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An adaptable vacuum gripper design for egg packaging, attached to the KUKA KR 60-3 industrial robot

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Abstract*— Packaging is for a company one of the main processes to satisfy the requirements imposed by the consumer within the production chain; however, at present, the automation of this process has not been fully developed in the poultry industry in Peru, delegating the responsibility to a significant number of workers. Due to this, there are long working hours, production delays, the integrity of both personnel and the product is exposed, and the trust placed by the consumer is compromised. In consideration of the technological advances involved in industry 4.0 and the complexity of developing an end effector capable of adapting to multiple variations in the egg packaging process, and Adaptable Vacuum Gripper design is proposed, coupled to the KUKA KR 60-3 industrial robot, that it be dynamic and efficient when packing a maximum of 30 eggs in their respective cardboard or plastic commercial packaging without compromising the state of the product, alternating the number eggs packed in relation to the distribution matrix of the end effector (5x6) and the capacity established by the type of packaging to be packaged. Likewise, the product can be coupled to any type of industrial robot through insignificant modifications that alter its base structure. With the proposed mechatronic device, it was possible to obtain an efficiency of 100%.

Keywords*— Poultry industry, packing, adaptable vacuum clamp, industry 4.0, mechatronic device.

I. INTRODUCTION

During the last years, both the consumption and production of chicken eggs have increased due to the constant increase in the population; Asia and South America are the continents with the highest growth rate [1]. In Peru, the per capita consumption of chicken eggs amounts to 16.9 Kg/person/year (270 eggs/person/year), being surpassed only by Mexico with 22.9 Kg/person/year (367 eggs/person/year) [2]; a clear example that supports the aforementioned is located in the year 2018 when the national production was around 453 000 tons, accentuating a growth of 9.0% in relation to the previous year [3]. Likewise, in April 2022, the poultry sector had a participation of 31.9%, which constitutes the gross value of agricultural production in Peru, positioning itself as one of the most important sources of animal protein at the regional and national level [4]. However, when closely analyzing the companies that make up this sector, it was determined that the greatest expense in production was due to the large number of personnel hired to process eggs, since it is necessary to prevent the product from arriving in a state that not to the consumer's liking [5].

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For issues like this, the development of robotic technology and industrial automation systems have caused a high impact on the food chain, taking part in the development of strategies to increase production [6], through the application of methods based on artificial intelligence (AI), image processing (IP) and sensor technology in order to maintain a high standard in the evaluation of product quality [7]; also, one of the potential applications of robotics, for the packaging process, within the food industry, It is found in pick-and-place operations, in which the grip or coupling with the product is prioritized to avoid damaging it, especially if it is uneven surface, through the design and analysis of an end effector that complements the basic functions of an industrial robot [8]. Due to the variability of the work environment and the multiple applications demanded by the automation of food processes, the most relevant jobs are mentioned.

Hong Jiang et al. propose in [9] the design of a manipulator for egg packing. The system has 24 suction cups and has a mechanical system with pneumatic drive that allows the tray to be held and detached from the base by extending and compressing pneumatic cylinders. The execution time is determined by a cycle of 10 seconds per pack (30 eggs) or 10 800 eggs per hour in the process. However, this work only focuses on the handling of the full tray, presents a single pneumatic control line in matrix, and bases its analysis on simulations with the product.

Zhongkui Wang et al. identify in [10] the importance of the versatility of an end effector through the design and implementation of a dual soft gripper. The design is based on the manufacture of 4 soft fingers, adding a commercial suction cup at the end of each finger. A vacuum ejector is used for the control of the pneumatic system, with a working pressure between -60 KPa and -90 KPa. It is possible to lift an object up to 1Kg, with an opening range of 128.6 mm to 193.6 mm. However, the work has a capacity limit. In addition, the dynamics of the end effector are focused on adaptation with the product, but not with the work environment.

Amal Prakash et al. analyze in [11] the design of an asymmetric flexible pneumatic bellows actuator (AFPBA) to palletize eggs and reduce the time and labor involved in processing. The pneumatic manipulator is composed of 3 fingers made of nitrile rubber. A control system is made for the force exerted by the Gripper, so that the product does not slide, managing to lift a weight of up to 200 grams safely. However, this work only focuses on individual coupling; In addition, it lacks a matrix that maximizes end-effector performance and sustains end-effector efficiency.

N. Jasman et al. propose in [12] the implementation of a vacuum suction gripper for the transport of parts. The objective is based on reducing the time of the pick and place process to reduce productivity losses. Likewise, it was possible to reduce the cycle time by 20%, making the process more frequent and increasing the flexibility of production. However, this work only focuses on the comparison with the conventional vacuum clamp, without considering the adaptability of the device with the product, in addition to limiting the capacity of the equipment to the transport of flat parts that facilitate its operation.

Felix Gabriel et al. identify in [13] the parameters that influence the correct seal and the force transmission of the vacuum grippers. In this method, they base their analysis on the prediction of the maximum expected loads and the deformation of the coupling suction cup, based on real dynamic experiments and obtaining energy savings of up to 85% for the optimization of the trajectory of a manipulator robot. However, this work only focuses on the study of individual coupling, limiting itself to a single type of system behavior pattern.

Given the shortcomings of the cases seen, it is proposed to make a mechatronic device that meets the appropriate characteristics to pack a maximum of 30 eggs, using a matrix of 5x6, so that the final effector is adaptable for any type of container.

II. DESCRIPTION OF THE PROPOSED METHOD

Figure 1 shows the block diagram of the proposed method.

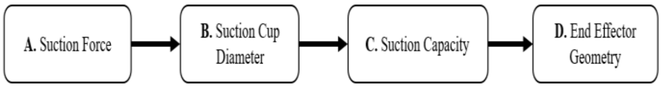

Fig. 1. Block diagram of the proposed method.

A. *Suction force*

The acceleration is determined by considering the following parameters of the industrial robot: an angular velocity on axis 1 of 128°/s and a range from the base of the robot to the final effector of 2 meters. Considering that the parameters are constant and that the transfer of the end effector is carried out from one point A to another point B in a circular and continuous manner, the acceleration generated by the following formula is calculated.

$$a = \frac{Vf^2 - Vi^2}{2 \times L_1} \quad (1)$$

Where a is the acceleration of the end effector, Vf is the final linear velocity of the end effector (m/s), Vi is the initial linear velocity of the end effector (m/s) and L_1 is the distance traveled by the end effector (m).
Knowing that the initial linear velocity is 0 m/s and the final linear velocity is $4.468\, m/s$, with a distance traveled of $6.283\, m$. Replace the values in (1) and get (2).

$$a = 0.356\, m/s^2 \quad (2)$$

The theoretical grip force is expressed in (3).

$$F_{th} = m \times \left(g + \frac{a}{\mu}\right) \times s \quad (3)$$

Where F_{th} is the theoretical grip force (N), m is the mass of the product (Kg), g is the acceleration of gravity ($9.81\, m/s^2$), a is the acceleration of the final effector (m/s^2), μ is the coefficient of friction and s is the safety factor.
Knowing that the total mass for 30 eggs of 200 grams each is $6\, Kg$, an acceleration of the final effector of $0.356\, m/s^2$, a coefficient of friction of 0.6 and a safety factor of 3. The values in (3) are replaced and (4) is obtained.

$$F_{th} = 187.26\, N \quad (4)$$

To calculate the suction force, the homogeneous distribution of the theoretical grip force in relation to the number of objects must be considered. The suction force is expressed in (5).

$$F_s = \frac{F_{th}}{n} \quad (5)$$

Where F_s is the suction force (N), F_{th} is the theoretical grip force (N) and n is the number of suction cups. Knowing that the number of suction cups is made up of a matrix of 5x6 (30 suction cups), and that it presents a total theoretical grip force of $187.26\, N$. The values in (5) are replaced and (6) is obtained.

$$F_s = 6.242\, N \quad (6)$$

B. *Suction cup diameter*

Knowing that the maximum load that an egg can withstand is $39\, N$. The limit of the suction cup breaking force is set at (7) and (8).

$$2 \times F_s \leq Fq < 39\, N \quad (7)$$

$$12.484\, N \leq Fq < 39\, N \quad (8)$$

The effective diameter of the suction cup is calculated considering the average physical dimensions of a chicken egg of $4.4\, cm$ transverse diameter and $5.6\, cm$ longitudinal diameter. The effective diameter is expressed as (9).

$$d = 1.12 \times \sqrt{\frac{m \times S}{Pu \times n \times \mu}} \quad (9)$$

Where d is the effective diameter (cm), m is the mass of the product (Kg), S is the safety factor, Pu is the depression (bar), n is the number of suction cups and μ is the coefficient of friction.

Knowing that the total mass for 30 eggs is 6 Kg, the safety factor is 3, the depression is - 0.44 bar, the use of 30 suction cups and a coefficient of friction of 0.6 is proposed. Replace the values in (9) and get (10).

$$d = 1.688\ cm \tag{10}$$

The nominal diameter of the suction cup is expressed in (11) and (12).

$$d < D < 2 \times d \tag{11}$$

$$16.88\ mm < D < 33.76\ mm \tag{12}$$

C. Suction capacity

The connection capacity is expressed in (13).

$$V = \frac{\pi}{4} \times {D_i}^2 \times R \times \frac{1}{1000} \tag{13}$$

Where V is the connection capacity (l), D_i is the inner diameter of the tube (mm) and R is the length from the generator to the suction cup (m).
Knowing that the vacuum connection pipe has an internal diameter of 2.5 mm and a length of 2 meters. Replace the values in (13) and get (14).

$$V = 0.0098\ l \tag{14}$$

The suction flow rate is expressed in (15).

$$Q = 3 \times \left(\frac{V \times 60}{T_1} + Q_L\right) \tag{15}$$

Where Q is the suction flow rate (l/min), V is the connection capacity, T_1 is the adsorption response time of the generator (s) and Q_L are the leakage (l).
Knowing that the connection capacity is $0.0098\ L$, the adsorption time is 300 ms and it is assumed that the system does not leak. The values in (15) are replaced and (16) is obtained.

$$Q = 5.88\ l/min \tag{16}$$

The suction capacity required by the generator is expressed in (17).

$$C_A = n \times Q \tag{17}$$

Where C_A is the suction capacity required by the generator (l/min), n is the number of suction cups and Q is the suction flow rate (l/min).
Knowing that a matrix of 6 suction cups is used per vacuum generator and that the suction flow rate is 5.88 l/min. The values in (17) are replaced and (18) is obtained.

$$C_A = 35.28\ l/min \tag{18}$$

D. End effector geometry

For the design of the end-effector coupling, flange measurements of the KUKA KR 60-3 industrial robot are available. The geometry of the coupling flange is shown in Figure 2.

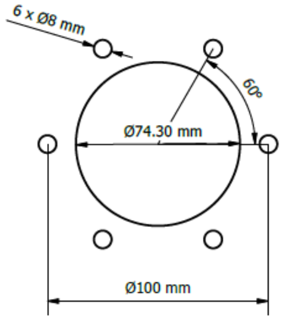

Fig. 2. Coupling flange geometry.

For the calculation of the location and separation of the coupling holes of the upper supports is, the fixing bolts, the nozzle supports and the suction flow distributor, the UNE-CR-ISO 14638:2005 standard was considered, the following relationships were established.

$$t_1 = 1.2 \times d_1 \tag{19}$$

$$t_1 \leq t_2 \tag{20}$$

$$p_1 \geq 2.2 \times d_1 \tag{21}$$

$$p_2 \geq 3.0 \times d_1 \tag{22}$$

Where d_1 is the hole diameter (mm), t_1 is the distance from the center of the hole to the front end (mm), t_2 is the distance from the center of the hole to the side end (mm), p_1 is the distance between the centers of the holes in the direction of load transmission (mm) and p_2 is the distance between the centers of the holes measured perpendicular to the direction of load transmission (mm).

Knowing the diameter of the hole and the position with respect to the transmission of the load for each case raised, the values in (19), (20), (21) and (22) are replaced, and the parameters described in the following table are defined.

TABLE I. PARAMETERS OF UBICATION AND HOLE SEPARATION OF THE UPPER PLATAFORM

Piece	Hole diameter (mm)	Parameters (mm)			
		t_1	t_2	p_1	p_2
Superior Support	20.0	24.0	24.0	252.0	X
Fixing bolts	4.0	6.0	24.0	X	252.0
Exhalation flow distributor	4.0	19.63	95.62	54.38	X
Nozzle bracket	3.0	9.2	90.0	37.19	X

Once the values are obtained, the design of the upper platform is shown in Figure 3.

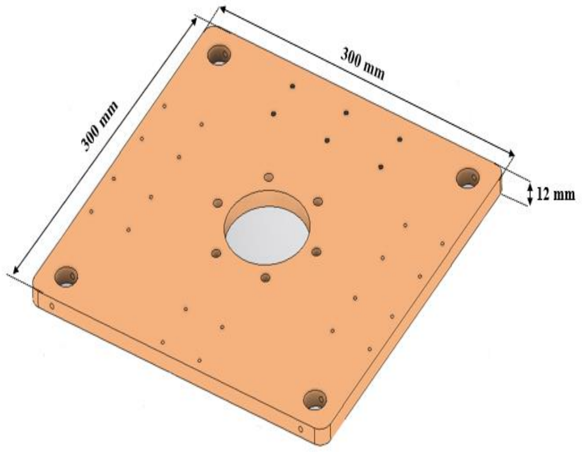

Fig. 3. Upper platform.

For the location of the holes of the suction cup holders, the schematic of the grooves of a commercial egg container is considered. Knowing the total lengths of the packaging and the symmetry between the grooves, the distance of the holes is determined by the following formulas.

$$d_x = \sum_{i=1}^{5} \frac{S(i)}{5} \quad (23)$$

$$d_y = \sum_{i=1}^{6} \frac{S(i)}{6} \quad (24)$$

Where d_x is the front distance between centers of the holes, d_y is the lateral distance between centers of the holes, and S is the distance between the centers of each groove in the package.
It has that $S = 48\ mm$ for all cases, replacing in (23) and (24) gives the relations (25) and (26).

$$d_x = 4.8\ mm \quad (25)$$

$$d_y = d_x \quad (26)$$

Knowing the diameter of the hole of the upper brackets and the suction cup holders, the values in (19), (20), (21) and (22) are replaced, and the parameters described in the following table are defined.

TABLE II. CONFIGURATION PARAMETERS AND HOLE SEPARATION OF THE LOWER PLATFORM

Piece	Hole diameter (mm)	Parameters (mm)			
		t_1	t_2	p_1	p_2
Bottom bracket	20.0	24.0	24.0	252.0	X
Suction cup holder	10.0	30.0	54.0	48.0	X

Once the values are obtained, the design of the lower platform is shown in Figure 4.

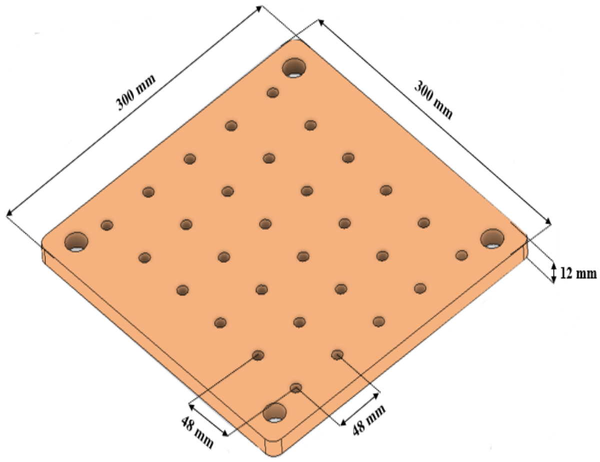

Fig. 4. Lower platform.

For the design of the upper support, the cylindrical shape of the pneumatic actuator to be used is considered. The thickness is expressed in (27).

$$E = \frac{D_C+1}{7} + 0.5 \quad (26)$$

Where E is the thickness of the area occupied by the pneumatic cylinder (mm) and D_C is the external diameter (mm).
Knowing that a cylinder with a diameter of 20 mm is used, the values in (26) are replaced and (27) is obtained.

$$E = 3.5\ mm \quad (27)$$

The diameter and height of the holder head are expressed in (28) and (29), respectively.

$$d_C = d_O - (sen^2\theta + cos^2\theta) \quad (28)$$

$$a_C = E_{PS} + 1 \quad (29)$$

Where d_C is the diameter of the head (mm), d_O is the diameter of the hole on the upper platform (mm), θ is the angle of inclination with respect to the upper platform (°), a_C is the height of the head (mm) and E_{PS} is the thickness of the upper platform (mm).
Knowing that the diameter of the hole is 20 mm, it has no angle of inclination, and the upper platform has a thickness of 12 mm. The values in (28) and (29) are replaced, and (30) and (31) are obtained.

$$d_C = 19\ mm \quad (30)$$

$$a_C = 13\ mm \quad (31)$$

For the design of the thread of the upper bracket the front cylinder head used is considered. The thread value is expressed in (32).

$$R_M = M16 \times 1.5 \quad (32)$$

Once the measurements are defined, the design of the upper support is shown in Figure 5.

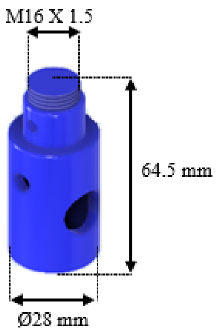

Fig. 5. Superior support.

For the design of the lower support, the diameter of the stem and the adjustment nut that will join them with the lower platform is considered. The thickness is shown in (33).

$$E_2 = \frac{D_V}{2} + 0.5 \quad (33)$$

Where E_2 is the thickness of the area occupied by the stem of the pneumatic cylinder used (mm) and D_V is the diameter of the stem (mm).
Knowing that the stem has a diameter of 6 mm. The value is replaced in (33) and (34) is obtained.

$$E_2 = 3.5\ mm \quad (34)$$

The diameter of the nut hole and the stem of the lower support are expressed in (35) and (36), respectively.

$$D_{OT} = D_T + 1.58 \quad (35)$$

$$D_{OV} = D_V + 0.5 \quad (36)$$

Where D_{OT} is the diameter of the nut hole (mm), D_T is the nut diameter (mm), D_{OV} is the diameter of the stem hole (mm) y D_V is the diameter of the stem (mm). Replace the values in (35) and (36) and get (37) and (38).

$$D_{OT} = 13\ mm \quad (37)$$

$$D_{OV} = 6.5\ mm \quad (38)$$

The height of the lower support body is expressed in (39).

$$a_{SI} = \left(\frac{e_{PI}}{2}\right) + 0.5 \quad (39)$$

Where a_{SI} height of the lower support body (mm) and e_{PI} is the thickness of the lower support (mm).

Knowing that the thickness of the lower platform is 12 mm and that the thickness of the head of the upper support is 5 mm. The values in (39) are replaced and (40) is obtained.

$$a_{SI} = 6.5\ mm \quad (40)$$

Once the measurements are defined, the design of the lower support is shown in Figure 6.

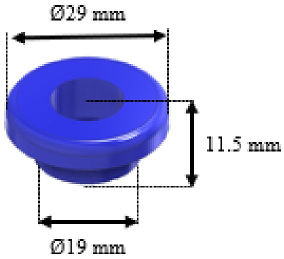

Fig. 6. Bottom support.

For the design of the suction cup support, the physical dimensions of the suction cup connection fitting and the suction cup adaptation thread are considered.
Knowing that the height and diameter of the base of the fitting are and respectively, 24.10 mm the fitting thread of the suction cup is 16.17 mm, in addition to the diameter of the hole on the lower platform and that the fitting thread of the bracket is for a nut $G1/8\ M10 \times 1$. The design of the suction cup holder is shown in Figure 7.

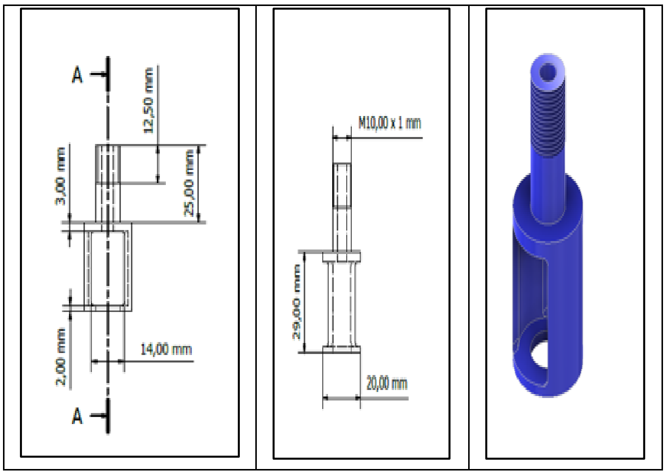

Fig. 7. Suction cup support.

For the distribution of the suction flow, it must be taken into account that the distributor block chosen is for a 4 mm diameter hose, the dimensioning and location of the adaptation holes for the distributor box, in addition to the height of the upper platform $(12\ mm)$ and the number of distributor blocks $(10\ unidades)$, the design and assembly of the suction flow distributor is shown in Figure 8.

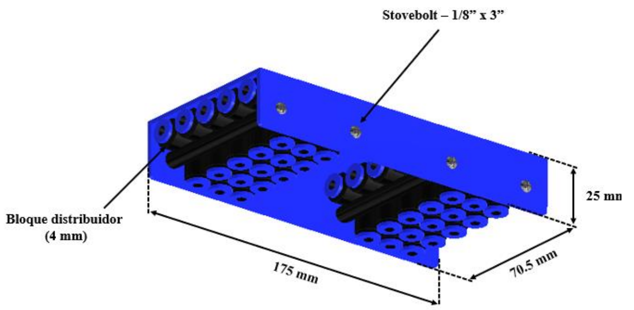

Fig. 8. Suction flow distributor.

Once the most relevant parts for the end effector design have been defined, the adaptable vacuum gripper is shown in Figure 9.

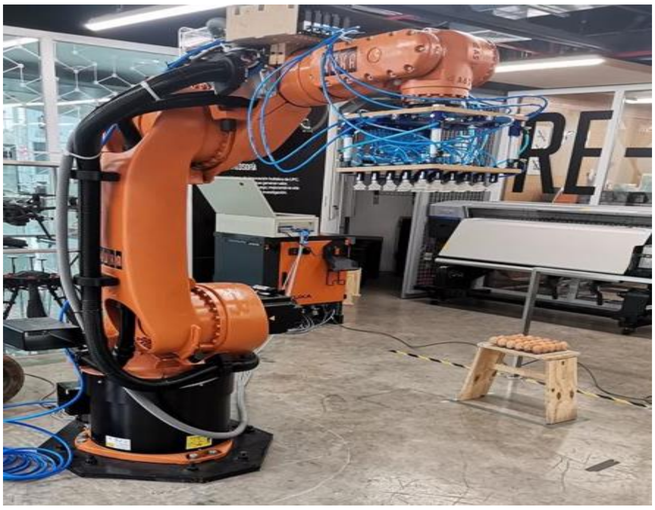

Fig. 9. Adaptable vacuum gripper final assembly.

III. RESULTS

The work environment is centered in a laboratory with a controlled environment where two reference points were set to carry out the pick and place of the eggs. The minimum packaging time was 14.46 seconds, while the maximum time is 14.91 seconds, where the real efficiency of the device is shown for the packages with the highest content, which compared to an operator the packaging time was reduced by 50%, approximately. Ten types of packing matrix with a feed pressure of 7 bar were used; each vacuum generator is limited to a maximum vacuum pressure of -44 KPa so as not to damage the eggshell. The width, length, and weight of 30 eggs that were used in the tests were measured, with tolerances of 0.05 mm and 0.1 g, highlighting the non-uniformity of the product with an average of 43,792 mm wide, 55,992 mm long and 60,427 g in weight. The number of tests and packaged eggs referring to the packaging matrix used is shown in Figure 10.

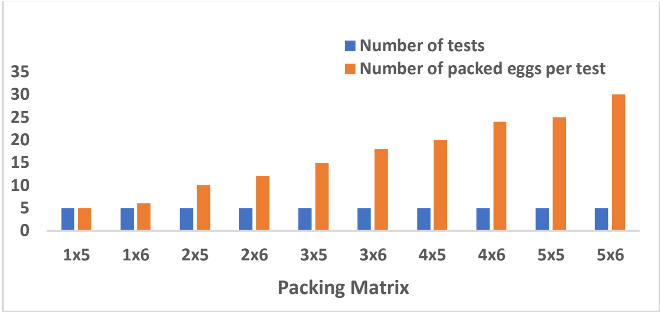

Fig. 10. Number of tests and number of packaged eggs to the packaging matrix.

Of the 40 tests carried out, a total of 660 eggs were transported distributed in the 4 tests per assigned container matrix.

The following ratio was used to obtain total efficiency.

$$Efficiency = \frac{Number\ of\ eggs\ packed}{Number\ of\ eggs\ per\ pack} \times 100 \qquad (41)$$

Knowing that the number of eggs to be packed is 660 and that the number of packaged eggs is 660, a total efficiency of 100% was obtained.

IV. CONCLUSIONS

An adaptable mechatronic device was designed for 10 types of packing matrix, with the capacity to transport a maximum of 30 eggs at a time. It is important to keep the feed pressure stable, otherwise the supply capacity will be lost. Likewise, the reference point must be fixed with high precision for the correct coupling of the product with the final effector, controlling the displacement of the gripper along the Z axis of the referential coordinate system used. On the other hand, it must be considered the state of the accessories used as a silencer is in each vacuum generator, because, if it presents obstruction in its output channel (channel 3), the suction flow will also be affected, decreasing its capacity by up to 80%. Finally, the established vacuum limit (-44 KPa) should not be exceeded, unless the surface of the product to be coupled has a higher rigidity and the verification of the operation of the system is carried out experimentally.

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VI. REFERENCES

[1]. Fenavi, “Consumo per cápita mundial de huevo”, Fenavi, 2019. [En línea]. Disponible: https://fenavi.org/estadisticas/consumo-per-capita-mundo-huevo/. [Último acceso: 20 09 2022].

[2]. Avinews, “La industria del huevo en latinoamérica, breve prespectiva”, Avinews, 09 07 2019. [En línea]. Disponible: https://avinews.com/la-industria-del-huevo-en-latinoamerica-breve-perspectiva/. [Último acceso: 20 09 2022].

[3]. Minagri, “Panorama y mercado del huevo de gallina”, Minagri, 11 2019. [En línea]. Disponible: https://cdn.www.gob.pe/uploads/document/file/438987/panorama__mercado_huevo_de_gallina.pdf . [Último acceso: 20 09 2022].

[4]. Minagri, “Producción y comercialización de productos avícolas”, Minagri, 04 2022. [En línea]. Disponible: https://siea.midagri.gob.pe/portal/phocadownload/datos_estadisticas/mensual/Avicola/2022/avicola_04_2022.pdf. [Último acceso: 20 09 2022].

[5]. Arachchige Udara, Chandrasiri Sasikala y Wijenayake Achintha. “Development of automated systems for the implementation of food processing”, Journal of Research Technology & Engineering (JRTE), vol. 3, issue 3, pp. 8-18, 2022.

[6]. Wonda Grobbelaar, Amit Verma y Vinod Kumar Shukla, “Analysing Human Robotic Interaction in the Food Industry,” Journal of Physics: Conference Series, 2nd International Conference on Smart and Intelligent Learning for Information Optimization (CONSILIO), vol. 1714, Goa, India, 2020.

[7]. Tzu-Chia Chen y Shu-Yan Yu, “The review of food safety inspection system based on artificial intelligence, image processing, and robotic,” Food Science and Technology, Campinas, vol. 42, e 35421, 2022.

[8]. S. T, P. Sreedharan y A. Prakash, “Design and Analysis of Soft Gripper for Pick and Place Operations in Food and Agricultural Industries,” 2021 International Conference on Communication, Control and Information Sciences (*ICCISc*), 2021, pp. 1-5, 2021.

[9]. H. Jiang, N. Tang, D. Huang y C. Zhang, “The Design and Analysis of Automatic Egg Packing Manipulator,” International Conference on Control, Automation and Systems Engineering (*CASE*), 2011, pp. 1-3, doi: 10.1109/ICCASE.2011.5997579.

[10]. Zhongkui Wang, Keung Or y Shinichi Hirai, “A dual-mode soft gripper for food packaging,” Robotics and Autonomous Systems, Volume 125, 2020, 103427, ISSN 0921-8890, doi: 10.1016/j.robot.2020.103427.

[11]. Amal Prakash, Anikesh Rajendran, VK Pranav y Pramod Screedharan, “Design, Analysis, Manufacturing and Testing of a SCARA Robot with Pneumatic Gripper for the Poultry Industry,” IOP Conference Series: Materials Science and Engineering, Vol. 1132, International Conference on Innovations in Mechanical Sciences (*ICIMS*), 2021, Kerala, India.

[12]. Jamaludin, AS, M. Razali, MN, Jasman, N., A. Ghafar, AN y A. Hadi, M. (2020). “Designo f spline surface vacuum gripper for pick and place robotic arms”. *Journal of Mdern Manufacturing Systems and Technology*, *4* (2), 48–55. https://doi.org/10.15282/jmmst.v4i2.5181

[13]. Gabriel, F., Fahning, M., Meiners, J. *et al.* Modeling of vacuum grippers for the design of energy efficient vacuum-based handling processes. *Prod. Eng. Res. Devel.* **14**, 545–554 (2020). https://doi.org/10.1007/s11740-020-00990-9

[14]. R. G. V. Andrade and L. Vinces, "A Comparative Analysis of Kinematics of Industrial Robot KUKA KR 60–3 Using Scientific Computing Languages," 2020 Asia Conference on Computers and Communications (ACCC), 2020, pp. 114-119, doi: 10.1109/ACCC51160.2020.9347897.

[15]. Alejandro, D., Matos, J., Vinces, L., Mirko, H. (2022). Analysis of an Automated System in a Robotized Cell for the Transport, Control, Classification, and Organization of Heterogeneous Packages. In: Iano, Y., Saotome, O., Kemper Vásquez, G.L., Cotrim Pezzuto, C., Arthur, R., Gomes de Oliveira, G. (eds) Proceedings of the 7th Brazilian Technology Symposium (BTSym’21). BTSym 2021. Smart Innovation, Systems and Technologies, vol 295. Springer, Cham. https://doi.org/10.1007/978-3-031-08545-1_45

[16]. Chicoma, M.U., Escobar, D.S., Vinces, L. (2022). Large-Scale FDM 3D Printing in 6 Degrees of Freedom on One ARM KUKA KR 60. In: Iano, Y., Saotome, O., Kemper Vásquez, G.L., Cotrim Pezzuto, C., Arthur, R., Gomes de Oliveira, G. (eds) Proceedings of the 7th Brazilian Technology Symposium (BTSym’21). BTSym 2021. Smart Innovation, Systems and Technologies, vol 295. Springer, Cham. https://doi.org/10.1007/978-3-031-08545-1_53

[17]. Andrade, R.G.V., Vinces, L. & Lau, K. A modular mechatronic gripper installed on the industrial robot KUKA KR 60-3 for boxing, unpacking and selecting of beverage bottles. Int J Interact Des Manuf (2022). https://doi.org/10.1007/s12008-022-00879-0