VALIDACIÓN EXPERIMENTAL DE UNA PINZA DE DOS DEDOS RETRÁCTILES

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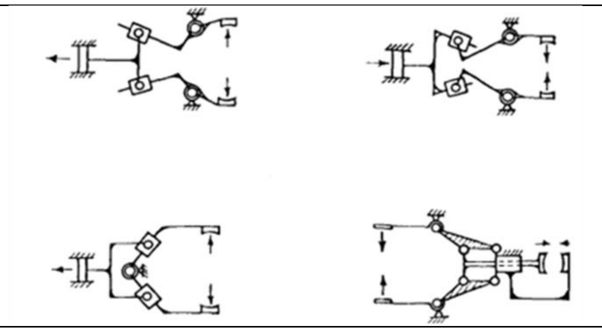
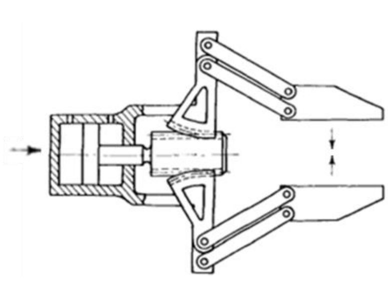
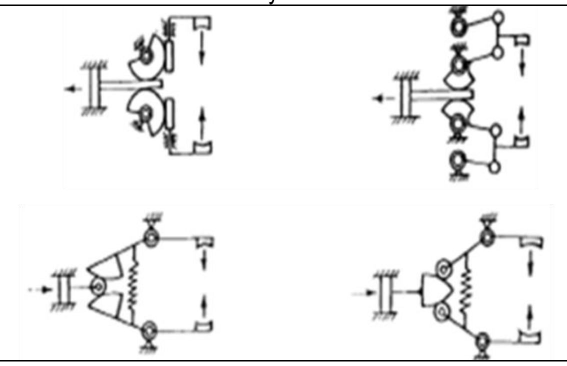
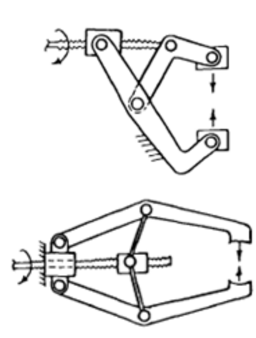
EXPERIMENTAL VALIDATION OF A RETRACTABLE TWO FINGER GRIPPER

1.- INTRODUCTION

A gripper is a dispositive used specifically to manipulate one or a few objects of similar form and size. When different objects are to be manipulated it is required to change grippers [1]. For this reason, a wide variety of grippers exist. Paying attention to the respective actuation systems, grippers can be classified in the following categories [1-3]:

- Mechanical grippers: of mechanisms, of sub-actuated mechanisms, of rack and pinion systems, of levers, of endless screw, and of pulley (Table 1).
- Vacuum, Bernoulli, needle, and magnetic (permanent or electromagnetic) grippers, according to the different types of elements that exert force on the object being manipulated (Table 2).
- Universal Grippers (Jamming system grippers), employed to grab irregular or fragile objects (Table 2).

Table 1: Different actuation systems for mechanical grippers [1-3]

Mechanical Grippers	
	
Actuated by mechanisms	Actuated by rack and pinion
	

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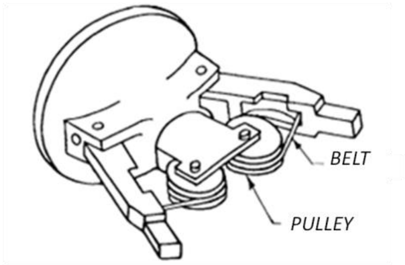
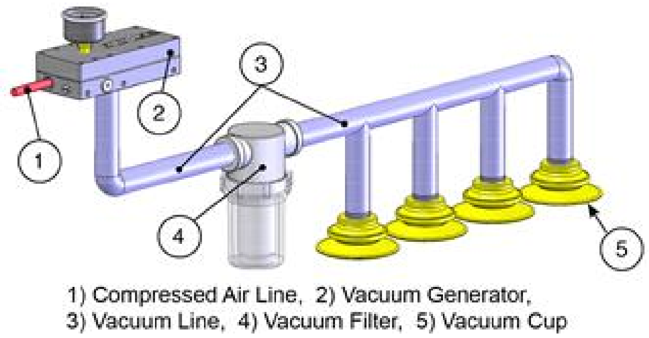
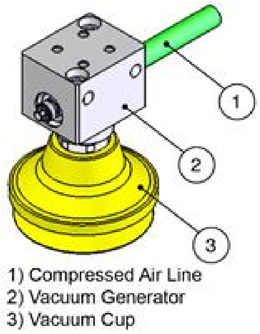
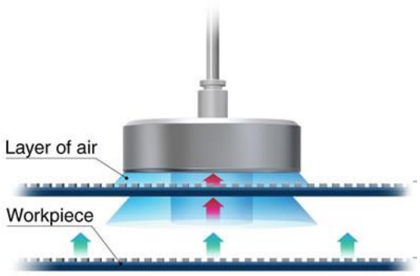
Actuated by levers	Actuated by a screw
	
Actuated by pulleys	

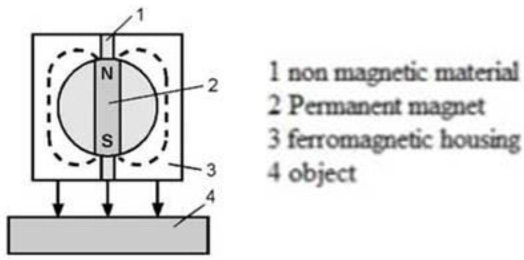
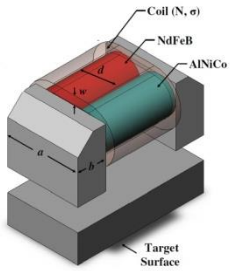
The most common type of grippers used are those with two fingers, due to their ability to grab cylindrical, prismatic, and pyramidal objects. Two finger grippers can travel rectilinear trajectories, curved trajectories, or a combination of both. Linear trajectory grippers, also denominated as parallel grippers, are typically used when the job does not require a change of gripper. Conversely, curved trajectory grippers are typically used when a gripper change is required; however, in the case of manipulating micro-objects, rectilinear or combined trajectories are applied [1], [4-6].

Pneumatic actuators are most commonly used due to their ease of installation and low cost. On the other hand, compared to hydraulic actuators, they do not have a good power to weight ratio and are difficult to control and feed. Still, in most cases these disadvantages do not have any influence [7-8].

When different types of objects are to be manipulated, multi-tool systems with automatic changers are used. Presently automatic tool changers exist, capable of supplying the required energy to operate the gripping tools [9].

Table 2: Vacuum and magnetic grippers [1-6]

Vacuum Grippers	
	
Bernoulli Gripper (low contact)	
	
Magnetic Grippers	

<table>
<tr><td>
</td><td>
</td></tr>
<tr><td>Permanent Magnet Gripper</td><td>Electromagnetic Gripper</td></tr>
<tr><td>Needle Gripper</td><td>Jamming System Gripper</td></tr>
<tr><td>
</td><td></td></tr>
</table>

In order to select a gripper tool the following aspects should be taken into account [10]:

- Required gripping force.
- Weight of the tool.
- Performance.
- Environmental conditions during the work process.
- Need of sensors.
- Velocity required on the fingers or elements of contact.
- Form of the fingers or elements of contact.

2. PURPOSE AND OBJECTIVE

The proposed gripping tool, object of study in the present article (Fig. 1), solves the problem of being able to manipulate objects having a size of 5 to 50 mm and weighing no more than 100 gr. The gripper is designed to grab objects that reside in spaces with small access points, such as biological materials (blood, vaccines, acids, etc.) where it is necessary to minimize contact of the object being manipulated with the exterior. The proposed solution allow the fingers of the gripping tool to be retracted, thus reducing its size, in order to deploy them once inside the operating vicinity and manipulate the object as shown in Fig. 1.

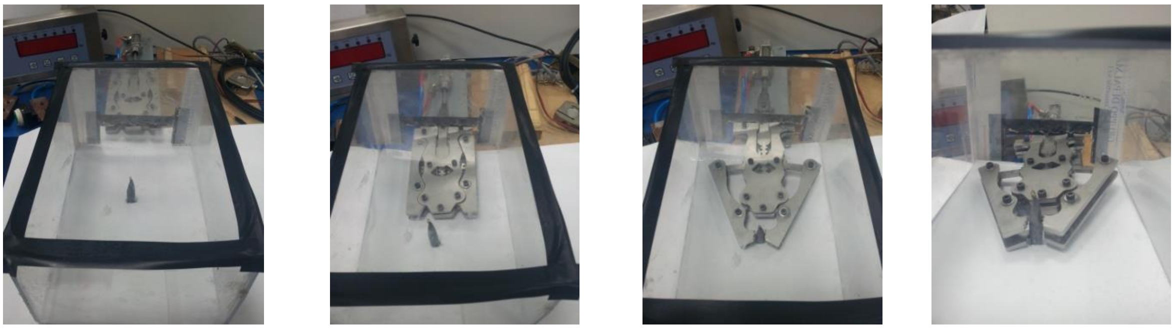


Fig. 1: Gripping operation of an object inside an enclosure communicated with the exterior via an opening.

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3. PROPOSED DESIGN.

In order to realize the gripping task proposed previously, a two finger gripper design actuated by a rack and pinion was chosen. This design was considered to be the simplest one so that the gripper could be compact and facilitate the possibility of both fingers being retracted, as shown in Fig. 2.

The design characteristics, incorporated to a model implemented in the Autodesk Inventor software, are shown in Table 3. The dimensions of the gripper with the fingers completely retracted and with the fingers holding objects of minimum and maximum size are presented in Fig. 2 and Fig. 3.

The gripper is actuated by means of a pneumatic cylinder whose characteristics are shown in Table 4.

It is desired to validate the proposed design in terms of its capacity to perform the proposed task. With this goal in mind, numerical analyses of the movement characteristics are performed and a model of the gripper is fabricated in stainless steel, as shown in Fig. 5.

Table 3: Mechanical characteristics of the proposed retractable two finger gripper

Mechanical Characteristics		
Denomination	Unit	Value
Gripper Aperture (see Fig. 3)	mm	5 - 50
Weight	kg	1,2
Gripping Force	N	1 - 10
Closing Time	s	0.8 - 1
Opening Time	s	0.8 - 1
Working Pressure	bar	6
Minimum Pressure	bar	2
Maximum Pressure	bar	8
Operating Temperature	ºC	-10 a 90

Table 4: Pneumatic cylinder characteristics

Stem diameter (mm)	Plunger diameter (mm)	Run (mm)	Service Pressure (bar)	Friction Losses (%)	Advancing Force (N)	Regression Force (N)
4	10	45	6	10	42,40	35,62

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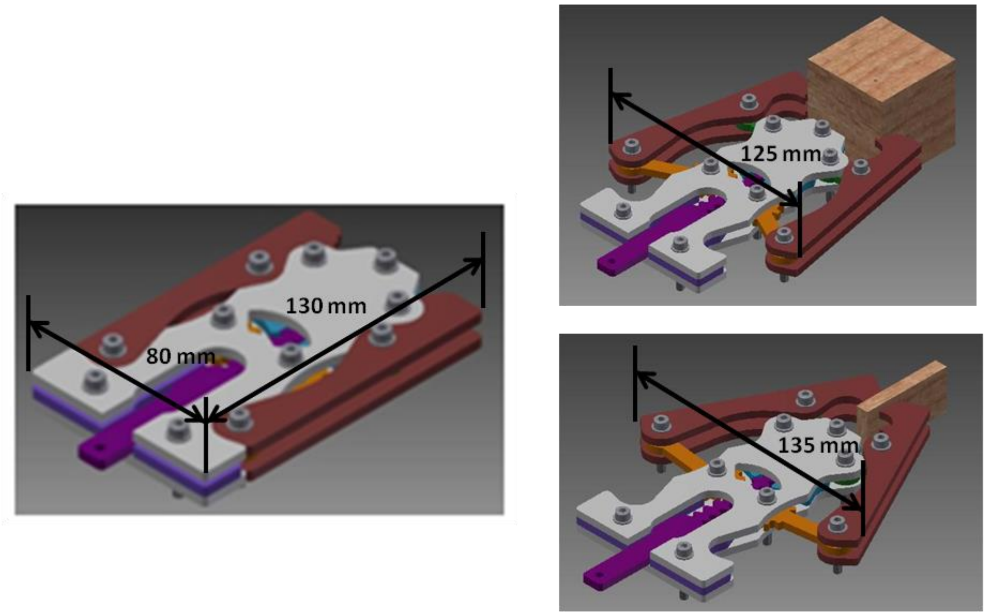

Fig. 2: Dimensions of the proposed gripper with fingers retracted and holding objects of maximum and minimum size

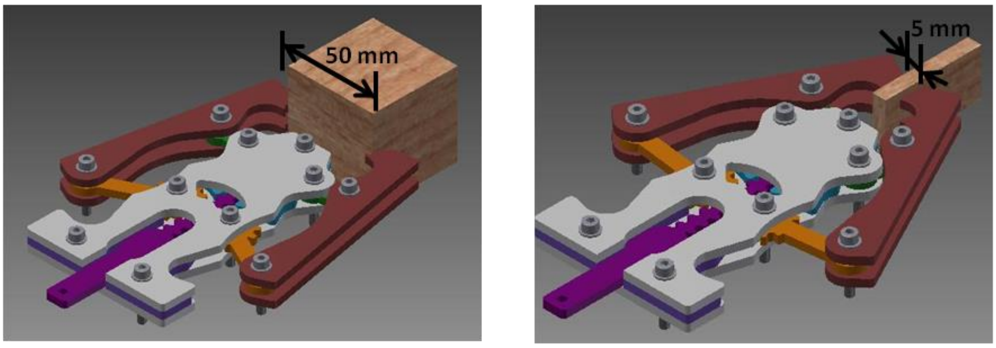

Fig. 3: Maximum and minimum size of considered object

Fig. 5: Model of the retractable two finger gripper in stainless steel

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4.- ANALYTICAL MODELS

4.1.- KINEMATIC ANALYSIS

The retractable two finger gripper consists of an articulated four bar mechanism whose entry link is actuated by a rack and pinion system and whose extreme end performs the gripping. The general shape of an articulated quadrilateral is shown in Fig. 6 and the positions of any point, P(x,y), in the coupler are given by Eq. (1) and Eq. (2).

$$\overline{x} = \overline{x(\varphi)} = \overline{x_a} + \overline{x_e} \quad (1)$$

$$\overline{y} = \overline{y(\varphi)} = \overline{y_a} + \overline{y_e} \quad (2)$$

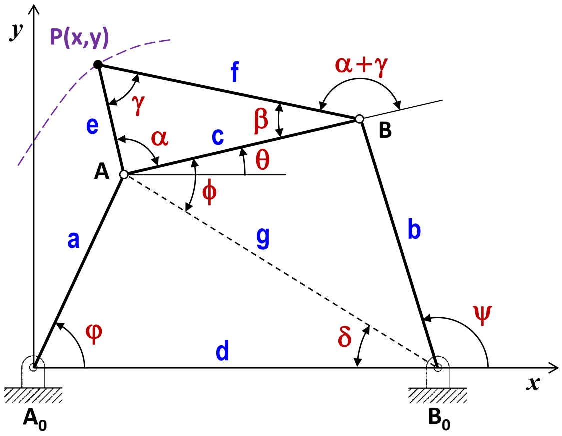

Fig. 6: Trajectory of a four bar mechanism with a coupling point

Substituting in Eq. (1) and Eq. (2) for the geometric values of the four bar mechanism with a coupling point results in Eq. (3) and Eq. (4).

$$x = a \cdot \cos\varphi + e \cdot \cos(\alpha + \theta) \quad (3)$$

$$y = a \cdot \text{sen}\varphi + e \cdot \text{sen}(\alpha + \theta) \quad (4)$$

Substituting in Eq. (3) and Eq. (4) for the angles Φ and δ represented in Fig. 6, Eq. (5) and Eq. (6) are obtained.

$$x = a \cdot \cos\varphi + e \cdot \cos(\phi - \alpha + \delta) \quad (5)$$

$$y = a \cdot \text{sen}\varphi + e \cdot \text{sen}(\phi - \alpha - \delta) \quad (6)$$

From the parameters δ, g, and Φ Eq. (7), Eq. (8), and Eq. (9) are obtained.

$$\delta = tg^{-1}\left(\frac{a \cdot \text{sen}\varphi}{d - a \cdot \cos\varphi}\right) \quad (7)$$

$$g = \sqrt{a^2 + d^2 - 2 \cdot a \cdot d \cdot \cos\varphi} \quad (8)$$

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$$\phi = \cos^{-1}\left(\frac{g^2 + c^2 - b^2}{2 \cdot c \cdot g}\right) \qquad (9)$$

Initially the coupling bar is parallel to the direction of the pneumatic cylinder pushing force, consequently, also to the rack displacement. In the gripping position for a 10mm object, the coupling bar has an angular position that has to be determined (see Fig. 7 and Fig. 8).

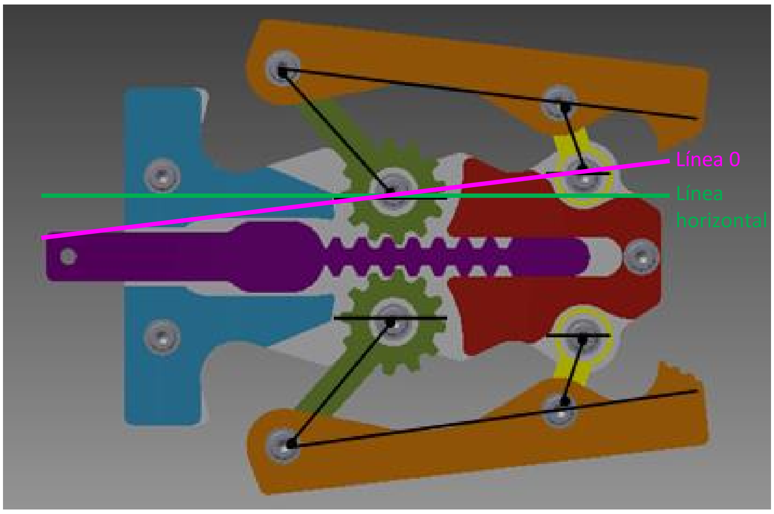

Fig. 7: Retractable two finger gripper mechanism

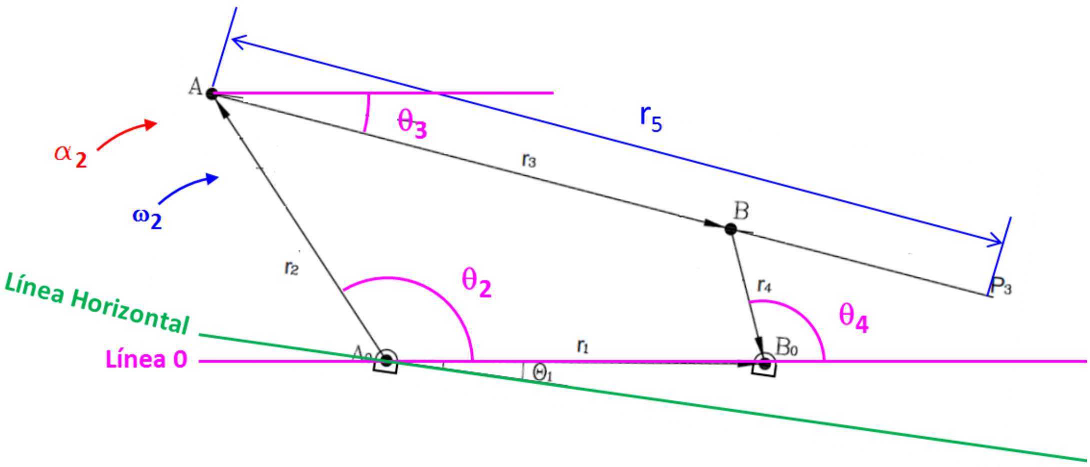

Fig. 8: Retractable two finger gripper mechanism parameters I

Knowing the entry velocity ω_2 (supplied by a pneumatic cylinder that pulls on the rack, making the pinion connected to bar 2 rotate, see Fig. 7),then the angular velocities of the rest of the links, ω_3 and ω_4, and of the mechanism that makes the gripper can be found using Eq. (10) and Eq.(11).

$$\omega_3 = \omega_2 \cdot \frac{r_2}{r_3} \cdot \frac{\operatorname{sen}(\theta_4 - \theta_2)}{\operatorname{sen}(\theta_3 - \theta_4)} \qquad (10)$$

$$\omega_4 = \omega_2 \cdot \frac{r_2}{r_4} \cdot \frac{\operatorname{sen}(\theta_2 - \theta_3)}{\operatorname{sen}(\theta_4 - \theta_3)} \qquad (11)$$

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It is necessary to indicate that the acceleration α_2 (see Fig. 8) is considered null since the pneumatic cylinder with regulated flow supplies a practically constant velocity. The angular accelerations of the links 3 and 4 are given by Eq. (12) and Eq.(13), respectively.

$$\alpha_3 = \frac{r_2\omega_2^2\cos(\theta_4-\theta_2)+r_3\omega_3^2\cos(\theta_4-\theta_3)+r_4\omega_4^2}{r_3\sin(\theta_4-\theta_3)} \quad (12)$$

$$\alpha_4 = \frac{r_2\omega_2^2\cos(\theta_4-\theta_2)+r_4\omega_4^2\cos(\theta_4-\theta_3)+r_3\omega_3^2}{r_4\sin(\theta_4-\theta_3)} \quad (13)$$

4.2.- DYNAMIC ANALYSIS

As shown in Fig. 9, the input torque M_2 (originated by the force F_2 supplied by the pneumatic cylinder) is calculated in Eq.(14). Applying the principle of virtual works, Eq. (15) and Eq. (16) relate the gripping force in the point of contact, F_{p3}, with the velocity in the point of contact, v_{p3}, and the angle formed by both vectors Θ_{Fv} given by Eq. (17). The velocity in the point of contact v_{p3} is determined using the theorem of relative velocities, Eq. (18). Solving for Eq. (18) gives Eq. (19).

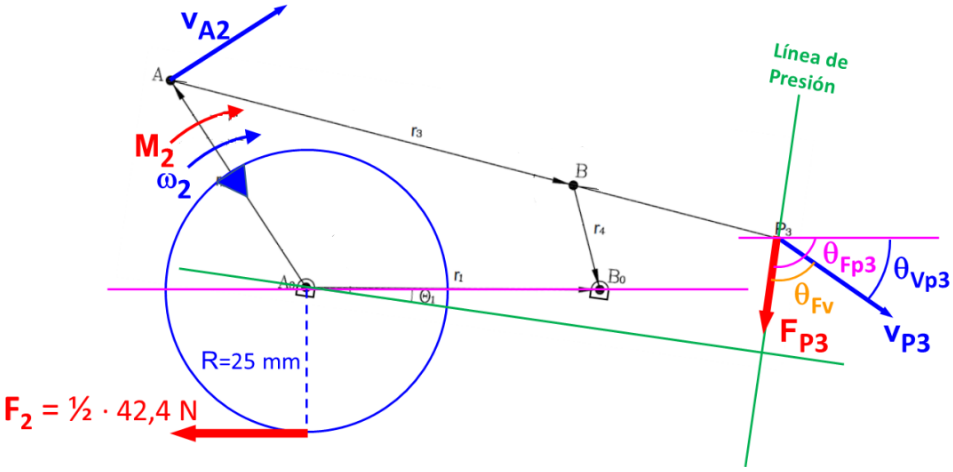

Fig. 9: Retractable two finger gripper parameters II

$$\overline{M_2} = \overline{F_2} \times \overline{R} \quad (14)$$

$$\overline{M_2}\cdot\overline{\omega_2} = \overline{F_{P3}}\cdot\overline{v_{p3}} \quad (15)$$

$$M_2\omega_2 = F_{P3}v_{p3}\cos\theta_{Fv} \quad (16)$$

$$\theta_{Fv} = \theta_{Fp3} - \theta_{Vp3} \quad (17)$$

$$\overline{v_{P3}} = \overline{v_{A3}} + \overline{v_{P3A3}} = \overline{v_{A2}} + \overline{v_{P3A3}} \quad (18)$$

$$\overline{v_{P3}} = \overline{\omega_2}\times\overline{r_2} + \overline{\omega_3}\times\overline{r_5} = \overline{\omega_2}\times\overline{r_2}\left(1+\frac{\overline{r_2}\ \overline{r_5}\sin(\theta_4-\theta_2)}{\overline{r_2}\ r_3\sin(\theta_3-\theta_4)}\right) \quad (19)$$

Keeping in mind the considered angles shown in Fig 9 and substituting in Eq. (16) for Eq. (14) and Eq. (19) results in Eq. (20). Solving Eq. (20) gives the relation between the gripping force at contact F_{p3} and the entry force F_2, Eq. (21). This relation gives the efficiency of the retractable two finger gripper.

$$F_2R = F_{P3}r_2\left(1+\frac{r_5\sin(\theta_4-\theta_2)}{r_3\sin(\theta_3-\theta_4)}\right)\cos\theta_{Fv} \quad (20)$$

$$\frac{F_{P3}}{F_2} = \frac{R}{r_2\left(1+\frac{r_5\sin(\theta_4-\theta_2)}{r_3\sin(\theta_3-\theta_4)}\right)\cos\theta_{Fv}} \quad (21)$$

5. NUMERICAL ANALYSIS.

The flow diagram shown in Fig 10 shows the implementation process of the analytical model of the proposed gripping mechanism in MATLAB.

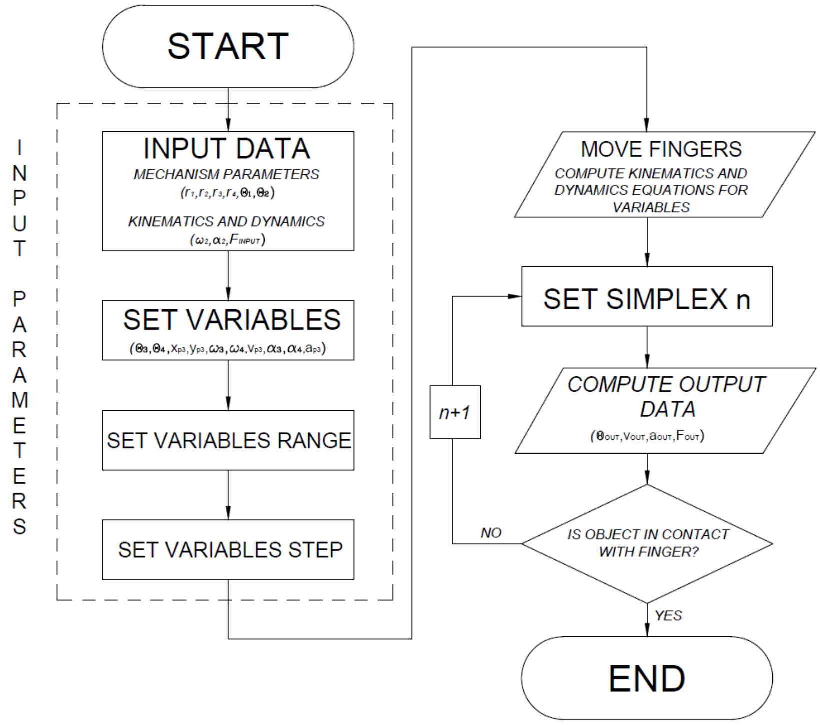

Fig. 10: Flow diagram of the numerical analysis

5.1.- CINEMATIC ANALYSIS

In table 5 the lengths of each of the links and the initial and final angles of the mechanism obtained from the MATLAB simulation are given. The simulation was programed to grab a 10mm wide object. The trajectory of the gripper mechanism with two retractable fingers until grabbing the 10mm object is given in Fig. 11.

Table 5: Link lengths and initial and final angles

Link Length (mm)		Initial Angle (rad)		Final Angle (rad)	
r_1	46,17	θ_1	-0,0868	θ_1	-0,0868
r_2	40	θ_2	2,7375	θ_2	1,3423
r_3	67	θ_3	-0,0868	θ_3	-0,5814
r_4	19	θ_4	2,5923	θ_4	0,1141
r_5	96				

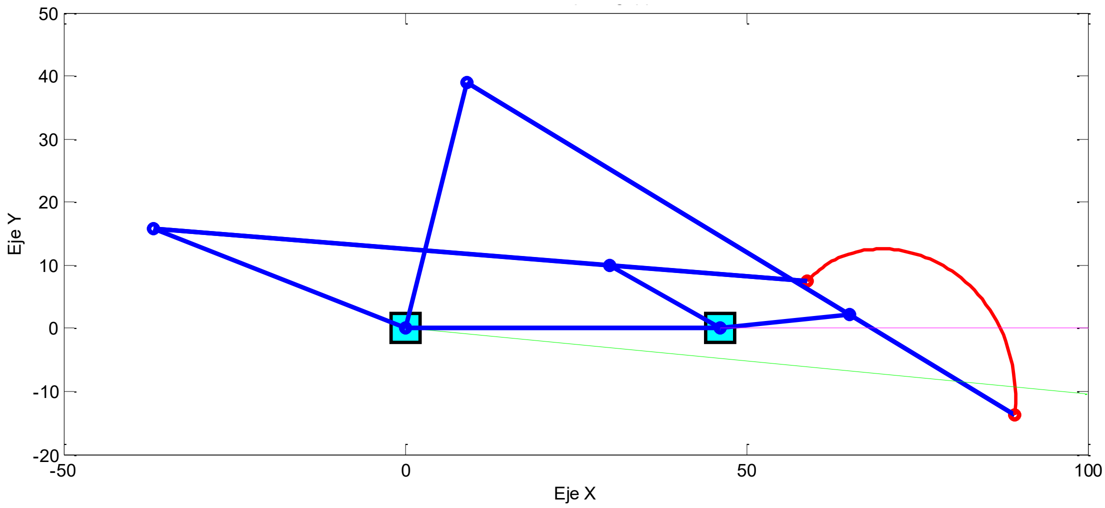

Fig. 11: Trajectory described by mechanism of the retractable two finger gripper

As shown in Fig. 12, in order to determine the angle of the velocity vector at the point of contact and the angle to grip a 10mm object, the instantaneous centre of rotation I_3 was previously determined, starting from the coordinates of the points A_0, A, B_0, and B. The coordinates of the aforementioned points, the instantaneous centre of rotation, and the point of contact P_3 are given in table 6.

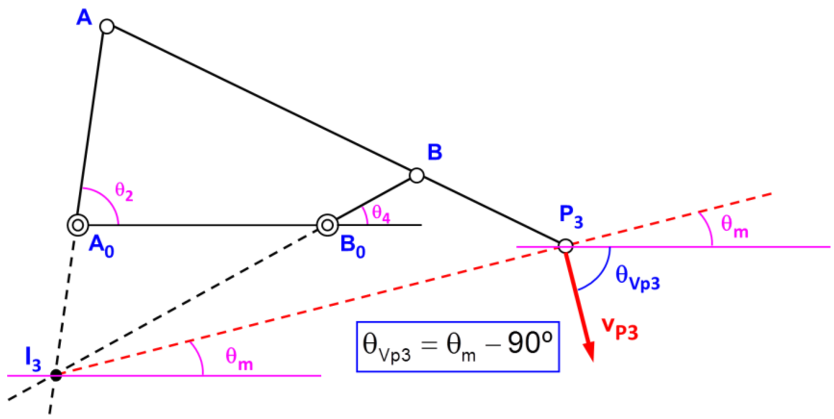

Fig. 12: Determination of the angular velocity in the point of contact

Table 6: Coordinates of the points of the gripper mechanism (in mm), in the holding position of a 10 mm object.

A_0		A		B_0		B		I_3		P_3	
X_{A0}	Y_{A0}	X_A	Y_A	X_{B0}	Y_{B0}	X_B	Y_B	X_{I3}	Y_{I3}	X_{P3}	Y_{P3}
0	0	9,06	38,96	46	17	65,05	2,16	-1,26	-5,42	89,28	-13,76

As shown in Fig. 12, the angle Θ_m is determined using Eq. (22) and the angular velocity of the point of contact, Θ_{vp3}, is determined using Eq. (23).

$$\theta_m = \tan^{-1}\left(\frac{y_{P3} - y_{I3}}{x_{P3} - x_{I3}}\right) = \tan^{-1}\left(\frac{-13{,}76 + 5{,}42}{89{,}28 + 1{,}26}\right) = -5{,}26^\circ \quad (22)$$

$$\theta_{Vp3} = \theta_m - 90^\circ = -5{,}26 - 90 = -95{,}26^\circ \quad (23)$$

Fig. 13 shows the variation of the velocity and acceleration of the link that establishes contact with the object throughout its entire trajectory. Table 5 shows the minimum and maximum positions of Θ_2 .

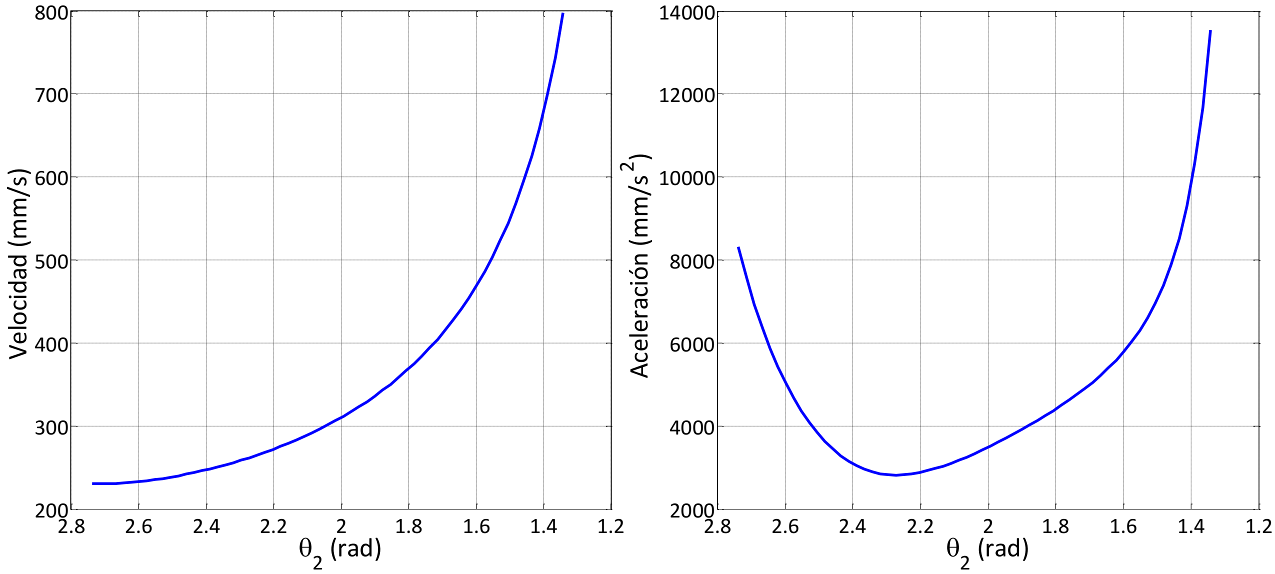

Fig. 13: Variation of the velocity (left) and acceleration (right) with respect to the entry angle

5.2.- DYNAMIC ANALYSIS

When an object is gripped, the pressure angle of the gripping force, F_{p3}, is practically normal to link 3, the angle being Θ_1 and given by the geometry of the proposed design as 4.97 º. Consequently, the angle Θ_{Fp3}, given in Fig. 11, is determined through Eq. (24).

$$\theta_{Fp3} = \theta_1 - 90° = -94{,}97° \quad (24)$$

In the gripping position, the angle between the velocity and the force is approximately 0º, as shown in Eq. (25).

$$\theta_{Fv} = \theta_{Fp3} - \theta_{Vp3} = 0{,}29° \approx 0° \quad (25)$$

Substituting the values of the parameters shown in table 5 into Eq. (21) give a relation between the gripping force F_{p3} and the entry force F_2 of 0.2015. Therefore, since the entry force F_2 supplied by the pneumatic actuator is 21.2N, the resulting gripping force is 4.27N.

The results obtained from the analytical and numerical models confirm the validity of the design. However, there is a great difference between the actuating force and the gripping force, an aspect that requires improvement in future designs.

6. EXPERIMENT.

Fig. 14 shows the experimental setup used to perform the experimental validation trials of the retractable two finger gripper. The setup consists of:

1. Pneumatic actuator and cylinder (Table 4).
2. Accelerometer. It is not necessary to measure high accelerations for this experiment, therefore a sensor for low accelerations was used to measure accelerations in the X, Y, and Z directions (Freescale, model MMA7260Q).

3. Force sensor CP 150.
4. National Instruments NI-USB 6009 data recorder and amplifier. A DAQ multifunction external card optimized for general applications.
5. Objects for gripping having a width from 5 to 10 mm..
6. Power supply.

Control and acquisition of data was implemented in LabVIEW. The virtual instrumentation is shown in Fig. 15.

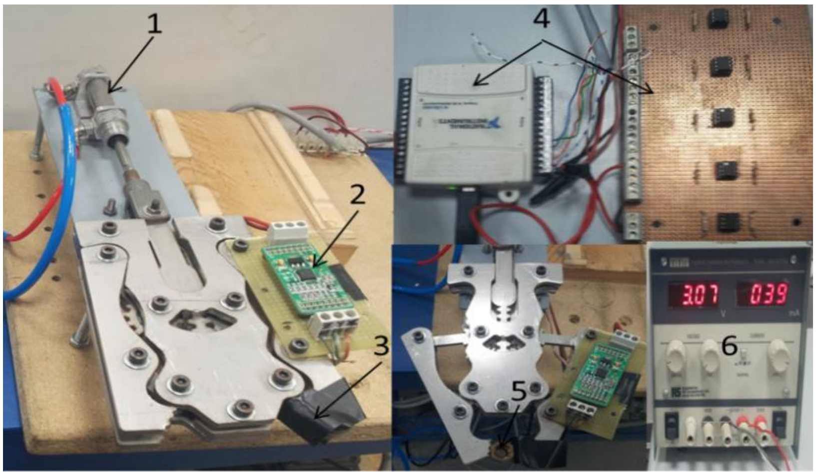

Fig. 14: Experimental setup for experimental validation

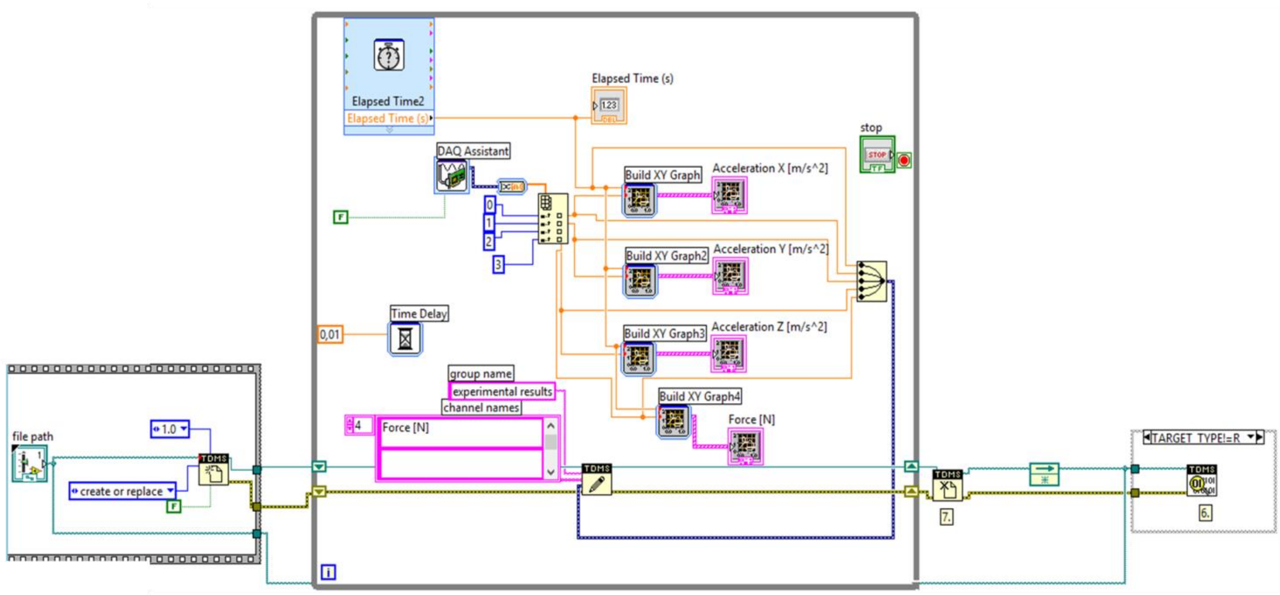

Fig. 15: Block diagram of LabVIEW virtual instrumentation.

6.1.- TESTING PROCEDURE

The trials were performed according to the following procedure:

- Before the trial, the prototype of the gripping system was installed and the entry pneumatic pressure was checked (6 bar). The consumption of air was regulated by means of regulating valves; in this way a constant velocity supplied from the piston pump was achieved.

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- The accelerometer was mounted on the gripper taking advantage of two bolts holding the links. See Fig. 14.
- A force sensor was adhered to the contact point of the gripper following the manufacturer's specifications.
- The data acquisition equipment was configured for the identification and treatment of the results.
- After the data acquisition equipment was configured and the acceleration and force sensors were calibrated trials were performed.
- Acceleration and force data were recorded simultaneously for objects between 5 and 10 mm as shown in Fig. 14.

6.2.- RESULTS

Fig. 16 shows graphs of the variations in acceleration experienced by the contact element of the gripper for the entire cycle of gripping and releasing of a 10mm object. As shown in the figure, the acceleration increases abruptly when the gripper establishes contact with the object and when it arrives to its final retracted position.

Fig. 17 shows the progression of the gripping force applied by the prototype holding a 10mm object. The gripping force increases rapidly while gripping since the pneumatic piston keeps actuating. Similar results were obtained for objects between 5 and 10mm wide.

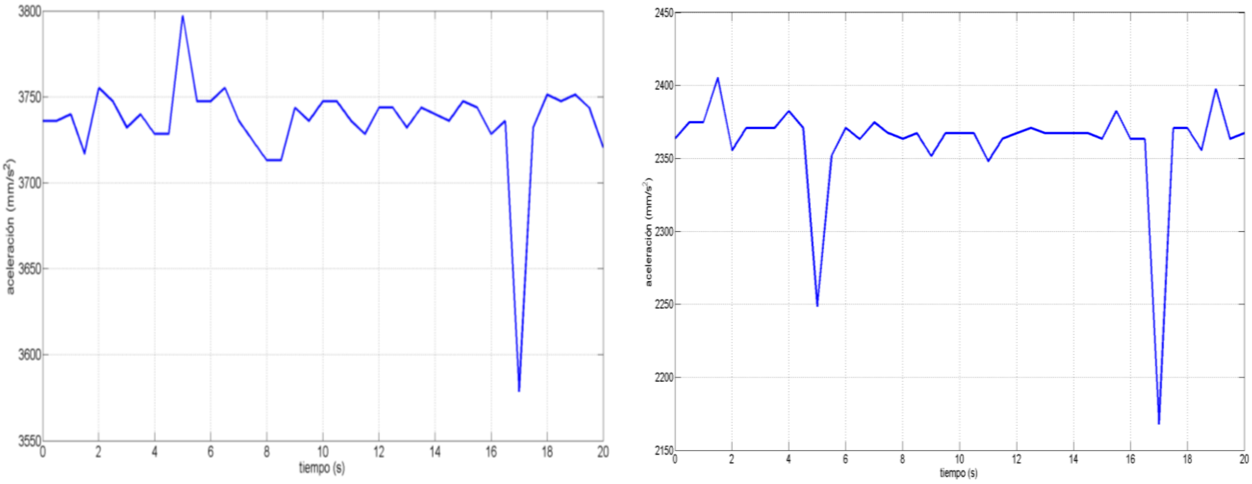

Fig. 16: Experimental acceleration. Y axis (left) and X axis (right).

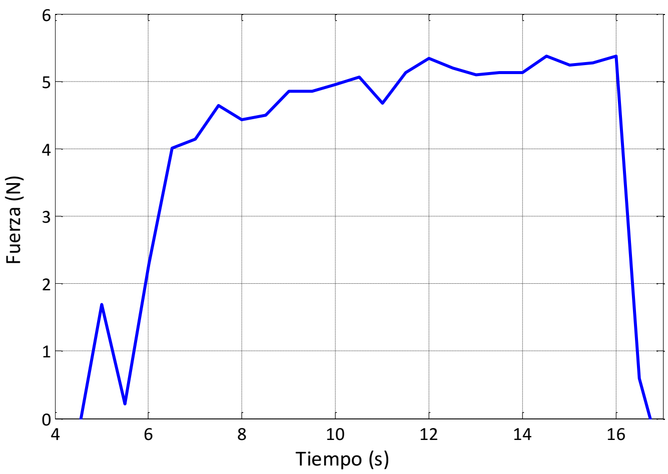

Fig. 17: Experimental gripping force

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7. CONCLUSION

The work shows the theoretical and experimental development of a two finger gripper where the fingers can be retracted in order to go through small apertures and then deploy itself to manipulate small objects. In the document a detailed description of the constructed gripper and analysis of the gripper's behaviour using cinematic and dynamic models are given. An experimental study is also performed, where the fabrication is addressed, put to point and experimental measurement of the different parameters of the gripper.

At the beginning of the article a detailed classification of different types of mechanical grippers is given, paying attention to the actuating system. Afterwards a model for a new gripper with two retractable fingers is presented and its interest in manipulating objects isolated by apertures is demonstrated. The obtained results of the analytical and numerical models and the experimental trials of a stainless steel prototype have evidenced its validity and industrial utility. However, in order to obtain an efficient gripper the following improvements have to be incorporated in a future model:

- Reduction in the impact on the object while gripping and on the structure of the gripper when retracting the fingers. This can be achieved by installing elastic materials on the claws and on the structure of the gripper.
- Improvement in the mechanical efficiency of the system. The current system consumes a great deal of energy in order to deploy the fingers in relation to gripping force achieved. This requires redesigning the dimensions of the equivalent mechanism of the articulate quadrilateral and minimizing frictional losses in the rack and pinion system.

TO KNOW MORE

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