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Vacuum Cup Grippers for Material Handling In Industry

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ABSTRACT

The vacuum cup grippers operate using Bernoulli Principle for generating high-speed flow between the vacuum cup and product surface thereby creating vacuum which lifted the product. Feasibility observations are studied to demonstrate and obtain an overall understanding on the capability and limitations of the vacuum cup gripper. Most of the robot grippers are not easily applicable due to the food products are often delicate, easily marked or bruised, adhesive and slippery.

In this paper, the study is an innovative approach of a gripper for handling variable in sizes; shape and weight of unpacked food products i.e. 'Vacuum cup gripper of Robot'. A substantial part of automated material handling and assembly is the interface between machine and work piece. The main objective of this report is to highlights the importance of vacuum cup universal gripper in industrial robot applications. Such grippers will deal exclusively with gripping of different variety of materials/parts by using vacuum cup gripper**.** This paper describes a gripping technology with vacuum cup system for large building components, such as two dimensional modules and three-dimensional modules.

The design parameter of the vacuum cup gripper i.e. end-effectors is a critical consideration in the applications of robotics for industrial operations. The end effectors must typically be designed for the specific application. In order to realize the full potential of future robotics technology, vacuum cup grippers must be designed more likely as human hand, both in their sensory and control capabilities as well as their anatomical configuration.

Key Words: Vacuum cup gripper, Influencing Parameter, Technology, Materials Composition, Gripping techniques.

1. INTRODUCTION

A vacuum cup gripper is an essential end-effectors tool of a robotic system. It serves as the robot's hand and allows the robot to manipulate objects for proper safely gripping. 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. Particularly, humanoid robot technology in this area attracts high attention of public interest [4].This paper's objective is to study current existing robotic vacuum cup grippers and explain the importance of vacuum cup gripper to achieve simple grasping tasks of different working plants. The vacuum cup gripper can be used in many materials handling applications.

The main aim of our work is to discuss the reliable solution for vacuum cup type grasping and manipulation of packed food products. Here some existing vacuum cup grippers and feasible mechanism solutions in the literature reviews have been described.

Vacuum cup grippers are those devices that actually grip an object for moving or placing it within the working range with vacuum cup type gripping system [6]. If the end-effectors vacuum cup type is not suited to the task, the task cannot be carried out satisfactorily [7]. End-effectors are usually specifically designed for their particular task, because the highest workload of on-site construction consists of handling and assembly operations, the vacuum cup gripper is most interesting in this area [5].

2. RESEARCH WORK ON VACUUM CUP GRIPPER

Vacuum cup grippers are used in the robots for grasping the non-ferrous objects and packets. It uses vacuum cups Fig.1 are the gripping device 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 [7]. It is only for one surface of gripping the objects. It may not be suitable for handling the pores objects all around.

Fig. 2: vacuum cup gripper

Many researchers have worked on robot grippers related with vacuum type as mentioned below:

Sood et al. [1] has formulated Range image Segmentation with Applications to Robot Bin-Picking using vacuum cup gripper. Lovel et al. [2] has discussed about a Optimized vacuum system design improves productivity'. Choi et al. [3] has elaborated design and feasibility gripper based on inflatable rubber pockets. Mantriota et al. [4] has also Theoretical model of the grasp with vacuum cup gripper. Fronz el al.[5] has also Recursive modeling and control of multi-link manipulators with vacuum cup grippers. Sam et al. [6] has developed a design approach of robotic gripper for reducing cost for handling food products. Laschi el al. [7] has a Design and Development of a soft robotic gripper for manipulation in minimally invasive surgery. Jaiswal et al. [9] has discussed about design construction of vacuum cup gripper of robots relevant to pick and place operating tool in which merits and demerits of vacuum cup gripper has been discussed. Jaiswal et al. [9] has design constraints of vacuum cup gripper an important material handling tool. The authors has discussed about the shape, size and temperature effect on vacuum cup gripper.

Suction cups are used to hold horizontal flat or vertical flat objects using strong suction cups to lift an item. The "vacuum" is used to lift large, flat, smooth sheets of material like wood paneling, metal, plastic and glass. A vacuum cup gripper of the robot arm as shown in Fig.2 shows 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.

3. COMPONENTS OF VACUUM CUP GRIPPER

The objects are generally work parts that are to be moved by the robot. These part-handling applications include machine loading and unloading, picking parts from a conveyor, and arranging parts onto a pallet. In addition to work parts, other objects handled by robot grippers include cartons, bottles, raw materials, and tools. The Single gripper is only one grasping device is mounted on the robot's wrist [9][9]. A double gripper two gripping devices attached to the wrist and is used to handle two separate objects. The two grasping devices can be actuated independently for single object. Grippers grasp and manipulate objects during the work cycle [7]. Typically, the objects grasped are work parts that need to be loaded or unloaded from one station to another. Grippers may be custom-designed to suit the physical specifications of the work parts that have to be grasped.

Vacuum-grippers become in suction cups, the suctions cups is made of rubber [9]. The suction cups are connected through tubes with under pressure devices for picking up items and for releasing items air is pumped out into the suction cups[1][3]. The vacuum pressure can be created with the following devices:

- Vacuum pumps
- Ejectors
- Suction bellows
- Pneumatic actuators

The vacuum cup grippers use suction cups (vacuum cups) as pick up devices. There are different types of suction cups and the cups are generally made of polyurethane or rubber and can be used at temperatures between -50^{0}C and 200°C. The suction cup can be categorized into four different types; universal suction cups, flat suction cups with bars, suction cups with bellow and depth suction cups as shown in Fig.3

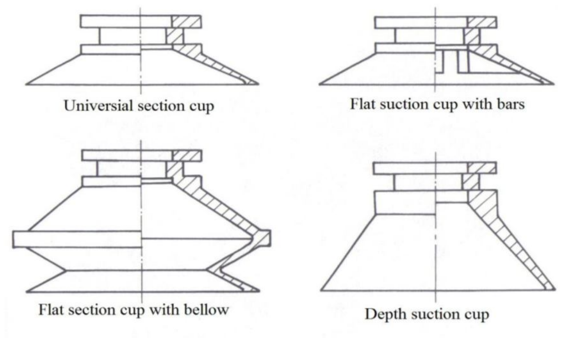

Fig.3: Shape of sectional view of Vacuum Cup

The universal suction vacuum cups are used for flat or slightly arched surfaces. Universal suction cups are one of the cheapest suction cups in the market but there are several disadvantages with this type of suction cups [5]. When the under pressure is too high, the suction cup decreases a lot which leads to a greater wear.

The flat suction cups as shown in Fig.3a. With bars are suitable for flat or flexible items that need assistance when lifted. These types of suction cups provides a small movement under load and maintains the area that the under pressure is acting on it which reduces the wear of the flat suction cup with bars and this leads to a faster and safer movement. Suction cups with bellows are usually used for curved surfaces. It is used for example when separation is needed or when a smaller item is being gripped and needs a shorter movement [6] [9]. This type of suction cups can be used in several areas but they allow a lot of movement at gripping and low stability with small under pressure. The depth suction cup can be used for surfaces that are very irregular and curved or when an item needs to be lifted over an edge [8] [9]. Item used as vacuum cup gripper with rough surfaces (surface roughness $\leq$ 3 µm) for some types of suction cups or items that are made of porous material [4]. An item with holes, slots and gaps on the surfaces is not recommended to be handled with vacuum cup grippers.

Fig.3a: Transparent Vacuum cup gripper

3a. Problems with surface configurations

- Curvy and sharp angled surfaces might not has sufficient flat surface contact to has enough of the cup exerting the required force on the contact surface.
- Porous or corrugated surface can prevent proper gripping, repeatable suction.
- Dirty surface can clog the airlines circuit.
- Such items are placed on plane platform to activate the work of handling with vacuum cup grippers.

3b. Vacuum cup gripper marks on some surfaces

In some cases (thick glass or mirror), these marks will need an additional step of packaging the items in the manufacturing process, increasing cost and manufacturing time [4] . Gripping can affect mark on surface of contact on the body [6].

3c. Vacuum cup gripper decreases the repeatability

This can prevent the robot from applying a sufficiently strong contact between the part being held and the work-piece or decrease the repeatability.

3d. Vacuum cup grippers need custom end-of-arm tooling to support them

To support different cups, it may be needed to come up with a custom end-effecter usually made of metal extrusion. If the part is complex, the design of the end-effecter can require a fair amount of trial and error. To handle such items need many vacuum cups located at different location for safe handling as Fig.3d.i for working action in system.

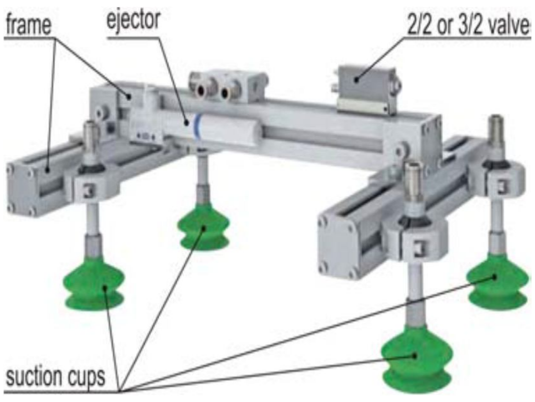

Fig.3d.i : Heavy Duty Vacuum cups gripper

3e. SLECTION OF VACUUM SWITCHS

Vacuum switches and pressure gauges Fig.3e are normally selected on the basis of the functions required in the application and on the switching frequency.

The following functions are available:

- adjustable switching point
- fixed or adjustable hysteresis
- digital and/or analog output signal
- status LED
- display with keypad
- connection with Female thread, Male flange or plug-in tube

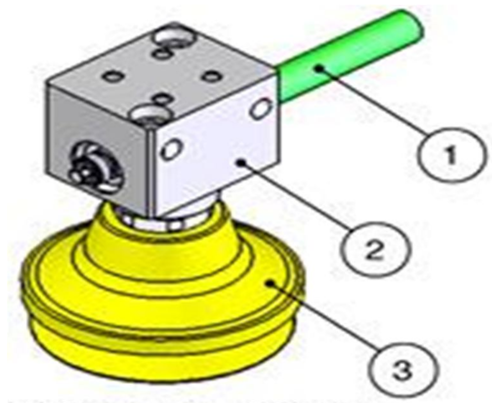

Fig.3e: Vacuum Creator Switch

3f. Calculating the weight of the Suction Pad

For all subsequent calculations, it is important to know the mass of the workpiece to be handled [5] [9].

Workpiece weight can be estimated as follows:

(i) Suction Pad Mass m [kg]: m =Mass density x Volume = ρ x L x B x H

ρ = Mass density [kg/m3]
L = length [m]
B = width [m]
H = height [m]

<u>Example</u>: m = 2.5 x 1.25 x 0.0025 x 7850
Workpiece mass, m = 61.33 kg
Load case I: horizontal suction pads, vertical force against the workpiece load
F = Force for theoretical holding [Newton]
m = mass [kg]
g = gravitational acceleration [9.81 m/s^2]
a = acceleration due to force [m/s^2]
S = safety factor = 1,5 minimum value
= 2.0 inhomogeneous/ porous materials/ rough surfaces
F =m x g x Factor of safety i.e. 61.33 x 9.81 x 1.5 = 902.471 N

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The suction pads are placed on a horizontal work piece which is to be moved sideways.

The theoretical suction force is the force acting perpendicular to the surface Fig.3f.
The specifications in the catalog are calculated values in Newton

Example:
Force for theoretical holding,

F_h =m x (g +a) x Factor of safety i.e. 61.33 x (9.81 +5) x 1.5
F_h = 1363 N and for rough surface = 66.33 x (9.81 + 5) x 2 = 1817 N

Comparison:

A comparison of the figures for load cases I and II results, in this example, in a maximum value for F_h =1817 N in load case II, and this value is therefore used for further design calculations.

Load case I: horizontal suction pads, horizontal force

FTH = Theoretical holding force [N]
F_a = mass x acceleration = m x a
m = mass [kg]
g = acceleration due to gravity [9.81 m/s^2]
a = system acceleration [m/s^2] (remember to include the "emergency off" situation!)
μ = Coefficient of friction = 0.1 for oily surfaces
= 0.2 ...0.3 for wet surfaces
= 0.5 for wood, metal, glass, stones,
= 0.6 for rough surfaces
S = safety factor (minimum value 1.5 for critical inhomogeneous or porous materials or rough surfaces 2.0 or higher)

The suction pads are placed on a horizontally on the work piece which is to be moved sideways and it can be moved upwards or downwards where cup feels shear force on the vacuum cup Fig.3f. Shear force is working tangentially to the surface of contacts of the object [7] [9]. The specifications in the catalog are measured values in Newton.

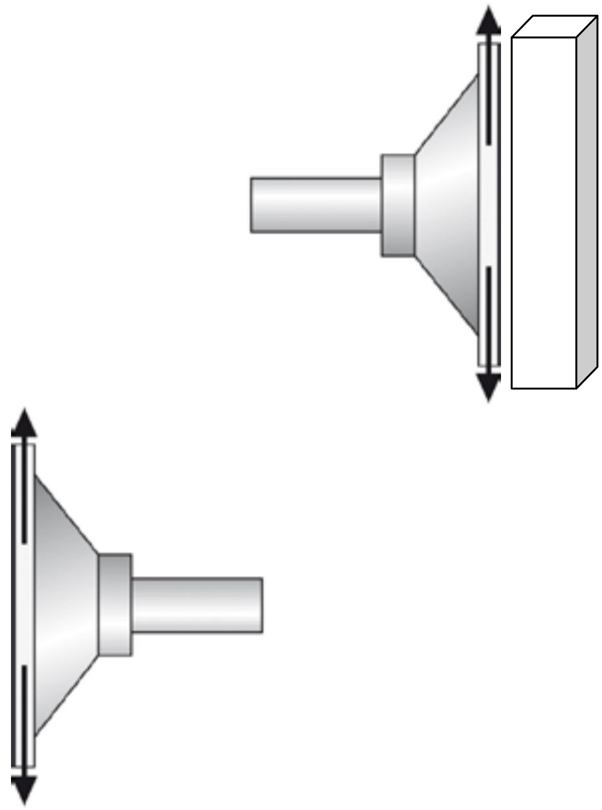

Fig 3f.: Shear Force acting on the Cup pairs

Example:
Theoretical gripping pressure on items as shown in Fig. 3g.,
For move horizontally, $\mathbf{F_s = m \times ((g + a)/\mu) \times S}$

Load case II: vertical suction pads, vertical force

$$\mathbf{F_s = (m/\mu) \times (g + a) \times S}$$

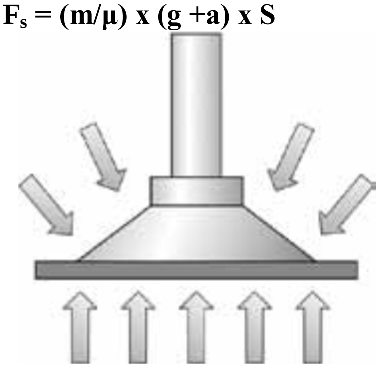

Fig. 3g.: Gripping Pressure Actuation

The coefficients of friction shown above are average values.

The actual values for the work piece to be handled must be determined by testing. For the example used for this description, load case III can be ignored, since the work pieces are to be handled only in a horizontal orientation.

This pressure difference is achieved by connecting the suction cup to a vacuum generator, which evacuates the air from the space between the cup and the workpiece [1] [5]. If the suction cup is in contact with the surface of the workpiece, no air can enter it from the sides and a vacuum is generated [3] [8]. The holding force of the suction cups increases proportionally with the difference between the ambient pressure and the pressure inside the cup

The holding force of a suction cup is calculated as below:

$$F_s = p \times A$$

F = Holding force, Newton

p = Intensity of pressure inside the cup, Kg/m^2

A = Effective suction area, m^2 (the effective area of a suction cup under vacuum)

This means the holding force is proportional to the pressure difference and the suction area. The greater the difference between ambient pressure and pressure in the suction cup or the larger the effective suction area, the greater the holding force [3] [8]. The force can vary depending on a change of the pressure difference and area parameters.

3g. Design of Suction Cup

The design of the suction cup always depends on the actual application. For this reason, various physical values must be calculated and determined before the correct selection of suction cup.

4. APPLICITION OF VACUUM CUP GRIPPER

- Wide range of applications for material handling,
- Handling technology and process engineering.
- Broad application in industry and research.
- Used for precision processes industry.
- Part feeding systems in the automotive industry.
- Packaging industry.
- Industrial robot applications in all sectors.
- Process engineering.
- Transportation of liquids and bulk material.
- Automated palletizing, de-palletizing.
- Commissioning and sorting of many different types of goods in various sizes with a single gripper or multiple grippers.
- Handling of workpieces made of many different materials, such as cardboard, wood, sheet metal (dry) and plastic,[4] with or without apertures.
- Modular design permits the combination of several vacuum cup gripper systems to form an overall system which is perfectly matched to the intended handling tasks.

5. ADVANTAGES OF VACUUM CUP GRIPPER

- 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 cup gripper to keep them running smoothly
- Increases the productivity of the company
- The efficiency of the company increases

higher

- Over travel forces reduces.

6. STUDY FOR DESIGIN PARAMETERS

The design of the gripper should fulfill the functional requirements as stated earlier. It is also mentioned that a suction or vacuum cup gripper is useful to pickup 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. The contribution of the gripper to the positional uncertainty during assembly should be well below the placement uncertainty of the assembly robot which depends on the assembly robot used.

Components should not be damaged during assembly i.e. plastic deformation should not occur when a sapphire sphere with a 1 mm diameter is placed on a planar aluminum [7] [9]. The functional requirements lead to the following specifications for the new gripper design:

- The components are gripped and fixed using suction pressure.
- 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 limited.
- 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 vacuum cup 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. During a pickup operation the assembler positions the gripper to make contact with the component to be picked up. When the gripper collides with the component the needle moves in axial direction into the gripper housing.

7. ASSUMPTIONS FOR DESIGNING OF VACUUM CUP GRIPPER

The design of vacuum cup gripper is having various factors to be considered. Some of the factors are considered as an assumptions like shape of object to be handled, weight of items for three types of load, distance to be moved is fixed distance,[9] the medium used to create the vacuum for gripping are pneumatic and hydraulics. The size of the object is limited due to lack of source availability, types of materials to be selected for the design of vacuum cup gripper may be rubber and synthetic materials, properties of the selected materials for their stability for sustaining the load as mentioned in book's data, surrounding environment e.g. air-pressure, temperatures. Assuming some of the factors as mentioned above, some of the critical factors would be taken care of for the design of vacuum cup gripper considering the object of safety and work satisfactory.

8. APPROACHES FOR SELECTION OF VACUUM CUP

The methods that are being used in this thesis are:

- Theoretical study for different lifting and gripping techniques.
- To be able to design a gripper tool for an industrial robot for different lifting and gripping.
- Techniques must be studied related to different gripping and lifting approaches.
- Must be known for deciding which types of gripping or lifting technique would be suitable for the design of the gripper tool.
- Several concepts of design consideration.

When the different concepts are designed, an evaluation and comparison of the concepts will be made. The concept that receives most points and meets the requirements in the best way will be selected for final design parameters.

9. CONCLUSION

Vacuum cup gripper in industrial robot applications has been discussed exclusively with

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gripping of different variety of parts comparing with other various types of vacuum cup grippers. The end effectors must typically be designed for the specific application. Vacuum cup gripper is fruitful for the, objects of very different shape, weight, and fragility can be gripped, and multiple objects can be gripped at once while maintaining their relative distance and orientation.

This diversity of Abilities may make the gripper well suited for use in unstructured domains for variable industrial tasks, such as food handling and others. The gripper's airtight construction also provides the potential for use in wet or volatile environments and permits easy cleaning.

This paper is to explore the utilities and advantages of vacuum cup gripper with its applications in industry for different product type manufacturing. Hence, the industries performance can be increased which would decrease the cost of the product effectively. The optimal performance of a vacuum cup gripper is maintained by resetting the gripper to a neutral state between gripping tasks.

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