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Flow Investigation Inside the Vacuum Gripper for Labeling Application with Dimensions of 100 mm × 100 mm Using the CFD Method

Investigasi Aliran di Dalam Vacuum Gripper untuk Aplikasi Perekatan Label Ukuran 100 mm x 100 mm dengan Metode CFD

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Abstract

Nowadays, the application of automation in the manufacturing sector is important to increase production efficiency. One of the variations in industrial automation is the vacuum gripper. Vacuum grippers are specifically designed to handle specific workpieces, such as labeling application. Label characteristics that easily bend and stick to the workpiece when peeled off require a specific gripper. This research was carried out using 2 methods, experimental method and CFD simulation method. The experimental method was carried out by collecting pressure data with Arduino. Data from this experiment will be used for the CFD simulation. Based on these experimental tests, the average vacuum pressure obtained was -44.372 kPa. From the simulation vacuum pressure on the 12 inlet holes was obtained. The largest vacuum pressure was at inlet 12 with a vacuum pressure value of -44372.11 Pa, while the smallest was at inlet hole 1 with a value of -44371.86 Pa. The pressure distribution is evenly distributed at all the suction point and has suited the design requirements.

Keywords: automation, vacuum gripper, label.

***SDGs*:**

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Abstrak

Saat ini penerapan otomasi pada sektor manufaktur menjadi penting dalam meningkatkan efisiensi produksi. Salah satu variasi dalam otomasi industri adalah *vacuum gripper*. *Vacuum gripper* dirancang khusus untuk menangani benda kerja tertentu, seperti aplikasi pelabelan. Label memiliki karakteristik yang mudah tertekuk dan akan menempel pada permukaan memerlukan *vacuum gripper* khusus. Penelitian ini dilakukan dengan 2 metode, yaitu metode pengujian eksperimental dan simulasi CFD. Data dari eksperimen tersebut nantinya akan digunakan untuk proses simulasi CFD. Berdasarkan pengujian eksperimen tersebut didapatkan tekanan vakum sebesar -44,372 kPa. Dari simulasi diperoleh tekanan vakum terbesar terdapat pada inlet 12 dengan nilai tekanan vakum sebesar -44372,11 Pa, sedangkan nilai terkecil terdapat pada lubang *inlet* 1 dengan nilai -44371,86 Pa. Tekanan terdistribusi merata pada seluruh *suction point* dan desain yang dibuat sesuai dengan kebutuhan.

Kata Kunci: otomasi, *vacuum gripper*, label.

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1. INTRODUCTION

Advances in automation technology, especially in the manufacturing sector, continue to develop to increase production efficiency in this industry and avoid health hazards (Phuyal, Bista and Bista, 2020). There are many variations of industrial systems developed, especially in the mechanical and automation sectors (Michael, Halim and Irawan, 2020). One of the variations is a vacuum gripper. The vacuum gripper is an important component of the robot manipulator which is installed at the end of the arm for object handling. Robotic end effectors or vacuum grippers were developed for increased flexibility and multifunctional approach, to expand the potential application fields (Jaiswal and Kumar, 2017; Papadakis *et al.*, 2020). This system is used especially in industries where handling workpieces is difficult due to variations in workpieces such as size, shape, and mechanical properties (Wang, Makiyama and Hirai, 2021).

There are 2 key performance indicators in vacuum gripping systems, the evacuation time and the energy consumption or the gripping force retrieve from the vacuum level in the system (Stegmaier *et al.*, 2023). Apart from that there are important factors that can reducing vacuum efficiency. Vacuum pressure efficiency may decrease due to leaks. Leaks can be caused by the surface of the vacuum gripper not being completely closed, a gap between the workpiece and the vacuum gripper, and connectors that are not installed tightly (Lee *et al.*, 2022).

Many researchers have worked on vacuum gripper. Hirose and Umetani, have developed soft gripper for versatile robot hand which compatible with various object (Hirose and Umetani, 1978). Pham and Yeo, have developed a knowledge-based system for gripper selection criteria and surface for grippin (Pham and Yeo, 1988). Urbano et al., have designed vacuum gripper for manipulate and assemble very small objects at the micro and nanoscale range with speed and precision, called microgrippers (Urbano *et al.*, 2021). Based on the previous research, the vacuum gripper needs to be designed specifically. The design of the gripper used is greatly influenced by the workpiece to be lifted. In this research the vacuum gripper is used for labelling application. The existing vacuum gripper model could not be used for labels, so a new vacuum gripper was designed at a low cost.

Affixing labels is a repetitive job, so implementing an automation system will increase production efficiency. PT. Matahari Megah, a company that designs and manufactures customized automatic machines, applies vacuum gripper technology to one of their products, which is assembly robot gripper. The assembly robot gripper is used to attach labels to cardboard packaging. Label characteristics that can easily bend and stick to the workpiece when peeled off require a specific gripper to properly lift the label with dimensions of 100 mm × 100 mm, and weight of 0.5 grams. If using a vacuum gripper with a suction cup that is already on the market, deformation will occur on the label and there is a possibility of bending during installation. If using special vacuum gripper for the label, the price offered is very high compared to a regular vacuum gripper. Therefore, it is necessary to design a new vacuum gripper that can lift labels and has a flat surface, so that label installation on cardboard can be done properly.

Computational fluid dynamics (CFD) is a simulation method to determine the characteristics of airflow that occurs in a chamber. This simulation method is applied to evaluate the system design. The design affects the ability of the vacuum gripper to lift the label and the speed of evacuation time to create a vacuum throughout the chamber. Having the evenly distributed on each inlet of the vacuum gripper will allow the label to be lifted completely and minimize the possibility of the label detaching from the gripper during the process of attaching it to the cardboard packaging. To prove that the CFD simulation carried out is correct or not, a validation stage is required. Validation is carried out with data captured by experimental testing. Experimental testing consists of collecting data on vacuum pressure with data acquisition.

The design of the vacuum gripper is very important, if there is a failure in label installation it will cause productivity to decrease, because the production process stops, and it can even damage the robot arm. This research aims to generate a design vacuum gripper that can apply labels to cardboard packaging without causing the label to deform.

2. METHODOLOGY

This research was carried out using 2 methods, experimental method and CFD simulation method. The experimental method was carried out by collecting data with Arduino. Data from this experiment will be used for the CFD simulation with Ansys 2023 R1 Student Version. CFD simulation method used to evaluate the system design. Research flow chart is shown in Figure 1.

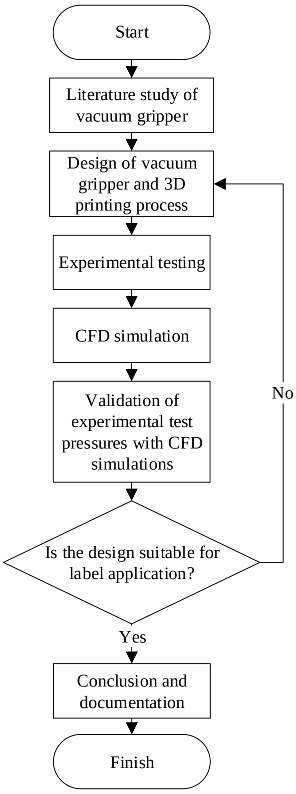

Figure 1. Flow chart.

2.1. Experimental Test

The vacuum gripper will be installed at the end of the robot arm as shown in Figure 2. The label that comes out of the printer will be sucked by the vacuum gripper and attached to the cardboard packaging.

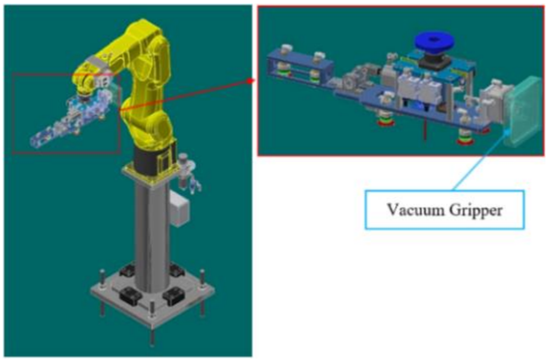

Figure 2. Assembly robot gripper.

Experimental testing was carried out by measuring the pressure when the label was on a vacuum gripper. The Arduino UNO board will be used for data acquisition of analog data from the pressure transducer. Arduino will change the output in voltage between 1-5 VDC into an analog reading value between 0-1023, then this value will be processed with code that has been created with the Arduino IDE software. The targeted pressure to lift the label is -44 kPa. The Arduino will be connected to a vacuum gripper that has been printed with a 3D printer, vacuum generator, and pressure transducer. The experimental test scheme is shown in Figure 3.

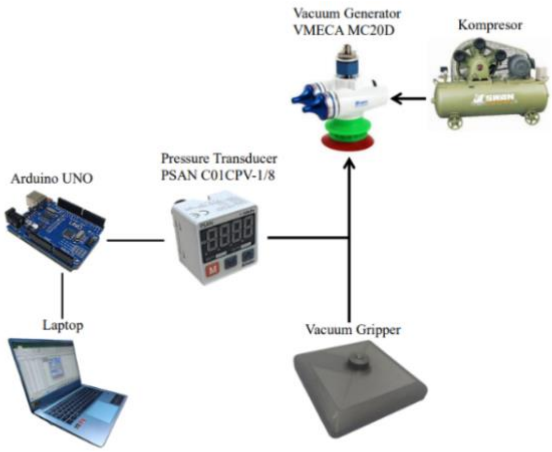

Figure 3. Experimental test scheme.

The basic principle of pneumatic pressure is that the air is distributed in all directions and spread throughout the system. The vacuum pressure formula is defined as (Alipour, Shahgholi and Jahanbakhshi, 2022):

$$P = F / A \qquad (1)$$

where:

P = Pressure (Pa)
F = Force (N)
A = Area (m^2)

2.2. CFD Simulation

The vacuum gripper geometric model that would be simulated has a shape like a pipeline using the converging-diverging nozzle concept at each inlet. This vacuum gripper design has 1 outlet hole and 12 inlet holes. The vacuum gripper geometric model is shown in Figure 4.

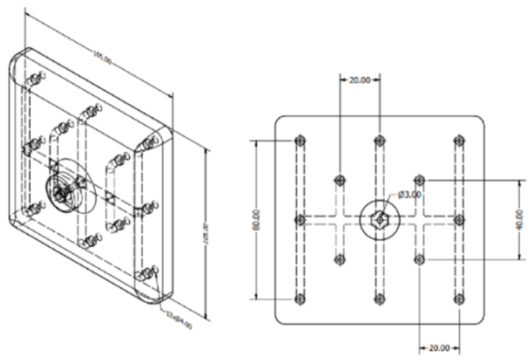

Figure 4. Geometric model of vacuum gripper.

The simulation would be carried out with conditions shown in Figure 5. There was a domain with dimensions of 150 mm × 150 mm × 75 mm. After the geometry is created, the meshing process is carried out. Meshing is the process of dividing a domain into small elements. The mesh very important in CFD simulations, the choice of mesh shape and size will influence the simulation results. The better the quality of the mesh created, the higher the level of convergence (Lintermann, 2021). The type of mesh used for the vacuum gripper is polyhedra. From meshing process was obtained the mesh size of 1,633,573 nodes; 2,181,054 faces; and 390,840 cells. The number of mesh configurations is sufficient to accommodate the flow phenomena that occur in the vacuum gripper and has a logical computing time. The domain and volume parts were defined as fluid, while the vacuum gripper body part was defined as solid. Vacuum gripper mesh is shown in Figure 6.

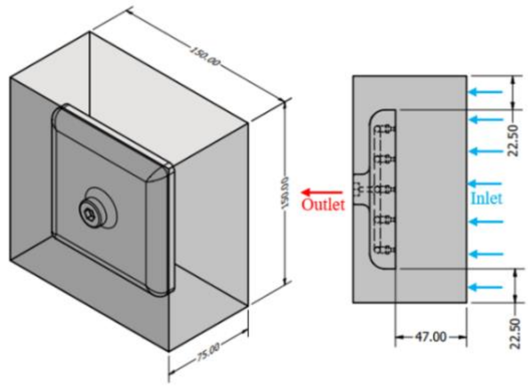

Figure 5. CFD Simulation domain.

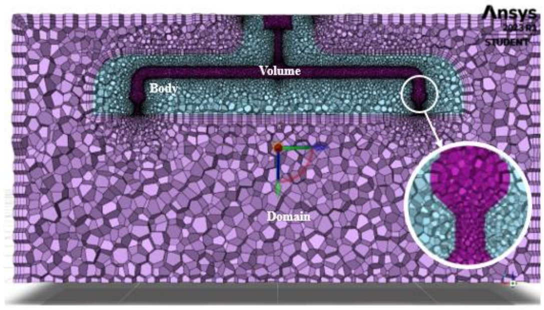

Figure 6. Vacuum gripper mesh.

The computational fluid dynamics (CFD) simulation procedure was carried out with Ansys Fluid Flow (Fluent with Fluent Meshing) software. The simulation was carried out with 3D dimension conditions, the type of solver used was Pressure-Based in steady time conditions, the viscous model used was Standard k-ε, the fluid used was single phase air with a density of 1,225 kg/m^3, a viscosity of 1.7894 x 10^{-5} kg/m-s, and a temperature of 15 °C. The solid material used for the vacuum gripper is onyx with a density of 1200 kg/m^3 (Sanei, Arndt and Doles, 2020). The boundary conditions for inlet and outlet are set as pressure. The inlet pressure gauge is set at 0 Pa, while the outlet pressure was obtained by experimental testing.

The Standard k-ε turbulence model developed by Launder & Spalding is a two-equation (RANS-based) turbulence model, consisting of k and ε transport equations for handling turbulence kinetic energy and dissipation respectively (Darmawan and Tanujaya, 2019).

k transport equation

$$\frac{Dk}{Dt} = \frac{1}{\rho}\frac{\partial}{\partial x_k}\left[\frac{\mu_T}{\sigma_K}\frac{\partial \kappa}{\partial x_k}\right] + \frac{\mu_T}{\rho}\left(\frac{\partial U_i}{\partial x_k} + \frac{\partial U_k}{\partial x_i}\right)\frac{\partial U_i}{\partial x_k} - \varepsilon \quad (2)$$

ε transport equation

$$\frac{D\varepsilon}{Dt} = \frac{1}{\rho}\frac{\partial}{\partial x_k}\left[\frac{\mu_T}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_k}\right] + \frac{C_1\mu_T}{\rho}\frac{\varepsilon}{k}\left(\frac{\partial U_i}{\partial x_k} + \frac{\partial U_k}{\partial x_i}\right)\frac{\partial U_i}{\partial x_k} - C_2\frac{\varepsilon^2}{k} \quad (3)$$

3. RESULTS AND DISCUSSION

3.1. Experimental Test Result

The vacuum system works intermittently by attaching and removing labels Figure 7. Based on experimental testing was obtained vacuum pressure graph shown in Figure 8. From this graph, the pressure in vacuum conditions is between -44 kPa to -44.7 kPa with a digital value of 437 to 434. The average vacuum pressure from the experimental test was -44,372 kPa. The experimental test setup is show in Figure 9.

Apart from the vacuum pressure, the time needed to condition the vacuum gripper to reach vacuum condition (evacuation time) was obtained. The faster the evacuation time will increase the energy efficiency of each cycle and make production process more efficient (Gabriel, Bobka and Dröder, 2020). From Figure 10 the average evacuation time required to lift a label once was 0.63 seconds.

Figure 7. Label lifted.

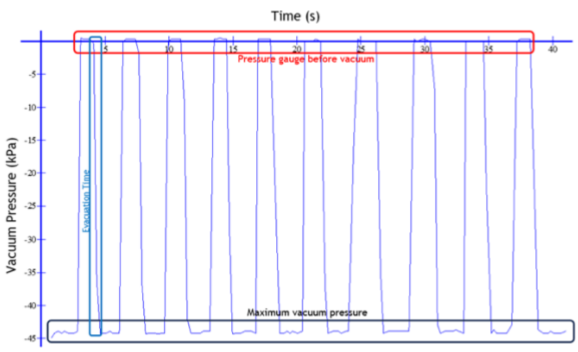

Figure 8. Experimental vacuum pressure graph.

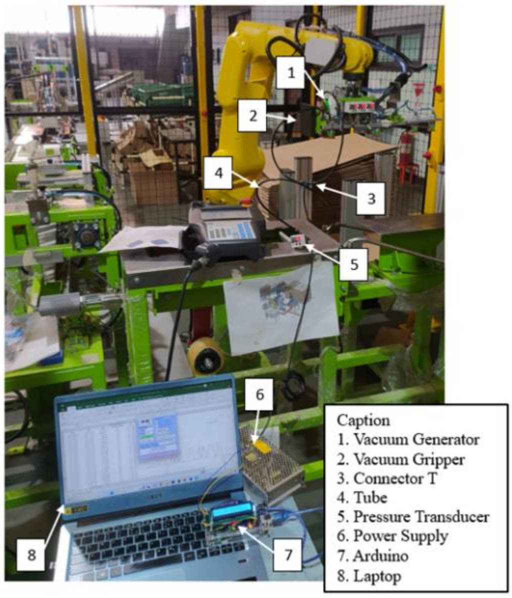

Figure 9. Experimental test setup.

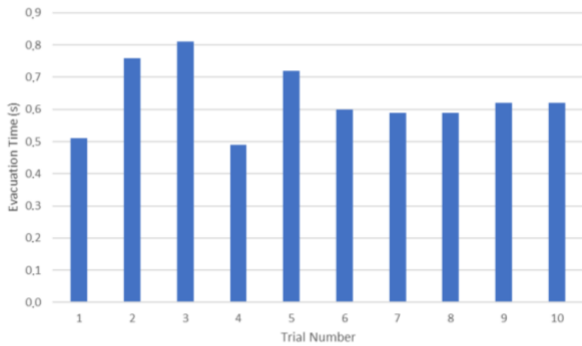

Figure 10. Evacuation time.

3.2. CFD Simulation Result

The CFD simulation was carried out with an average value of outlet pressure when it reached the vacuum condition of -44372 Pa. The simulation was using Ansys Student 2023 R1 on an Acer Swift SF3124-41 laptop with an AMD Ryzen 5 3500U with Radeon Vega Mobile processor. The results of the CFD simulation were contour pressure and contour velocity.

Contour pressures were used to determine the amount of vacuum pressure that occurs at each inlet hole and pipeline in the vacuum gripper. The highest vacuum pressure was produced at inlet 12 with a value of -44372.11 Pa, while the smallest vacuum pressure value was produced at inlet 1 with a value of -44371.86 Pa. Meanwhile, at other inlet holes the vacuum pressure was between -44371.92 Pa to -44372.09 Pa. Base on simulation it is known that the pressure at each 12 inlet holes of vacuum gripper is even. With evenly distributed pressure it shows that there was no leak in the vacuum system, so each inlet holes will grip each side of the label and create strong gripping stability on the vacuum gripper so that the label installation process can be carried out properly (Yaqub *et al.*, 2021). The pressure contour at the inlet of the vacuum gripper is shown in Figure 11.

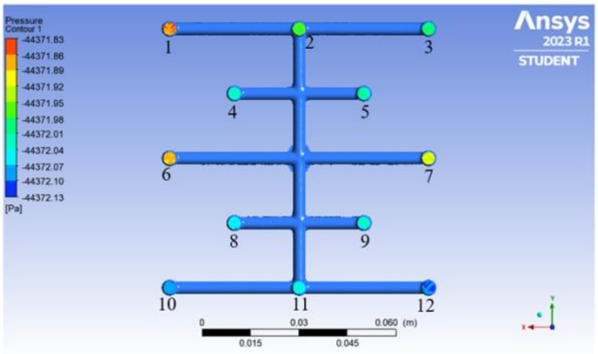

Figure 11. Pressure contour at the inlet of the vacuum gripper.

In the vacuum gripper line, the highest vacuum pressure reached was -44372.11 Pa at the inlet line with blue color, while the lowest vacuum pressure reached was -44371.86 Pa at the inlet line with red color. The overall vacuum pressure value in the vacuum gripper pipeline was not much different from the pressure value at the outlet of -44372 Pa. This even pressure can be achieved because the shape of the inner vacuum gripper has a symmetrical shape with 12 inlet holes. The pressure contour of the vacuum gripper pipeline is shown in Figure 12.

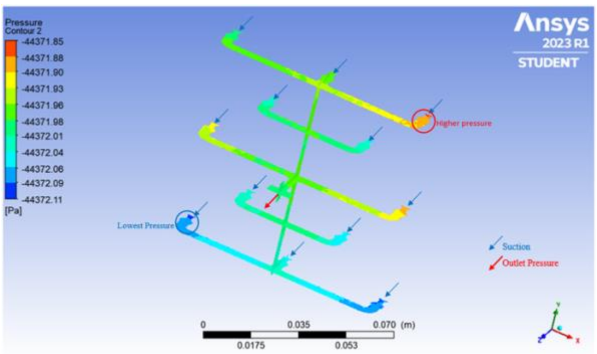

Figure 12. The pressure contour of the vacuum gripper pipeline.

The flow velocity in the vacuum gripper line is also important, so to find out the airflow velocity pattern in the vacuum gripper, a velocity contour was created. From the simulations, the airflow velocity in the vacuum gripper was between 0.0256 m/s to 0.0897 m/s, with a maximum velocity reaching 0.1571 m/s at several points. The flow pattern that occurs in the vacuum gripper with small diameter pipe is irregular or turbulent, this is due to increased friction in the air close to the wall (Leschziner, 2020).

Based on Bahamon and Martinez, the inlet design using the converging-diverging nozzle concept causes a significant increase in velocity due to the law of conservation of mass, from 0.0129 m/s to 0.0647 m/s and continues to increase when passing through the throat to the diverging section (Bahamon and Martinez, 2023). So that the pressure along the line becomes low and vacuum condition can be achieved. The contour velocity of the vacuum gripper pipeline is shown in Figure 13.

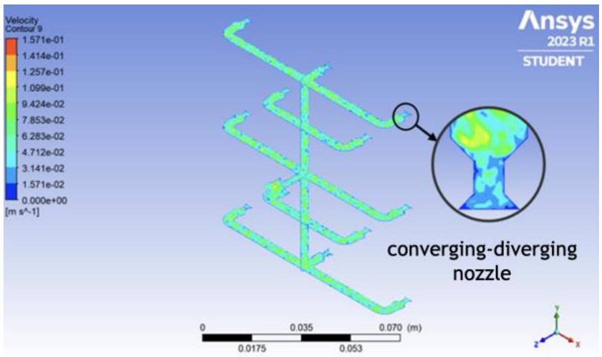

Figure 13. The contour velocity of the vacuum gripper pipeline.

From the results of the CFD simulation, validation is needed to find out whether the simulation carried out was correct and accurate. The validation method that can be carried out by comparing the results of CFD simulations with experimental testing. To achieve a vacuum condition, the pressure in a chamber must be the same (Suprapto and Widodo, 2017). So, it can be said that the pressure at each inlet is the same as the outlet pressure obtained from experimental tests with an average of -44372 Pa.

Table 1. Comparison of experimental vacuum pressure with CFD simulation.

Inlet	CFD Simulation Pressure (Pa)	Experimental Pressure (Pa)	Deviation (Pa)	Sample Standard Deviation (Pa)	%
1	-44371.86	-44372	0.14	0.042	0.00010
2	-44371.97		0.03	0.009	0.00002
3	-44371.98		0.02	0.006	0.00001
4	-44372.03		0.03	0.009	0.00002
5	-44372.02		0.02	0.006	0.00001
6	-44371.88		0.12	0.036	0.00008
7	-44371.92		0.08	0.024	0.00005
8	-44372.06		0.06	0.018	0.00004
9	-44372.03		0.03	0.009	0.00002
10	-44372.09		0.09	0.027	0.00006
11	-44372.03		0.03	0.009	0.00002
12	-44372.11		0.11	0.033	0.00007

Table 1 is shown the difference between the experimental pressure values and the CFD simulation results. The pressure difference is most visible in the 5 inlet holes, namely inlet 1, inlet 6, inlet 7, inlet 10, and inlet 12. The largest deviation value occurs in inlet 1 with a sample standard deviation of 0.042 Pa or 0.00010%. In the simulations that have been carried out, there are deviations or differences in pressure values, but these differences are very small with a percentage below 5%. So that it can be said that the pressure on the inlet surface is even and the simulation that has been carried out is accurate (Lintermann, 2021).

4. CONCLUSION

Based on the simulation, the pressure at each gripper vacuum inlet is even, with the vacuum pressure produced on each inlet being about -44372 Pa. The largest vacuum pressure was at inlet 12 with a value of -44372.11 Pa, while the smallest vacuum pressure value was at inlet 1 with a value of -44371.86 Pa. When compared with the pressure in experimental testing with a vacuum pressure of -44372 Pa. The largest deviation is at inlet hole 1 with a sample standard deviation of 0.042 Pa or 0.0001%. So that it can be said that the simulation carried out is accurate and correct. In this way, the design of the vacuum gripper that has meet the design requirements and can be used to attach labels to cardboard.

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REFERENCES

Alipour, N., Shahgholi, G. and Jahanbakhshi, A. (2022) 'Evaluation and comparison and the performance of pressurized and vacuum cylindrical distributors in soybean cultivation', *Results in Engineering*, 16, p. 100546.

Bahamon, J. and Martinez, M. (2023) 'Study of Fluid-Dynamic Behavior In A Convergent-Divergent Nozzle by Shape Optimization using Evolutionary Strategies Algorithms', in *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*. *The Institution of Mechanical Engineers*, Los Angeles, USA: The Institution of Mechanical Engineers (12), pp. 2844–2862.

Darmawan, S. and Tanujaya, H. (2019) 'CFD Investigation of Flow Over a Backward-facing Step using an RNG k-? Turbulence Model', *International Journal of Technology*, 10(2), pp. 280–289.

Gabriel, F., Bobka, P. and Dröder, K. (2020) 'Model-Based Design of Energy-Efficient Vacuum-Based Handling Processes', *Procedia CIRP*, 93, pp. 538–543..

Hirose, S. and Umetani, Y. (1978) 'The Development Of Soft Gripper For The Versatile Robot Hand', *Mechanism and Machine Theory*, 13(3), pp. 351–359.

Jaiswal, A.K. and Kumar, B. (2017) 'Vacuum Gripper-an Important Material Handling Tool', *International Journal of Science & Technology*, 7(1), pp. 1–8.

Lee, S.H. *et al.* (2022) 'Passive air leakage detection mechanism for enhanced vacuum suction actuator efficiency', *Microsystem Technologies*, 28(10), pp. 2353–2359.

Leschziner, M.A. (2020) 'Friction-Drag Reduction by Transverse Wall Motion – A Review', *Journal of Mechanics*, 36(5), pp. 649–663.

Lintermann, A. (2021) 'Computational Meshing for CFD Simulations', in K. Inthavong et al. (eds) *Clinical and Biomedical Engineering in the Human Nose: A Computational Fluid Dynamics Approach*. Singapore: Springer, pp. 85–115.

Michael, V., Halim, A. and Irawan, A.P. (2020) 'Design of pick and place and color sorting system using VDI 2221', in *IOP Conference Series: Materials Science and Engineering. 3rd Tarumanagara International Conference of the Applications of Technology and Engineering (TICATE) 2020*, Jakarta, Indonesia: Universitas Tarumanagara, p. 012165.

Papadakis, E. *et al.* (2020) 'On the Use of Vacuum Technology for Applied Robotic Systems', in *6th International Conference on Mechatronics and Robotics Engineering (ICMRE). 2020 6th International Conference on Mechatronics and Robotics Engineering (ICMRE)*, pp. 73–77.

Pham, D.T. and Yeo, S.H. (1988) 'A knowledge-based system for robot gripper selection: criteria for choosing grippers and surfaces for gripping', *International Journal of Machine Tools and Manufacture*, 28(4), pp. 301–313.

Phuyal, S., Bista, D. and Bista, R. (2020) 'Challenges, Opportunities and Future Directions of Smart Manufacturing: A State of Art Review', *Sustainable Futures*, 2, p. 100023.

Sanei, S.H., Arndt, A. and Doles, R. (2020) 'Open Hole Tensile Testing of 3D Printed Continuous Carbon Fiber Reinforced Composites', *Journal of Composite Materials*, 54(20), pp. 2687–2695.

Stegmaier, V. *et al.* (2023) 'A Behavior Model for Digital Twins of Vacuum Suction Cups', *Procedia CIRP*, 118, pp. 958–963.

Suprapto and Widodo, S. (2017) *Pengenalan Teknologi Vakum*. 1st edn. Yogyakarta, Indonesia: Pustaka Pelajar. [Print].

Urbano, D.G. *et al.* (2021) 'A Semi-Empirical Fluid Dynamic Model of a Vacuum Microgripper Based on CFD Analysis', *Applied Sciences*, 11(16), p. 7482.

Wang, Z., Makiyama, Y. and Hirai, S. (2021) 'A Soft Needle Gripper Capable of Grasping and Piercing for Handling Food Materials', *Journal of Robotics and Mechatronics*, 33(4), pp. 935–943.

Yaqub, K. *et al.* (2021) 'Design, Simulation and Implementation of An Efficient Vacuum System and Gas Load Calculations for A 6 Mev Industrial LINAC', *Vacuum*, 187, p. 110151.