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DESIGN AND DEVELOPMENT OF NOVEL AIR BELLOW ACTUATOR FOR ROBOTIC APPLICATION

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ABSTRACT

For robotic and light duty automation industry, the actuator should have high force to weight value. In this paper the alternative of the small pneumatic cylinder is presented, linear Bellow Actuator. Advantages regarding bellow actuator for robotic application are discussed. Bellow actuator for small scale application, around **50N to 500N** force requirement it is not available in the market. Bellow actuators in common posses' very high retentive force. These properties for most of the robotics or light weight pick and place automation application seems not beneficial and reduces its uses. In this paper, guideline to make the bellow actuator having low retentive force is presented that includes the design process, manufacturing method and the results of the experiments like velocity profile, retentive force profile, Force vs. pressure graph. Obtained properties of bellows were then compared with pneumatic cylinder. .

KEYWORDS: Air Bellow Actuator, Robotic Actuator, Bellow.

I. INTRODUCTION

In robotics, many kinds of actuators are used. The main types of actuators are Electric, Pneumatic and Hydraulic. From this Hydraulic is used only when very high force is required otherwise it is simply omitted from the system. For the controlled and variable speed application, electrical actuator is preferred. For point to point motion like pick and place, griper action, constant force application pneumatic cylinders are used. The main problem of the cylinder is the length of the cylinder when it is fully retracted. So we have the cylinder having stroke length equal to 100 mm then the space required for the cylinder to work is more than 200mm. This is the main drawback of the cylinder to use it in robots. Bellows in this case can be better alternative of pneumatic cylinder.

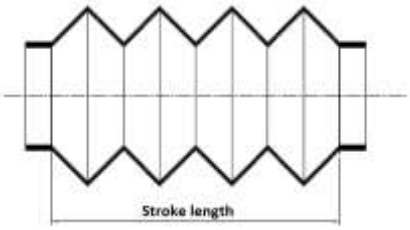

Figure 1: Basic shape of bellow

Bellows are just like flexible bag whose volume can be altered by allowing the air flow through it. Initially bellows were used at fireplace to blow the high quantity of air. These bellows was made of leather but with the time, the material of the bellow is now improved. In these days bellows are used in measuring units, expansion joints, cameras, anesthesia machines, musical instruments like harmonium and melodeon, cuckoo clocks.

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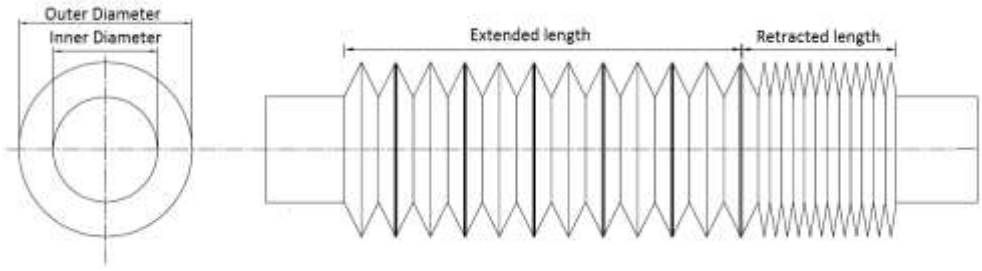

Figure 2: Fundamental terms related to bellows

Bellows can have the ratio of stroke length to retracted length equal to 3 to 4. Because of the peculiar geometry of bellow that allows the reduction in dimension. Along with this property there are many good properties like high force to weight ratio, high level of geometric tolerance that makes bellow actuator well suited to use in place of the cylinder

There are multiple types of bellows. From geometry we can divide them into two types. 1.) Single Core Bellows 2.) Multi Core Bellows. In multi core bellows sealing is provided by the bellows itself so there is no sealing is required on the shaft.

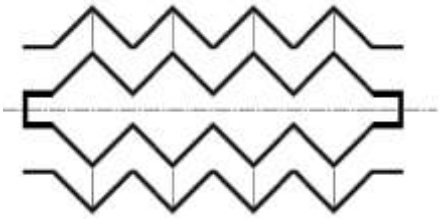

Figure 3: two core bellows

Bellows are also used as actuators for heavy duty application like press, rolling, bending. Generally, these bellows are made of rubber. The main drawback of these kinds of actuators is the high retentive force value.

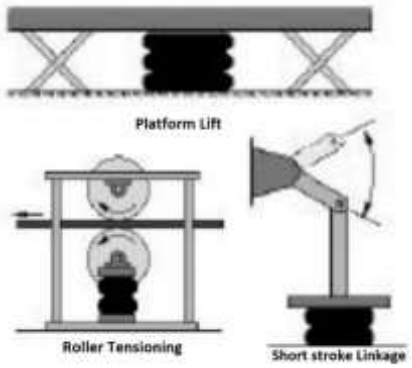

Figure 4: two core bellow actuator high force application

The main problem with these bellows is having the high retentive force it possesses. The work to reduce retentive force was carried out.

II. BELLOWS FOR ROBOTIC PURPOSE

Pneumatic cylinder is generally not capable of withstanding the cantilever load on the shaft of the cylinder so it is required to provide the guide-ways for the load. In most of the cases Cylinders are supported with the linear guide-ways. The system made of pneumatic cylinder will usually consist of three components, 1.) Load carrying system/Guide way 2.) Pneumatic cylinder 3.) Supports for mounting cylinder. But in the case of bellows the bellows can be directly fitted on the support system i.e. load carrying unit which significantly reduces the overall size of the system and reduces the extra accessories required for mounting the cylinder.

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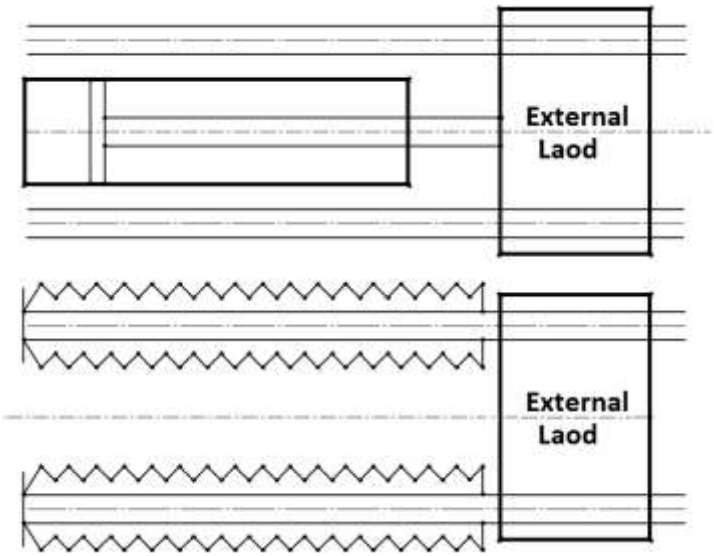

Figure 5: cylinder actuated and bellows actuated task

In Robotics the actuator unit should have high force to weight ratio. As discussed above, bellow can replace the cylinder and the supporting unit with flexible material makes the system light weight with the same load carrying capacity.

Now a day bellow actuators are available for the heavy duty application but it is made of rubber. The problem with the rubber bellow is high retentive force and the variation of retentive force throughout the stroke length. The Figure 6 suggests that the force at the full stroke is reduced approximately by 70% at 6 bar. Thus our goal was to make bellow actuator having low retentive force and can be used for the robotic application.

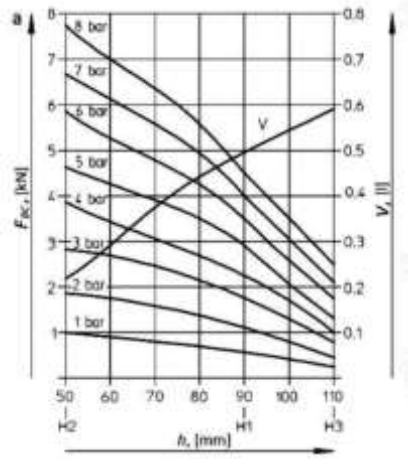

Figure 6: force vs. stroke length in heavy bellow actuators

III. DESIGN OF ACTUATOR

For deriving the dimension, the following design procedure was followed. In general circular, Octagonal or circular cross section bellows can be used to make actuators. In our case we made hexagonal bellow. The reason for selecting hexagonal cross section is described in the following section. While deriving the dimension of the bellow the actuator is assumed ideal and the friction of retentive force are neglected. Design input are taken as, Force (F) = 600 N, Pressure (P) 5 bar. To produce force 1200mm^2 effective area is needed. But shaft diameter (D_0) is 8 mm. Ideally force produced by bellow actuator can be given as,

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$$F_{ideal} = P \times (A - A_0) \quad (1)$$

From the above mentioned formulae the value of the cross section of the bellow was calculated which is equal to 1250.24 mm^2.

Length of side of the bellow then calculated using basic geometric relationship came out to be 21 mm. For experiment Stroke length of the bellow was taken as 250 mm and retracted length was taken as 40 mm. For mounting purpose on both the side sleeve of length 45 mm and diameter 40 mm was taken. Based on this values other dimensions of the bellow can be easily found out using basic engineering graphics concepts**.** Actual force produced by the bellow can be calculated by the following formulae.

$$F_{actual} = F_{ideal} - F_b - F_s \quad (2)$$

F_b = backward retentive force

F_s = frictional force due to seal

The net force exerted on load,

$$F_{net} = F_{actual} - F_m \quad (3)$$

F_m = frictional force of mechanism and guides

The guideline to select the material and its properties are described in [4]. Chrome leather was finalised as the bellow material based on the availability and considering the following properties. Thickness of the bellow was calculated and taken equals to 1 mm on the basis of strength criteria.

Fabrication of Bellows :

When the bellows are made from the sheet, generally two methods are used, 1.) Sewing and 2.) Folding. In case of sewed bellow, the retentive force tries to contract the bellow whereas in folded bellow the retentive force tries to extend the bellow. The folding method is preferable over the sewing method because of the leakage issues and linear retentive force. Guidelines for making bellows are given in the **[4]**. Manufacturing of the bellow was conducted under the guidance of the professional bellow manufacturer.

IV. EXPERIMENTATION AND RESULTS

To measure the forces and the velocity of the linear bellow actuator the test rig was made. At the free end of the actuator the load cell was coupled. The schematic diagram of the test rig is mentioned below.

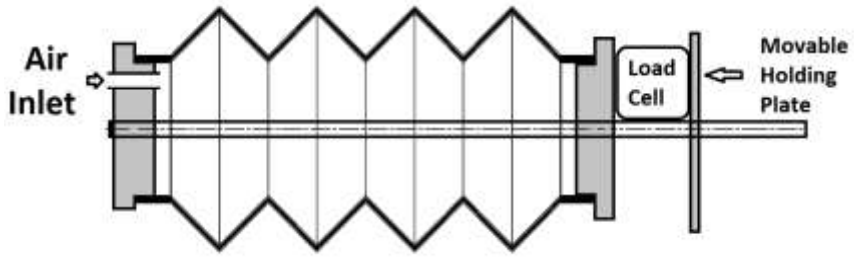

Figure 7: Schematic Diagram of Experimental Setup

Using load cell, the value of the retention force and the force produced by the actuator at different pressure was measured. To measure the velocity of the actuator open source video analysis software named tracker was used. The results of the experiments are stated as below.

Results:

In no load condition, the force required to hold the current position of the actuator was find out which is shown in below figure.

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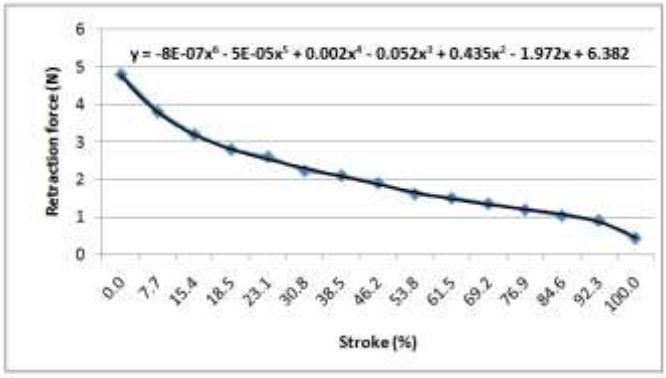

Figure 8: graph of Retraction force vs. Stroke Length

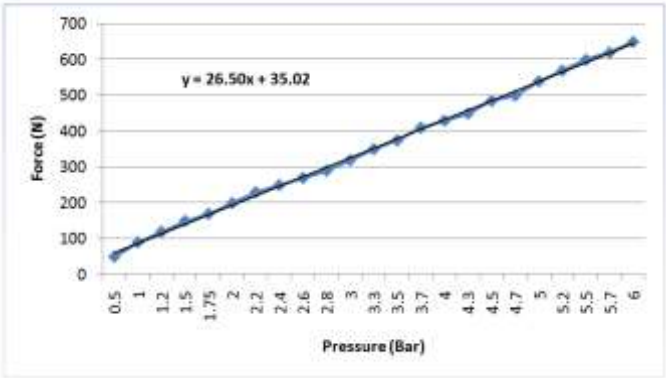

Figure 9: Actuator Force vs. Pneumatic Pressure Characteristics

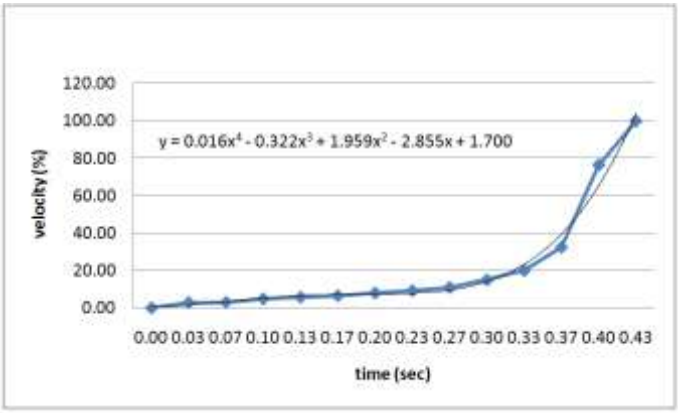

Figure 10: Actuator Velocity Characteristic Plot (at 6 bar)

Comparison between the proposed actuator and the standard pneumatic cylinder:

The characteristics of pneumatic cylinder are taken from [7] to qualitatively compare with the proposed bellow. Below mentioned table gives the comparison between pneumatic cylinder and Bellow having same capacity of producing force @ 6 Bar.

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Table 9. Comparison table for Bellow Actuator and Standard Pneumatic cylinder

Characteristics	Bellow actuator	Cylinder
Force (N)	650	754
Stroke Length (mm)	250	250
Ideal length (mm)	300	60
Overall weight (gram)	410	1271
Reciprocating mass (gram)	120	320
Size (OD in mm)	40	40

V. CONCLUSION

As stated in the table of the results section, comparison of bellow actuator with pneumatic cylinder clearly shows that the bellow actuator reduces the overall space required and overall weight of the mechanism. Along with this, Bellows can allow significant tolerance in linear as well as in angular motion. Bellow does not require any extra support as to hold the pneumatic cylinder. Bellows reduce the sealing surfaces required for the application than cylinder. Bellows can be used as the better alternative of pneumatic cylinder in robotic application. Depending upon the application, the different configurations of the bellow make possible to use them in most of the cases.

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