develops between the cup and the flat surface has little to no air or water in it because most of the fluid has already been forced out of the inside of the cup, causing a lack of pressure i.e. vacuum pressure.[14] The pressure difference between the atmosphere on the outside of the cup and the low-pressure cavity on the inside of the cup keeps the cup adhered to the surface.

When the user ceases to apply physical pressure to the outside of the cup, the elastic substance of which the cup is made tends to resume its original, curved shape. [8]

The length of time for which the suction effect can be maintained depends mainly on how long it takes for air or water to leak back into the cavity between the cup and the flat surface.

3. Research Work on Vacuum Gripper:

Many researchers have worked on robot grippers and vacuum grippers as mentioned below:

Hirose et al. [1] have presented soft gripper for versatile robot hand for different application of gripping the objects. Scott et al. [2] have elaborated Omni gripper in which a form of robot universal gripper. Wright et al. [3] have elaborated softly gripper for design grippers in handbook of industrial vacuum gripper. Tella et al. [4] have described about a contour adapting gripper. Pham et al. [5] have developed a knowledge based system related robot vacuum gripper selection criteria and choosing vacuum gripping. Pham et al. [6] have also presented a hybrid expert system for selecting robot gripper and developed strategies the gripping design and selection in robotics.

Shimoga Bicci et al. [7] have presented robotic grasping and different contour for contact. Dougeri et al. [8] have presented picking up flexible piece out of a bundle robotics and automation magazine. Choi et al. [9] have elaborated design and feasibility gripper based on inflatable rubber pockets. Sam et al. [10] have developed a design approach of robotic gripper for reducing cost for handling food products.

Brown et al. [11] have developed universal vacuum gripper based on granular materials.

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Kragten et al. [12] have elaborated vacuum gripper under actuated hands: fundamentals performance analysis and design. Whereas, Rodenberg et al. [13] have developed transactions gripper. Eizicovits et al. [14] have presented efficient sensory grounded grasp pose quality mapping for vacuum gripper. Ullrich et al. [15] have developed actuated and guided vacuum gripper for medical application.

4. FACTORS INFLUENCING THE DESIGN PARAMETERS

Vacuum grippers are used in the robots for grasping the materials and objects in packets. It uses vacuum cups as the gripping device as shown in Fig.1 which is also commonly known as suction cups. This type of grippers will provide good handling if the objects are smooth, flat, and clean and stored in cartoons. It has only one surface for gripping the objects. It may not be suitable for handling the pores objects all around. [6]

Fig.1: Vacuum Gripper Application for lifting

A. Working Components:

Vacuum cups (5) are used to hold horizontal flat or vertical flat objects using strong suction cups to lift an item as shown in Fig.2. The “vacuum” is used to lift large, flat, smooth sheets of material like wood paneling, metal, plastic and glass. A vacuum gripper of the robot arm place the position and securely plants one or more airtight suction cups to the material. The vacuum requires less power than either of the other designs, but is also more prone to mishaps due to misaligned suction cups that fail to achieve an airtight seal. The number of cup depends on the load, material shape and size for balancing the load to be lifted. Compressed air line (1) is used to function as vacuum generator to create vacuum inside the vacuum line for proper functioning of the setup. Vacuum filter (4) is used to filter the foreign materials in Vacuum line (3) and vacuum generator (2) is used to create vacuum pressure inside the vacuum line.

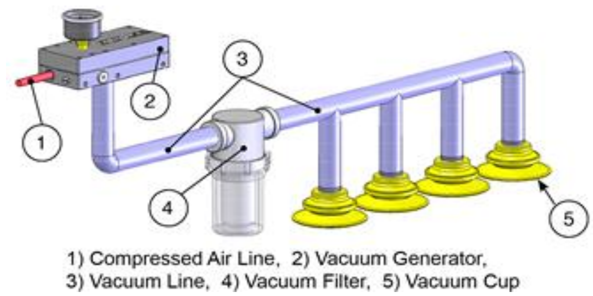

Fig. 2: Vacuum Generation Setup

B. Piping used for Compressed Air:

The compressed air piping materials can be divided into two basic types:

i) Metal ii) Non-metal.

Metal Pipe: It can be black iron, stainless steel, copper, aluminum, etc. with proper thermal/ pressure characteristics.

Black Iron or Steel Pipe: In the compressed air systems, materials will corrode when exposed to condensate (H_2O) and thus become a major source of contamination to the whole system.

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[9] This pipe is usually threaded connected 3" diameter and smaller, welded with larger diameters. Compared to copper and aluminum, it is much heavier and harder to work with but less expensive. [11] The internal corrosion issue is much more significant with oil- free air than with lubricated compressors.

Stainless Steel: it is a good selection particularly when exposed to oil-free wet air and its extremely high acid level condensate. Stainless steel is often lighter for the same pressure temperature rating and installs well when welded. [6][11] Threaded stainless steel often tends to leak. Ring seals that are used in Victaulic connections will work well. As piping material however, the potential lower installation cost and faster welding which it makes the most overall economic.

Copper Pipe: It is a common selection for sensitive air systems. When selected and connected correctly it is very rugged. The working pressure of copper piping is 250 N/m^2 for Type "M" hard, Type "L" hard and Type "K" soft and 400 N/m^2 for Type "K" hard. Further, since 50/50 solder melts at 421°F, it will be more resistant to high temperatures. [8]

Aluminum compressed air pipe: Aluminum compressed air pipe for low pressure loss due to friction in inner surface and eliminate "self-contamination," but also to offer enhanced flexibility to meet the ever-changing compressed air distribution needs.[9][13] Such air pipe as applied today has become very popular. This is particularly desirable in the automotive support industry with changing assembly and sub-assembly areas.

Non-metal Pipe: It is commonly called "plastic" pipe, has been offered for many years as compressed air piping because:

- It is lighter than most metal and easier to handle.
- It can be installed with no special tools (such as welders, threaders, etc.).
- It is generally non-corrosive.
- Installation with the appropriate gluing material is fast.
- The labor (which can also be unskilled) is less costly than most metals (copper, stainless, black iron), and the total job may often be less expensively installed.

Early days PVC was used for compressed air piping. It was not long before the fact that it sometimes "shattered" and failed, sending sharp pieces throughout the area. [4] However, this material and all others offered to date have two significant limitations:

- Most of these are limited to an operating temperature of 140°F to 200°F. The failure in an after cooler can easily reach or exceed these numbers. PVC, for instance, is limited to about 160°F at 125 N/m^2, but it actually starts to weaken at 70°F.
- Most of these materials are not compatible with compressor oils in general and particularly many synthetics.
- Although pipeline fires are rare today, when there is one in plastic pipe, there is a good chance that it will melt through the plastic pipe and migrate into the plant.

C. Temperature Ratings for Thermoplastic Piping

As with all other thermoplastic piping components, the maximum non-shock operating pressure is a function of temperature. The heat of compression should be fully dissipated so that the maximum temperature ratings (140°F for ½", 120°F for ¾") are not exceeded in the pipe system. The pressure ratings for typical thermoplastic piping and fittings are about a

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constant 185 N/m^2 for all sizes in the temperature range -20°F to 100°F and are gradually reduced above 100°F as shown in the table above. Overall, the compressed air industry has not accepted any type of "plastic" pipe as appropriate and safe for down-stream compressed air.

Aluminum tubing that can be easily assembled with normal hand tools can bring a great deal of flexibility to an operating air system or sub-system.[9] These are particularly effective for specific work areas, which may have to change on a routine basis.

5. MODEL DESIGNING ASSUMPTIONS

a. Suction Cup:

A suction cup, also known as a sucker, is an object that uses the negative fluid pressure of air or water to adhere to nonporous surfaces, creating a partial vacuum. [7]

Suction cups are peripheral traits of some animals such as octopuses and squids, and have been reproduced artificially for numerous purposes.

The working face of the suction cup is made of elastic, flexible material and has a curved surface. When the center of the suction cup is pressed against a flat, non-porous surface, the volume of the space between the suction cup and the flat surface is reduced, which causes the air or water between the cup and the surface to be expelled past the rim of the circular cup.[5][13] The cavity which develops between the cup and the flat surface has little to no air or water in it because most of the fluid has already been forced out of the inside of the cup, causing a lack of pressure. The pressure difference between the atmosphere on the outside of the cup and the low-pressure cavity on the inside of the cup keeps the cup adhered to the surface.

The length of time for which the suction effect can be maintained depends mainly on how long it takes for air or water to leak back into the cavity between the cup and the surface, equalizing the pressure with the surrounding atmosphere.[2] This depends on the porosity and flatness of the surface and the properties of the cup's

Calculations: The force required to detach an ideal suction cup by pulling it directly away from the surface is given by the formula:

$$F = AP$$

Where:

F is the force,

A is the area of the surface covered by the cup,

P is the pressure outside the cup (typically atmospheric pressure)

This is derived from the definition of pressure, which is:

$$P = F/A$$

For example, a suction cup of radius 4.0 cm has an area of π(0.040 m)^2 = 0.00502 square meters. Using the force formula ($F = AP$), the result is F = (0.00502 m^2) (100,000 N/m^2) = 5020 N.

The above formula relies on several assumptions:

a) The outer diameter of the cup does not change when the cup is pulled.

b) No air leaks into the gap between the cup and the surface.

c) The pulling force is applied perpendicular to the surface so that the cup does not slide sideways or peel off.

b. Pneumatic Gripper: A pneumatic gripper is a specific type of pneumatic actuator that typically involves either parallel or angular motion of surfaces, "tooling jaws or fingers" that will grip an object.[11] When combined with other pneumatic, electric, or hydraulic components, the gripper can be used as part of a "pick and place" system that will allow a component to be picked up and placed somewhere else as part of a manufacturing system.[11]

Some grippers act directly on the object they are gripping based on the force of the air pressure

ISSN (online): 2250-141X
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supplied to the gripper, while others will use a mechanism such as a gear or toggle to leverage the amount of force applied to the object being gripped. [14]Grippers can also vary in terms of the opening size, the amount of force that can be applied, and the shape of the gripping surfaces.

c. Hydraulic Gripper:

i. Thick lubrication:

All hydraulic and lubricating fluids have practical limits on the acceptable operating temperature range - both high and low levels. Fluid temperature stability is essential to the success of mechanical systems. [3] The machine loses stability and experiences conditional failure whenever the system's fluid temperature violates these limits.

Temperature extremes have a pronounced effect on component materials as well as machine performance, when temperature is too low and fluid viscosity is high. [7] At low temperatures, the fluid often reaches the point where it actually congeals and will no longer flow (pour point).

ii) Low Temperature Effects:

Low temperature can damage the temperature stability of a hydraulic fluid or lubricant just as much as high temperature. Very low fluid temperatures usually result from exposure of some system part to the external environment, particularly when operation takes place in arctic or high-altitude conditions. Such low temperatures can cause petroleum-based fluids to increase in viscosity and eventually reach the critical point where the fluid actually congeals and will no longer pour or flow.[3]Such fluid immobility can starve a pump, cause damaging vaporous cavitation and produce high fluid and mechanical friction, not to mention lubricant starvation of bearing surfaces.[5][8] Certainly, the usefulness of a fluid as a lubrication medium at low temperature hinges upon its viscosity and pour-point characteristics.

For hydraulic circulating systems, high oil viscosity causes a drastic drop in the oil's static pressure as suction draws the oil into the pump's inlet. This pressure reduction results in the creation of vaporous bubbles and causes air normally dissolved in the oil to be desorbed and become entrained as air bubbles. When the pump compresses this bubbly oil, the bubbles violently implode on the high-pressure side, creating loud noises, strong vibrations and wear of internal pump parts. [1]Under these high-viscosity conditions, other system problems arise, such as filters that go into bypass, and on occasion, even collapse.

iii). High Temperature Effects:

As industry continues to design systems of higher power density, fluid temperatures well above the current norms will become increasingly common.[8] Such high temperature conditions can disrupt the stability of conventional working fluids, compromise system performance and significantly reduce the life of operating components.[15]In many systems exposed to hostile environments and severe duty cycles, the need for supplemental heat transfer capability and/or synthetic fluids will become apparent.

The reduction in fluid viscosity is one of the most obvious effects of high temperature operation. Viscosity decreases rapidly with increasing temperature because the mobility of the fluid molecules becomes hyperactive as gas is desorbed and lighter fractions of the fluid vaporize.[4] The shear stability of oil is the property which reflects the susceptibility of a given blend to viscosity degradation.

ISSN (online): 2250-141X
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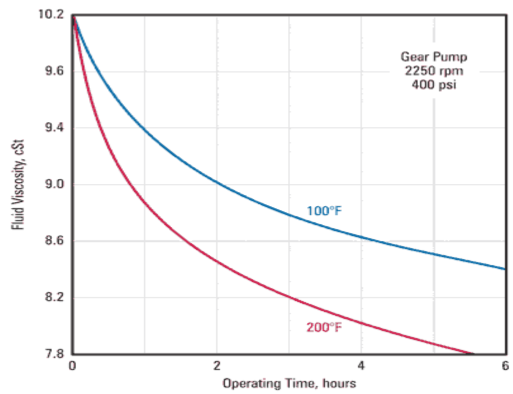

Fig.3: Effect of Temperature and Operating Time on Shear Stability of Fluid

Note that from Fig.3 gas solubility increases significantly with temperature for all petroleum products. The increased level of oxygen resulting from greater air content seriously affects the oxidation rate of the fluid and lowers its expected service life. Modern formulations of lubricating fluids contain vital additive packages to help the fluid satisfy essential operating functions.[11][15] Unfortunately, high temperature operation can deplete all such additives, but especially rust inhibitors, foam depressants, antioxidants and anti-wear ingredients.

High fluid temperature can cause a chain reaction leading to total system destruction.[5]High-temperature operation has a pronounced effect on the wear of all bearing type surfaces in a system.

iv). Heat Generation and Removal

Friction is the conversion process in a fluid type system. Because molecular friction generates heat in a sheared fluid, the higher the viscosity, the more heat this friction produces. [6]Fluid systems generally produce heat by converting mechanical energy or fluid pressure energy. Many points in the system can add heat, particularly points with high frictional resistance. [3] Good examples include such sources as bearings, fluid being pushed through orifices and various restrictions, and frictional drag on the fluid as it courses through restricted passages.

The first avenue of escape from generated heat is by natural dissipation. With natural cooling, heat in the system fluid dissipates into the surrounding air, primarily by conduction and convection. [6]All metal surfaces in contact with the fluid serve as heat-transfer surfaces.

6. FUNCTIONAL REQUIREMENTS OF VACUUM GRIPPER

The design of the gripper should fulfill the functional requirements. It is also noted that a suction (or vacuum) gripper is useful to pick up and fixate a wide variety of material. Also it is fast, widely used and when the component is placed it can be released using a puff of air, thereby fulfilling the first two functional requirements. [4][9]The other functional requirement is the ‘contribution of the gripper to the positional uncertainty during assembly should be well below the placement uncertainty of the assembly robot. [8]

ISSN (online): 2250-141X
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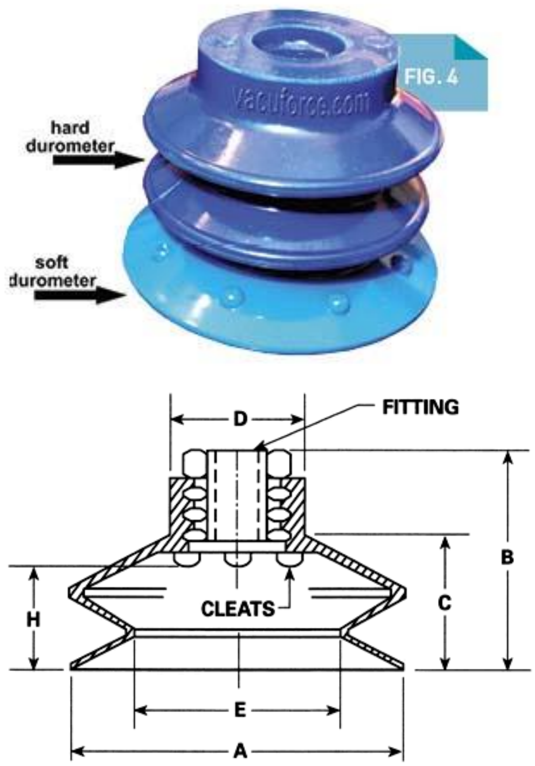

Fig.4: Vacuum Griper Sectional Shape

The functional requirements as shown sectional dimension in Fig.4 lead to the following Specifications for the new gripper design: the components are gripped and fixated using suction

• The total positional deviation introduced by the gripper should be less than 5 micrometers.

• The equivalent mass which is rigidly connected to the component should be less than 1.4 gram.

• The stiffness of the gripper in axial direction should be less than 2.5 N/mm.

7. CONSISTANCY CHECKS

As discussed in Fig.2 a vacuum chamber and radial holes in the needle are used to create a pressure in the needle. However, since the flow restriction between the vacuum chamber and the environment is limited, air will flow from the environment to this chamber or vice versa, depending on the pressure inside the chamber.[14]A high flow loss is an indication of a poor flow resistance and may cause the gripper to blow away small components.[3]

The column is guided in vertical direction using roller bearings. [13] A force sensor is mounted under the gripper needle using a clamp as shown in Fig.5.

Fig.5: Vacuum Gripper Assembly

8. VARIOUS LIMITATIONS & APPROACHES

- Improves considerably the safety of the company and human beings
- A robot can perform some activities that are dangerous for the human like handle potentially hazardous products, manipulate heavy loads, etc.
- Allows the possibility of doing many different activities related to shipments.
- This increases his profitability and faster rate of work performance.
- Allows the realization of optimum quality jobs.
- The level of incidents is very small.
- Less maintenance of the robots vacuum gripper to keep them running smoothly.
- Increases the productivity of the company.
- The efficiency of the company increases higher.
- Over travel forces reduces.

9. SAFETY FACTOR CONSIDERATION

Components should not be damaged during assembly i.e. plastic deformation should not occur

ISSN (online): 2250-141X
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when a sapphire sphere with a 1 mm diameter is placed on a planar aluminum. [4][9]The functional requirements lead to the following specifications for the new gripper design:

- the components are gripped and fixated using suction
- the total positional deviation introduced by the gripper should be less than 5 micrometers
- the equivalent mass which is rigidly connected to the component should be less than 1.4 gram
- the stiffness of the gripper in axial direction should be less than 2.5 N/mm
- the axial position of the needle is constrained using a mechanical type gripper

The bellow is also used to prevent rotation of the needle around its axis. As a result the needle is constrained in 6 degrees of freedom (DOF) during movement of the assembler. [3]During a pickup operation the assembler positions the gripper to make contact with the component to be picked up.

10. APPLICATION

- Vacuum grippers are highly useful in the heavy industries, automobiles, compact disc manufacturing, and more for material handling purposes.
- It is also used in the tray & box manufacturing, labeling, sealing, bottling, and so on for packaging purposes.

11. CONCLUSIONS:

There are many factors to consider, the paper became more instructive and challenging as discussed like material selection and load variations.

The aim of this paper was to understand the design parameters of a gripper tool. The proper materials and shapes of the gripper tool can be considered if a stronger structure is desired to be lifted. The gripper tool needs only a few seconds to active the electromagnets and lifts. With vacuum structures the elasticity of the skin material in particular, seems to be one of the controlling factors.

The step of this research shows the influence of the material configuration and the properties of the material on the effective amount of vacuum creation to lift the proper load.

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