REDUCTION OF LOW VACUUM PRESSURE READING ON VACUUM PROCESSOR ASSEMBLY OF MATRIX PNP HEAD THROUGH 4M+1E ANALYSIS

Darwin B. Alcantara
Leonardo Z. Sarmiento

Automation Technology and Solutions-Engineering Department
P. IMES Corp., Block 16, Phase IV, CEZ, Rosario, Cavite
dalcantara@pimes.com.ph lsarmiento@pimes.com.ph

ABSTRACT

Vacuum pressure is of paramount importance in the pick and place process of semiconductor equipment. It serves as a critical factor in ensuring precise and reliable handling of delicate semiconductor components during assembly and manufacturing processes.

Verification of the vacuum pressure in the Matrix pick and place head is a critical aspect of maintaining consistent performance and ensuring the system operates within the specified range. The vacuum processor assembly in the Matrix PnP Head requires a regulated clean dry air inlet pressure of 27 PSI, with a vacuum output requirement of ≥24 in-Hg. However, one of the challenges is to consistently achieve the ≥24 in-Hg vacuum pressure output using the designated 27 PSI inlet pressure during vacuum pressure testing. This paper's objective is to address the issue of low vacuum pressure readings that fall below the required threshold of ≥24 in-Hg during testing. The goal is to establish that consistently achieving ≥24 in-Hg cannot be realized and, as a result, define a new vacuum pressure output requirement that does not compromise the product's reliability and performance on the end-user's side.

1. 0 INTRODUCTION

The contract manufacturing of semiconductor equipment involves assembling and testing complex components that are critical to the semiconductor manufacturing process. As a contract manufacturer, relying on accurate testing processes to ensure the quality and reliability of the manufactured equipment is important. The Vacuum Processor Assembly of Matrix PNP Head has experienced occurrences of defects, specifically low vacuum pressure readings during vacuum pressure verification testing. These issues have led to downtime and scrap generation. Figure 1 displays the trend data from January 2021 to January 2023 for the low vacuum pressure defect, which shows a clear upward trend in occurrences. To address this matter, a series of experimentations will be conducted to identify the contributing factors. Subsequently, appropriate corrective actions will be taken to mitigate the low vacuum pressure issue, ensuring improved performance and product quality.

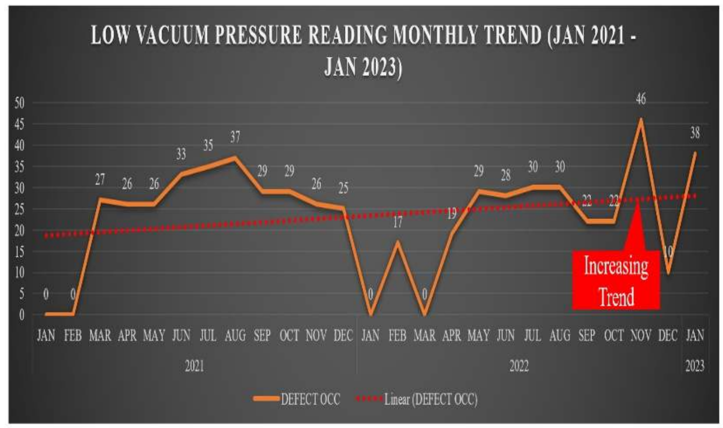

Figure 1. Low Vacuum Pressure Reading Defect Occurrence

2.0 THEORY OF OPERATION

2.1 Matrix Pick and Place Head

A Matrix Pick and Place Head (PnP) is shown in Figure 2. It precisely pick devices from a tray or boat having one XY pitch spacing between device pockets and then precisely place the devices in a tray or boat having a different XY pitch spacing between pockets. The heads contain 2 rows of pick tips. The front row tip spacing is adjustable in X Pitch, but fixed in Y Pitch. The rear row is adjustable in both X and Y Pitch. The two rows have independent X pitch drive.

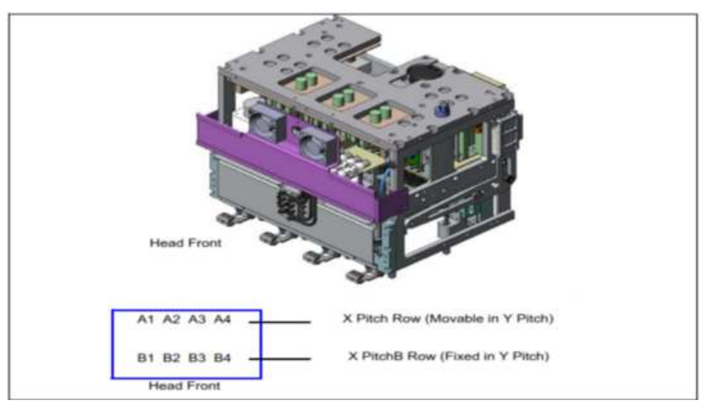

Figure 2. Matrix Pick and Place Head

A Matrix Pick and Place Head (PnP) have 8 Pick body assemblies, arranged in two x-pitch rows (B1 to B4 and A1 to A4). Each of the 2 X-pitch rows has its own X-pitch motor, and the 2 motors are driven independently of one-another. The pick bodies which is mainly responsible for picking the devices from a tray, have a pick tips.

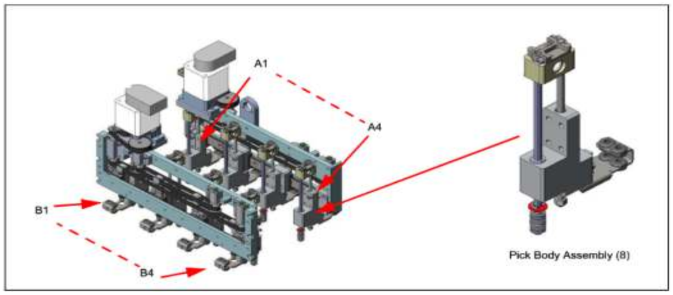

Figure 3. Pick Body Assembly

2.2 Vacuum/Blow-Off Pneumatic Flow of Matrix PnP Head

The ability to pick-and-place devices is accomplished using vacuum and blow-off pressure. As individual pick tips are lowered to pick devices, vacuum pressure is switched on to the pick tips. As a pick tip makes contact with a device, the vacuum pressure "sticks" the device to the pick tip. This vacuum pressure continues to be applied as the pick tip retracts and the head moves to the place position. During place operation, the pick tip is lowered. As the device contacts the pocket, the vacuum pressure is switched off, and blow-off pressure is applied to rapidly disengage the pick tip from the device and blow the device down into the pocket.

Regulated clean dry air (CDA) flows supplied to the head for vacuum using clear pneumatic tube and blow-off. The vacuum supply is fed to a manifold with 8 vacuum Venturis which generate the individual vacuum supplies for the 8 pick tips. These Venturi outputs are routed to the 8 vacuum-blow off solenoid valves (SV15). The outputs are also routed separately to 8 vacuum sensors. The blow-off supply is also fed to a manifold, and 8 outputs are also fed to the SV15 valves. The solenoid valves are controlled from the PC via CANopen messages, which are acted on by the DIO3232 board in the head, shown in Figure 4.

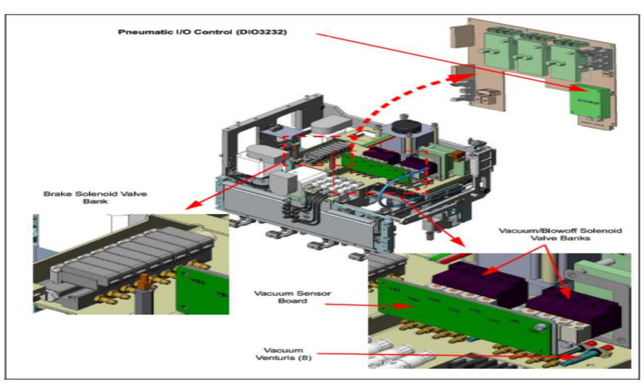

Figure 4. Pneumatic Control Components

2.3 Vacuum Processor Assembly of Matrix PNP Head

The main responsible for vacuum/blow-off pneumatic flow of Matrix PnP head is the Vacuum Processor sub-assembly. It consists of vital components such as vacuum processor manifold, vacuum Venturis, 3-port control valve, vacuum sensor board, male stud elbows, set-screw orifice, precision balls, Venturi clamp plates and fitting barbs.

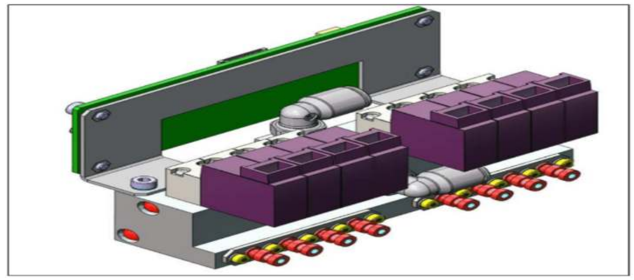

Figure 5. Vacuum Processor Assembly

2.3.1 Vacuum Processor Manifold

Vacuum processor manifold is a fabricated housing body component which mainly distribute, control, and direct the flow of gas and consolidate multiple input or output connections into a single component for vacuum processor.

Figure 6. Vacuum Processor Manifold

2.3.2 Vacuum Venturi

Vacuum Venturi or Venturi vacuum generator is a device that uses Venturi effect to create vacuum by forcing a gas through a constricted section. There are 8 vacuum Venturis in the vacuum processor.

Figure 7. Vacuum Venturi

2.3.3 3-Port Control Valve

The 3-port control valve basically controls air flow in one direction. In the event of reverse flow, it re-directs reversed air pressure flow to Blowoff Line. There are 8 control valves in the vacuum processor.

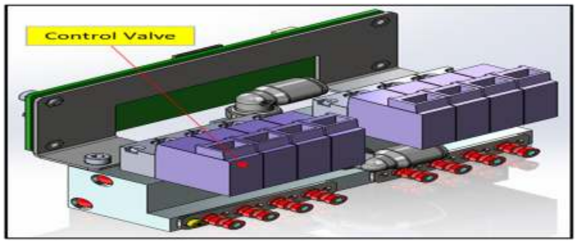

Figure 8. 3-Port Control Valve

2.3.4 Vacuum Sensor Board

These is a printed circuit board assembly where vacuum sensors are installed where the vacuum pressures are being measured.

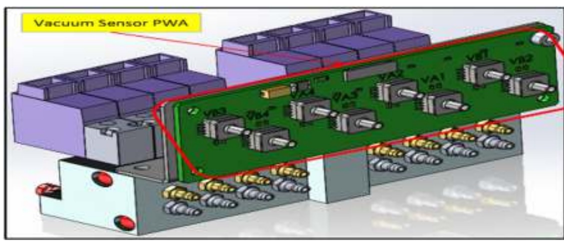

Figure 9. Vacuum Sensor Board

2.3.5 Male Stud Elbow

There are two male stud elbows in the vacuum processor of Matrix PNP Head. The first one is used to connect the pneumatic tube where the inlet pressure of regulated CDA will be supplied. The second one is used as exit for excess air pressure from blow-off line.

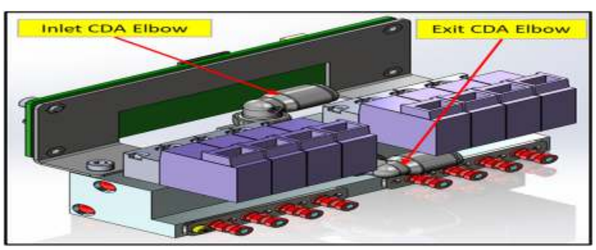

Figure 10. Male Stud Elbow

2.3.6 Set Screw Orifice

This set screw orifice restricts air flow preventing backlash of sudden pressure changes while maintaining over-pressure prevention by allowing to pass small percentage of air flow.

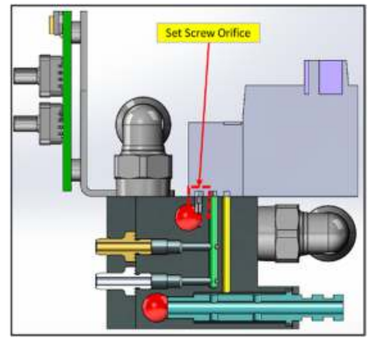

Figure 11. Set Screw Orifice

2.3.7 Precision Ball

The precision balls in vacuum processor serves as seal for high pressure line and blow-off line of vacuum processor manifold. There are four precision balls in the vacuum processor.

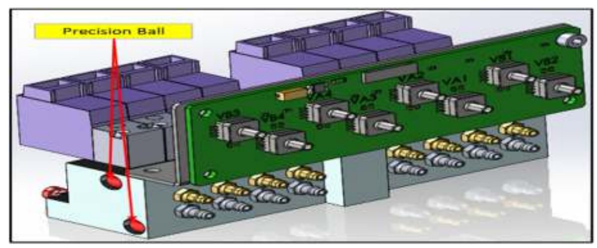

Figure 12. Precision Ball

2.3.8 Venturi Clamp Plate

Venturi clamp plate is used to cover and hold the Venturi vacuums. There are two plates in the vacuum processor.

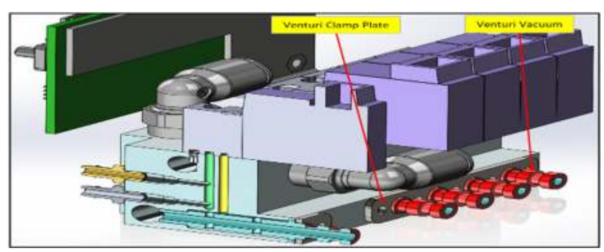

Figure 13. Venturi Clamp Plate

2.3.9 Fitting Barb

There are two types of fitting barbs in the vacuum processor which are both installed in the low-pressure line. The first one is the fitting barbs for tube connection to vacuum sensors. The second one is used for tube connection going to pick body. There are total of 16 fitting barb, 8 each in the vacuum processor.

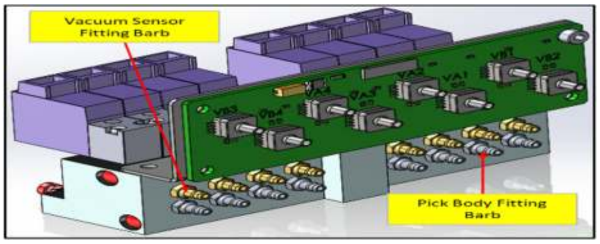

Figure 14. Fitting Barb

2.4 Testing Procedure of Vacuum Processor Assembly

Vacuum processor assembly has several test steps to be done in order to make sure reliability and efficiency of pick and place process. One of the test steps specific to vacuum pressure reading is the vacuum pressure test.

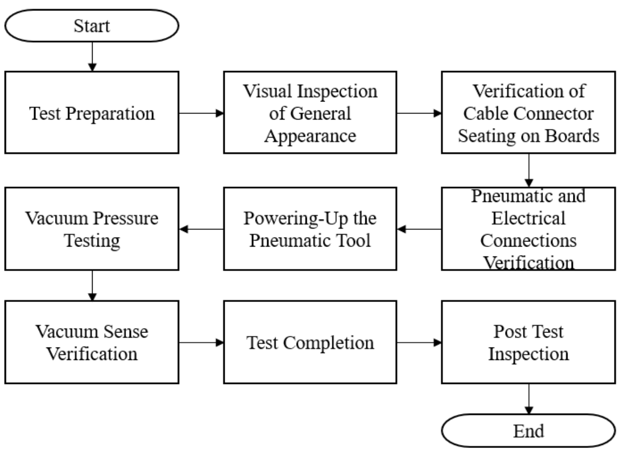

Figure 15. Vacuum Processor Assembly Test Process Flow

Figure 15 shows the testing process flow for vacuum processor assembly focusing to vacuum pressure test prior to installation into Matrix PnP Head. Below is the description of each step:

1. Test Preparation – Preparation of needed tools and equipment for the procedure.
2. Visual Inspection General Appearance – Inspection for loose/missing hardware, damage, cleanliness and general appearance.
3. Verification of Cable Connector Seating on Boards – Verification if all cable connectors on all controllers and boards are fully seated and plugged in correctly.
4. Pneumatic and Electrical Connections – Connecting the facility air supply to pneumatic tool to vacuum processor. Vacuum pressure test cable is also connected from test cart to 3-port control valves.
5. Power-Up the Pneumatic Tool – Starting the test cart, and program for test. Pneumatic tool should also be set to 27 PSI inlet supply for vacuum processor as required by the test instruction.
6. Vacuum Pressure Test – A length of tubing is connected to vacuum port of the pneumatic tool which is connected to fitting barbs (related to pick body) A4-V. Figure 16 shows an illustration of pneumatic tube connected B1-V fitting barb.

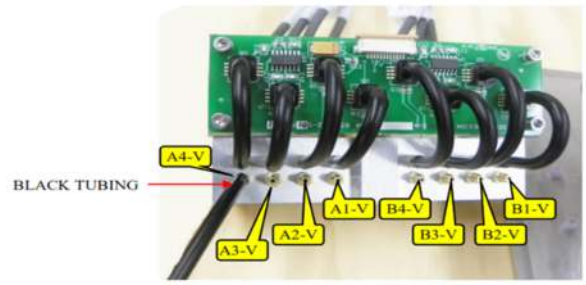

Figure 16. Tube Connection to A4-V Fitting Barb.

The pneumatic tool is then set to pressure position. Vacuum reading is observed from pressure gauge of pneumatic tool. Vacuum pressure should be ≥24 in-Hg which is shown in Figure 17. The observed value is recorded in the test checklist. The tube will be moved to A3-V, A2-V, A1-V, B4-V, B3-V, B2-V, B1-V and repeat the process until all vacuum pressures have been recorded. All the readings should be ≥24 in-Hg.


Figure 17. Vacuum Pressure Reading from Pressure Gauge.

7. Test Completion – Turn off the test cart, closing of computer program used and disconnection of test cable and pneumatic tubes from vacuum processor.
8. Post-Test Inspection – Ensure that all test checklist have all the data recorded, tested assembly is clean and free of debris, and test fixture and supporting tools have been removed from vacuum processor.

3.0 METHODOLOGY

Fishbone analysis was conducted first to check for potential cause/s of low vacuum pressure reading in vacuum processor assembly testing.

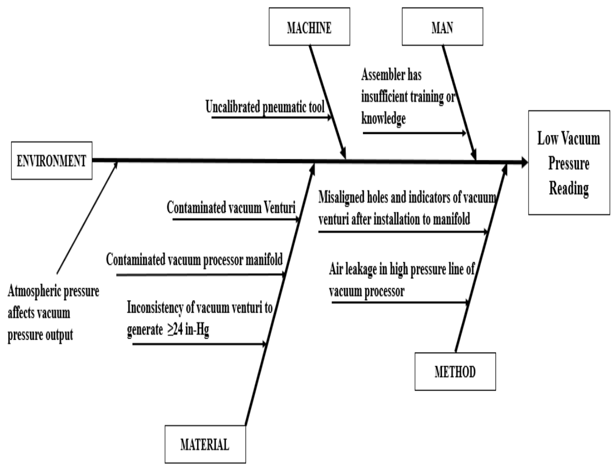

Figure 18. Fishbone diagram for Low Vacuum Pressure.

3.1 Failure Analysis and Validation of Potential Factor

Potential factors from fishbone diagram were affirmed through series of simulations to further validate the cause/s of low vacuum pressure reading which was occurring specifically to vacuum pressure test step.

3.1.1 Man

Assembly and test technicians responsible for the assembly and testing of vacuum processor assembly, respectively, are training certified. Therefore, this is not a factor of the problem.

3.1.2 Machine

The test cart and pneumatic tool used for vacuum processor test procedure is calibrated. Therefore, this is not a factor of the problem.

3.1.3 Method

3.1.3.1 Materials for Misaligned Vacuum Venturi Factor

- Vacuum Processor Assembly
- Pneumatic Tool
- Test Cart
- Test Cables and Pneumatic Tubes

3.1.3.2 Procedure

One of the identified factors for method is the misaligned holes and/or indicator of vacuum Venturis after installation to manifold. Figure 19 shows that vacuum Venturi's indicator and the holes on the vacuum body must orient prior to its installation to manifold based on customer's assembly process requirement.

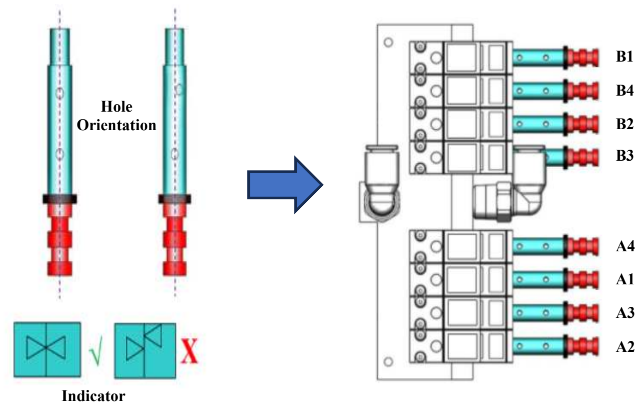

Figure 19. Vacuum Venturi hole alignment and installation.

The first step is to perform the vacuum pressure test step based on correct hole alignment of vacuum Venturis on a vacuum processor assembly.

Table 1 shows the vacuum pressure reading per vacuum Venturi from A1 to A4 and B1 to B4 with correct hole alignment. This data will be used as an initial data for test evaluation.

Item #	Inlet Pressure (PSI)	Vacuum Pressure Req't (in-Hg)	Vacuum Pressure Reading per Vacuum Venturi (in-Hg)							
			A2	A3	A1	A4	B3	B2	B4	B1
M8-02268	27	≥24	23.8	23.7	24.1	24.0	24.2	24.0	24.0	24.0

Table 1. Vacuum Pressure Readings with Correct Hole Alignment of Vacuum Venturi

The second step is to intendedly misalign vacuum Venturis hole alignment by approximately -30.0° for those with low vacuum readings which are A2 and A3 and perform vacuum pressure test step.

Table 2 shows that there is no significant change in vacuum pressure reading in A2 and A3 vacuum Venturi with misaligned holes compared to Table 1.

Item #	Inlet Pressure (PSI)	Vacuum Pressure Req't (in-Hg)	Vacuum Pressure Reading per Vacuum Venturi (in-Hg)							
			A2	A3	A1	A4	B3	B2	B4	B1
M8-02268	27	≥24	23.8	23.6	24.1	24.0	24.2	24.0	24.0	24.0

Table 2. Vacuum Pressure Readings with -30° Misaligned Hole of Vacuum Venturi on A2 and A3.

The third step is to intendedly misalign two vacuum Venturis hole alignment by approximately -30.0° with good vacuum readings which are B3 and B2 and perform vacuum pressure test step.

Table 3 shows that there is no change in vacuum pressure reading in B3 and B2 vacuum Venturi with misaligned holes compared to Table 1.

Item #	Inlet Pressure (PSI)	Vacuum Pressure Req't (in-Hg)	Vacuum Pressure Reading per Vacuum Venturi (in-Hg)							
			A2	A3	A1	A4	B3	B2	B4	B1
M8-02268	27	≥24	23.8	23.6	24.1	24.0	24.2	24.0	24.0	24.0

Table 3. Vacuum Pressure Readings with -30° Misaligned Hole of Vacuum Venturi on B3 and B2.

The last step is to intendedly misaligned the vacuum Venturi indicators and hole of A2, A3, B3 and B2.

Table 4 shows that there is no change in vacuum pressure reading in A2, A3, B3 and B2 vacuum Venturi with misaligned holes and indicators compared to Table 1.

Item #	Inlet Pressure (PSI)	Vacuum Pressure Req't (in-Hg)	Vacuum Pressure Reading per Vacuum Venturi (in-Hg)							
			A2	A3	A1	A4	B3	B2	B4	B1
M8-02268	27	≥24	23.8	23.6	24.1	24.0	24.2	24.0	24.0	24.0

Table 4. Vacuum Pressure Readings with -30° Misaligned Indicator and Hole of Vacuum Venturi on A2, A3, B3 and B2.

In Figure 20, we observe the vacuum readings for the misalignment experiment of vacuum Venturis. Specifically, the results are shown for the following scenarios:

- Letter "A" represents the vacuum Venturis with correct hole alignment.
- Letter "B" displays the results of vacuum Venturi with initially low vacuum pressure, intentionally misaligned holes.
- Letter "C" shows the results of two pre-selected vacuum Venturi with initially good vacuum readings, intentionally misaligned holes.
- Letter "D" is a combination of scenarios "B" and "C," featuring both misaligned holes and misaligned indicators.

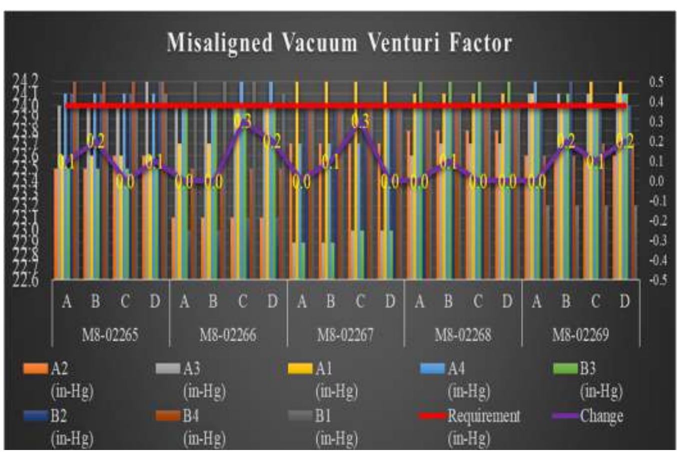

Figure 20. Misaligned Vacuum Venturi Pressure Reading

The data presented in Figure 20 displays that misalignment between the indicator and hole of the vacuum Venturis leads to marginal fluctuations in the vacuum pressure readings, ranging from 0.1 to 0.3 in-Hg. Notably, vacuum processor assemblies that initially exhibit good vacuum pressure readings retain their stability even in the presence of misaligned holes and indicators of vacuum Venturis. Therefore, this factor is not the cause of low vacuum pressure reading.

3.1.4 Method

3.1.4.1 Materials for Air Leakage in High Pressure Line Factor

- Vacuum Processor Assembly
- Pneumatic Tool
- Test Cart
- Test Cable and Pneumatic Tubes
- Ultrasonic Air Leak Detector

3.1.4.2 Procedure

The last factor for method is the air leakage in high pressure line of vacuum processor assembly specific to precision ball locations. Improper sealing of vacuum processor assembly using precision ball can cause air leakage which can lead to variations in vacuum level even if the inlet pressure is constant.

Five units from previous evaluation was also used for this evaluation since all of them has low vacuum pressure readings. The vacuum Venturis have been re-aligned according to correct orientation. Vacuum pressure test step was done for vacuum Venturi location with low vacuum reading. Once the reading was confirmed to be low vacuum, ultrasonic air leak detector was used to detect if there's any air leakage specific to four locations of precision ball.

In Figure 21, it is evident that there is no presence of air leakage in any location of any vacuum processor assembly. Consequently, this factor can be ruled out as the cause of low vacuum pressure readings.

Figure 21. Air Leakage in High Pressure Lines

3.1.5 Environment

3.1.5.1 Materials for Changing Atmospheric Pressure Factor

- Vacuum Processor Assembly
- Pneumatic Tool
- Test Cart
- Test Cable and Pneumatic tubes
- Pristine Sets of Vacuum Venturis (Fresh Lot)
- Barometer Watch

3.1.5.2 Procedure

A significant change in atmospheric pressure can affect the vacuum generated by a vacuum Venturi system. The vacuum Venturi relies on the pressure difference between the atmospheric pressure and the pressure at the Venturi nozzle to create the suction or vacuum.

To evaluate the atmospheric pressure factor, five units will undergo vacuum pressure testing on separate days. Before the testing begins, it is important to measure and record the atmospheric pressure in the production area where the tests will be conducted using a barometer watch. The atmospheric pressure readings from each of the five days will be carefully compared to identify any variations or differences. These atmospheric pressure measurements will then be compared to the corresponding vacuum pressure readings obtained during the testing process.

Table 5 presents the atmospheric pressure measurements obtained during the vacuum pressure testing conducted on five separate days. The data exhibited variability throughout the observed period. However, all recorded values remained within the acceptable range of normal atmospheric pressure, adhering to a tolerance level of ±1%.

Day	Normal Atmospheric Pressure (in-Hg)	Actual Atmospheric Pressure (in-Hg)
1	29.89 ~ 29.95	29.91
2		29.92
3		29.90
4		29.92
5		29.92

Table 5. Five Separate Days Atmospheric Pressure Data

Following the determination of atmospheric pressure for each day, the next step involved conducting a vacuum pressure test using the M8-00265 vacuum processor assembly. A total of five sets, which corresponds to 40 vacuum Venturis in total, were subjected to testing under pristine conditions. Each set was tested on a separate day to ensure accurate and independent evaluation.

Table 6 displays that out of the 40 vacuum Venturis, 12 displayed a vacuum pressure reading greater than 24 in-Hg while 28 showed less than 24 in-Hg reading while tested in a normal atmospheric pressure environment.

Set / Day	M8-02265 Vacuum Pressure Reading per Vacuum Venturi (in-Hg)							
	A2	**A3**	**A1**	**A4**	**B3**	**B2**	**B4**	**B1**
1	24.0	23.7	24.1	23.5	23.2	23.4	23.1	23.8
2	23.7	23.5	24.0	24.0	23.4	23.6	23.2	23.9
3	23.3	23.8	23.6	23.9	24.0	23.4	23.6	24.1
4	23.7	23.7	23.6	23.4	24.1	24.2	24.1	24.0
5	24.1	24.0	23.8	23.2	23.8	23.8	23.7	23.5

Table 6. Vacuum Pressure Readings for Five Separate Days

In Figure 22, it displays the atmospheric pressure readings for five different days during the vacuum pressure test step. The observed readings fluctuate visibly, ranging from zero to 0.2 change. Despite these fluctuations, all the recorded readings for the five separate days remain within the acceptable range of normal atmospheric pressure, which is between 29.89 to 29.95 in-Hg. The data analysis suggests that there is no significant change in atmospheric pressure during the testing process. As a result, changing atmospheric pressure cannot be considered a contributing factor to the low vacuum pressure reading problem.

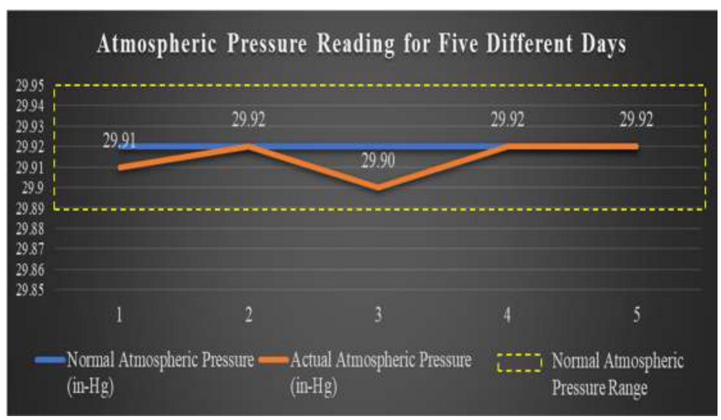

Figure 22. Atmospheric Pressure Readings for Five Separate Days

3.1.6 Material

3.1.6.1 Materials for Contaminated Vacuum Processor Manifold Factor

- Vacuum Processor Assembly
- Pneumatic Tool
- Test Cart
- Test Cable and Pneumatic Tubes

3.1.6.2 Procedure

The first factor for material is the contaminated vacuum processor manifold. Contamination in the vacuum processor manifold can obstruct the airflow resulting in a decrease in the vacuum pressure output. It can also cause uneven distribution of air pressure resulting in variation in the vacuum pressure across vacuum Venturis.

Five units from previous evaluation was used for this evaluation since all of them has low vacuum pressure readings. It will undergo vacuum pressure test step again.

Table 7 shows the data gathered after vacuum pressure test in which will be used as an initial data for this evaluation.

Item #	Inlet Pressure (PSI)	Vacuum Pressure Req't (in-Hg)	Vacuum Pressure Reading per Vacuum Venturi (in-Hg)							
			A2	A3	A1	A4	B3	B2	B4	B1
M8-02265	27	≥24	23.5	24.0	23.6	24.1	23.5	24.1	24.2	24.0
M8-02266			23.1	24.0	23.7	24.0	24.0	23.0	23.5	24.2
M8-02267			23.7	22.9	24.2	23.6	22.9	24.0	24.0	24.0
M8-02268			23.8	23.7	24.1	24.0	24.2	24.0	24.0	24.0
M8-02269			23.6	24.1	24.1	24.2	24.0	24.0	23.6	23.2

Table 7. Initial Data for Contaminated Vacuum Processor Manifold Factor

After the initial data was gathered, the vacuum Venturis from each vacuum processor assembly and fitting barbs were initially removed to clean the vacuum processor manifold. The vacuum processor was cleaned by blowing compressed air directly to each hole where vacuum Venturis were installed to blow-off any dirt, debris or foreign materials. The vacuum Venturis are re-installed to each hole where they are initially located and performed vacuum pressure test step.

Table 8 shows that there is no change in vacuum pressure readings in any unit or Venturi vacuum locations.

Item #	Inlet Pressure (PSI)	Vacuum Pressure Req't (in-Hg)	Vacuum Pressure Reading per Vacuum Venturi (in-Hg)							
			A2	A3	A1	A4	B3	B2	B4	B1
M8-02265	27	≥24	23.5	24.0	23.6	24.1	23.5	24.1	24.2	24.0
M8-02266			23.1	24.0	23.7	24.0	24.0	23.0	23.5	24.2
M8-02267			23.7	22.9	24.2	23.6	22.9	24.0	24.0	24.0
M8-02268			23.8	23.7	24.1	24.0	24.2	24.0	24.0	24.0
M8-02269			23.6	24.1	24.1	24.2	24.0	24.0	23.6	23.2

Table 8. Data after Cleaning the Vacuum Processor Manifold

The verification process of the vacuum processor manifold cleaning involves switching the vacuum Venturis between hole locations to assess their performance. At least two-hole locations with low vacuum readings are selected, and their corresponding vacuum Venturis are interchanged with those from hole locations with good vacuum readings, and vice versa. The following swaps were carried out for each specific vacuum processor:

- For M8-2265:
- A2 was switched with A3.
- A1 was switched with A4.
- For M8-2266:
- A2 was switched with A3.
- B4 was switched with B1.
- For M8-2267:
- A4 was switched with A1.
- B3 was switched with B2.
- For M8-2268:
- A3 was switched with A1.
- A2 was switched with A4.
- For M8-2269:
- A2 was switched with B2.
- B1 was switched with A1.

By performing these interchanges, the effectiveness of the vacuum processor manifold cleaning process is evaluated, and any improvements or changes in vacuum readings are observed.

Table 9 shows that after switching the vacuum Venturis, the resulting vacuum pressure readings also switched. The switching of vacuum Venturis leads to a reversal of the vacuum pressure readings in affected hole locations. The hole locations that initially have a low vacuum pressure readings now exhibits good vacuum pressure readings, and vice versa.

Item #	Inlet Pressure (PSI)	Vacuum Pressure Req't (in-Hg)	Vacuum Pressure Reading per Vacuum Venturi (in-Hg)							
			A2	**A3**	**A1**	**A4**	**B3**	**B2**	**B4**	**B1**
M8-02265			24.0	23.5	24.1	23.6	23.5	24.1	24.2	24.0
M8-02266			24.0	23.1	23.7	24.0	24.0	23.0	24.2	23.5
M8-02267	27	≥24	23.7	22.9	23.6	24.2	24.0	22.9	24.0	24.0
M8-02268			24.0	23.7	24.1	23.8	24.2	24.0	24.0	24.0
M8-02269			24.0	24.1	23.2	24.2	24.0	23.6	23.6	24.1

Table 9. Cleaning Verification and Switching Vacuum Venturis Data

Based on Figure 23, it is evident that there is no change in the initial vacuum pressure reading compared to the vacuum pressure reading after vacuum manifold cleaning. This observation indicates that the vacuum pressure remains consistent before and after the cleaning process. The figure suggests that this factor is not the root cause of low vacuum pressure readings.

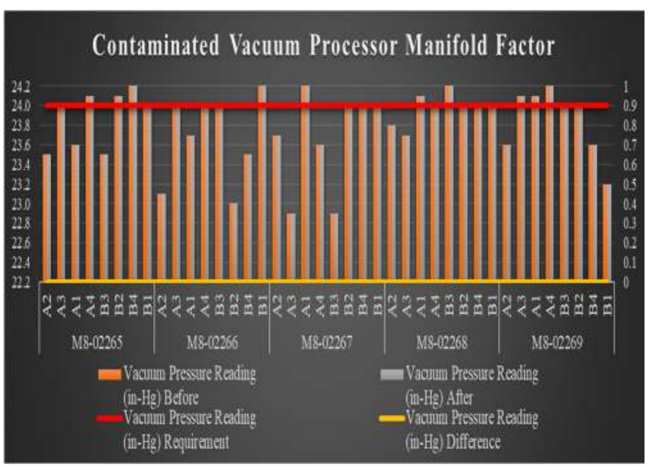

Figure 23. Contaminated Vacuum Processor Manifold Factor Before and After Compressed Air Cleaning

3.1.7 Material

3.1.7.1 Materials for Contaminated Vacuum Venturi Factor

- Vacuum Processor Assembly
- Pneumatic Tool
- Test Cart
- Test Cable and Pneumatic tubes
- Sets of Vacuum Venturis (Low Vacuum Reading)
- Deionized Water
- Ultrasonic Cleaner

3.1.7.2 Procedure

The second factor of material is the contaminated vacuum Venturi. The same with the first factor, contamination can obstruct the airflow preventing the Venturi from generating any significant vacuum pressure, resulting to low vacuum pressure reading.

The test evaluation used for this factor is cleaning the vacuum Venturi with low vacuum pressure readings. Two methods of cleaning were applied which are use of compressed air to blow off dirt, debris or foreign material and ultrasonic cleaning using deionized water.

Table 10 shows initial data from 40 pieces or 5 sets of vacuum Venturi with low vacuum reading was used for each method of cleaning. These sets of vacuum Venturi came from previous testing done in the production.

Set	Data	Vacuum Venturi Location	Vacuum Pressure Reading (in-Hg)
1	1	A2	23.5
	2	A3	23.6
	3	A1	23.8
	4	A4	23.3
	5	B3	23.7
	6	B2	23.3
	7	B4	22.9
	8	B1	23.6
2	9	A2	23.4
	10	A3	23.3
	11	A1	23.8
	12	A4	23.4
	13	B3	23.0
	14	B2	23.5
	15	B4	23.6
	16	B1	23.2
3	17	A2	23.9
	18	A3	23.8
	19	A1	23.5
	20	A4	23.9
	21	B3	23.7
	22	B2	23.6
	23	B4	23.1
	24	B1	23.8
4	25	A2	23.7
	26	A3	23.3
	27	A1	23.7
	28	A4	23.9
	29	B3	23.7
	30	B2	23.6
	31	B4	23.8
	32	B1	23.4
5	33	A2	23.7
	34	A3	23.7
	35	A1	23.0
	36	A4	23.6
	37	B3	23.9
	38	B2	23.8
	39	B4	23.1
	40	B1	23.9

Table 10. Initial Data of Vacuum Venturis for Compressed Air Cleaning.

The initial evaluation method involves cleaning the vacuum Venturis using compressed air. To facilitate a comprehensive cleaning process and minimize the possibility of residue or contaminants remaining, the Venturis are disassembled into three parts, as illustrated in Figure 24. This disassembly allows for a more thorough cleaning of all components involved.

Figure 24. Disassembled Vacuum Venturi

The disassembled vacuum Venturis were cleaned by gradually increasing the air pressure, starting from a lower setting until reaching 25 PSI. The airflow was directed through the normal and opposite directions of Venturi airflow to dislodge contaminants effectively. Each piece of the disassembled vacuum Venturi underwent two rounds of cleaning to ensure thoroughness. Following cleaning, the vacuum Venturis were reassembled and installed in the M8-00265 vacuum processor assembly according to the arrangement specified in Table 10. Finally, the vacuum pressure test step was performed.

Based on the data presented in Figure 25, it is observed that only two out of the 40 vacuum Venturis met the specified requirement of ≥24 in-Hg. Specifically, Set 1 data showed a vacuum pressure reading of 24.2 in-Hg, and Set 3 data showed 24.1 in-Hg after cleaning with compressed air. However, despite the increase in vacuum pressure readings for these two instances, the data indicates fluctuations in the difference between the before and after vacuum pressure readings. These fluctuations suggest that cleaning the vacuum Venturis with compressed air is not an effective solution for addressing the low vacuum pressure readings consistently. Based on this analysis, it can be concluded that the contamination of the vacuum Venturis and subsequent cleaning with compressed air do not appear to be the primary contributing factors to the low vacuum pressure readings.

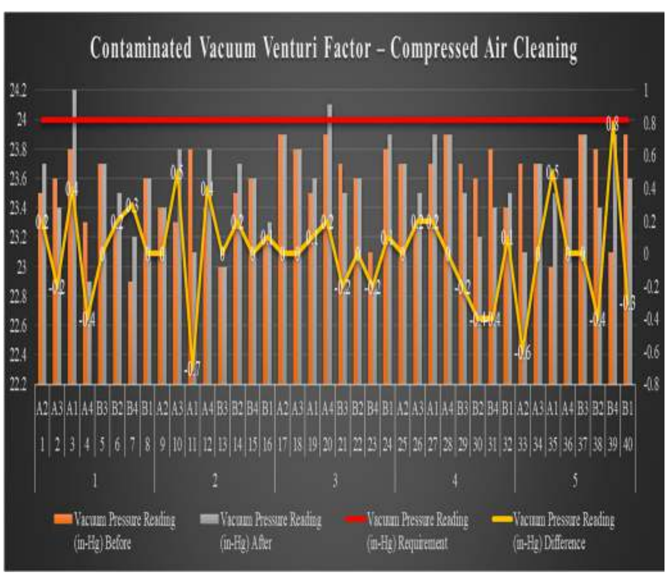

Figure 25. Contaminated Vacuum Venturi Before and After Compressed Air Cleaning

For the last evaluation method, the vacuum Venturis are cleaned using deionized water in an ultrasonic cleaner. This approach provides a different cleaning process compared to the initial method. The evaluation is conducted using data from 40 pieces or 5 sets of vacuum Venturis that have initially shown low vacuum readings which is showed in Table 11. It's important to note that this particular set of Venturis differs from the ones used in the initial evaluation.

Set	Data	Vacuum Venturi Location	Vacuum Pressure Reading (in-Hg)
1	1	A2	23.9
	2	A3	23.9
	3	A1	23.8
	4	A4	23.8
	5	B3	23.9
	6	B2	23.9
	7	B4	23.8
	8	B1	23.9
2	9	A2	23.5
	10	A3	23.5
	11	A1	23.4
	12	A4	23.4
	13	B3	23.5
	14	B2	23.5
	15	B4	23.5
	16	B1	23.5
3	17	A2	23.0
	18	A3	23.0
	19	A1	23.1
	20	A4	23.1
	21	B3	23.0
	22	B2	23.1
	23	B4	23.1
	24	B1	23.1
4	25	A2	22.9
	26	A3	23.4
	27	A1	23.7
	28	A4	22.5
	29	B3	23.1
	30	B2	23.2
	31	B4	23.4
	32	B1	23.8
5	33	A2	23.7
	34	A3	22.6
	35	A1	22.8
	36	A4	23.4
	37	B3	23.5
	38	B2	23.2
	39	B4	23.0
	40	B1	23.0

Table 11. Initial Data of Vacuum Venturis for Ultrasonic Cleaning.

Similar to the initial evaluation method, the second evaluation method involves disassembling the vacuum Venturis into three parts. The disassembled components undergo a pre-cleaning step by rinsing them with a gentle stream of DI water. Subsequently, the components are placed in an ultrasonic cleaner filled with DI water with 60 kHz setting, where they are cleaned for a duration of five minutes. Each component is cleaned one after another. Following the ultrasonic cleaning cycle, the components are thoroughly rinsed with DI water to ensure the removal of any loosened contaminants. The components are then left to air dry for 15 minutes in a room with a temperature of 24°C. To ensure complete dryness, they are subsequently air-blown. Once the components are dry, they are re-assembled and installed as sets in the M8-00265 vacuum processor assembly. Finally, a vacuum pressure test step is performed to evaluate the effectiveness of the cleaning process

Based on the data presented in Figure 26, it is observed that only three out of the 40 vacuum Venturis met the specified requirement of ≥24 in-Hg. Specifically, Set 1 data showed a vacuum pressure reading of 24.1 in-Hg, and Set 2 data showed two occurrences of 24.2 in-Hg after ultrasonic cleaning using DI water. The data indicates that vacuum pressure readings increased in three instances. However, there were fluctuations in the difference between before and after readings, suggesting that cleaning the vacuum Venturis with DI water in an ultrasonic cleaner is not effective in addressing low vacuum pressure. The data does not support contamination and cleaning it with DI water in ultrasonic cleaner as the primary factors contributing to the issue.

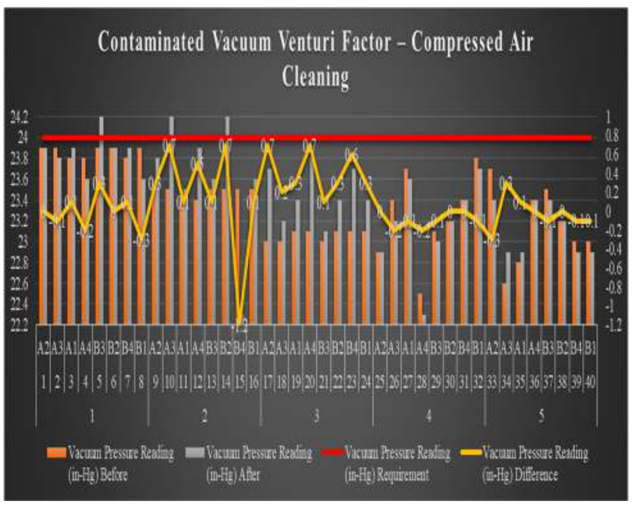

Figure 26. Vacuum Pressure Reading Result for 376 Vacuum Venturis

3.1.8 Material

3.1.8.1 Materials for Inconsistency of Vacuum Venturi to Generate ≥24 in-Hg Vacuum Pressure Factor

- Vacuum Processor Assembly
- Pneumatic Tool
- Test Cart
- Test Cable and Pneumatic tubes
- Pristine Sets of Vacuum Venturis (Fresh Lot)

3.1.8.2 Procedure

The performance of a vacuum Venturi relates to its ability to consistently and effectively generate the desired vacuum pressure output. Consistency, in particular, is a crucial factor influencing the Venturi's performance. It refers to the Venturi's capacity to reliably and consistently produce the desired vacuum pressure output over an extended period.

According to the technical datasheet of vacuum Venturi, when the inlet pressure is within 26.1 to 31.9 PSI, the maximum achievable vacuum pressure in 24.2 in-Hg. However, there is no indicated lower limit vacuum pressure.

To evaluate the consistency factor, a vacuum pressure test step is performed using the M8-00265 vacuum processor assembly. A total of 47 sets, equivalent to 376 vacuum Venturis, are tested under pristine conditions. This comprehensive evaluation allows for a thorough assessment of the Venturis' consistency in generating the required vacuum pressure output.

One at a time, each set of vacuum Venturis are installed in M8-00265 vacuum processor assembly to perform vacuum test steps and record all the vacuum pressures.

In Figure 27, data on vacuum pressure readings after conducting vacuum pressure tests using 376 pristine vacuum Venturis is presented. Out of the total 376 vacuum Venturis tested, 53% (equivalent to 200 units) exhibited good vacuum pressure readings, while the remaining 47% (equivalent to 176 units) showed low vacuum pressure readings. The results indicate that the vacuum Venturis were unable to consistently generate vacuum pressure of ≥24 in-Hg, as required. The majority of the tested units (47%) did not meet the specified vacuum pressure requirement, implying that the vacuum Venturis' performance falls short in achieving the desired threshold. Based on this analysis, it can be concluded that the vacuum Venturis cannot reliably deliver the necessary vacuum pressure. Therefore, the root cause of the low vacuum pressure reading problem.

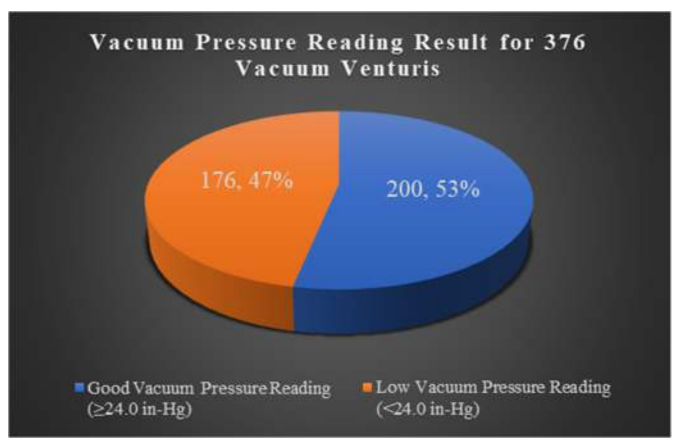

Figure 27. Vacuum Pressure Reading Result for 376 Vacuum Venturis

In light of this findings, the recognition of variability in vacuum pressure outputs prompted to consider the possibility of re-evaluating the existing vacuum pressure requirement. Lowering the requirement emerged as a potential solution without compromising product's reliability and performance in end-user's side. However, as it is aimed to implement this change, it is understood the critical importance of approaching it with utmost caution, as we lack direct knowledge of the vacuum pressure conditions in our customers' applications.

We engage with our customer by sharing the test results, observations, and the proposed change to the vacuum pressure requirement. The customer verifies the concern and deemed it valid. We actively sought their insights into the application needs and specific use cases. After comprehensive testing and validation on their side, the customer defined that the new vacuum pressure requirement for Matrix PnP Head is 27 PSI at ≥23 in-Hg.

It is worth noting that the ≥23 in-Hg is vacuum pressure requirement for Matrix PnP head which is for final verification or testing. In order to establish the new vacuum pressure requirement for the vacuum processor assembly, specifically intended for sub-assembly testing, we will define it based on this reference value. This approach ensures alignment with the desired performance standard while catering to the specific testing needs of the sub-assembly process.

In order to define the new vacuum pressure requirement for vacuum processor assembly, 6 sets of vacuum Venturi, equivalent to 48 pieces, will undergo vacuum pressure test using M8-00265 and will be integrated each set into Matrix PnP Head. This is done to also identify the vacuum loss, which is the pre-requisite for identifying new requirement, due to the increase of length hoses and additional components and connections after integration.

Figure 28 shows the vacuum pressure reading for sub-test or vacuum pressure test for vacuum processor assembly and final test for Matrix PnP Head. Out of the 48 vacuum Venturis, one showed an increase in vacuum pressure reading, 34 displayed a decrease, and 14 demonstrated no change. The retain value has 14 occurrences, 29.17% of total quantity, the loss value of 0.1 in-Hg has eight occurrences, 16.7% of total quantity, and the highest occurrence in terms

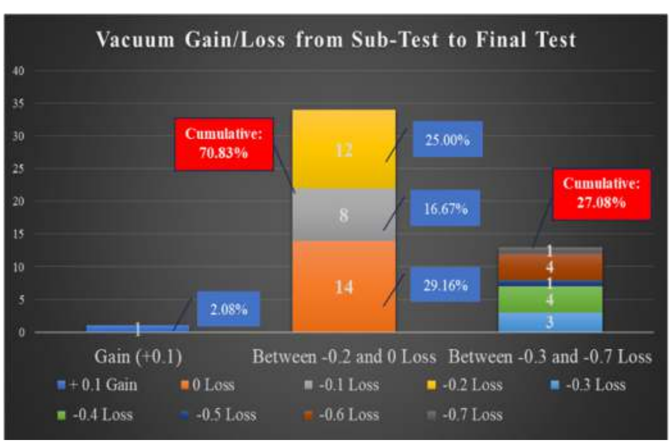

Figure 28. Vacuum Gain/Loss from Sub-Test to Final Test

of loss value is 0.2 in-Hg which has 12 occurrences, 25% of the total quantity. The total percentage of 0.2 in-Hg loss to retaining the vacuum pressure after final test is 70.83%. The lost value from 0.3 to 0.7 has 14 combined occurrences, 27.08% of total quantity.

The mean value of the total losses is also 0.2 in-Hg. The lowest vacuum pressure value in sub-test is 23.5 in-Hg which has three occurrences. This lowest value 23.5 in-Hg from sub-test is higher than the final test requirement which ≥23 in-Hg. The highest loss value in quantity and mean value of the total losses which is 0.2 in-Hg is then subtracted from the 23.5 in-Hg. With this, new vacuum pressure requirement on vacuum processor assembly is **≥23.3 in-Hg vacuum output at 27 PSI input.**

4. 0 RESULTS AND DISCUSSION

The investigation, comprising a thorough 4M+1E analysis, has successfully identified the root cause behind the issue. It has been established that the inconsistency in generating the required ≥24 in-Hg vacuum pressure is attributable to a material-related factor: the Vacuum Venturi's Inconsistency. The outcome of the analysis demonstrates that the performance variation in the Vacuum Venturi has a direct impact on the vacuum pressure generation.

The data-driven approach to experimentation has provided valuable insights into the behavior of the system and the factors affecting vacuum pressure generation. By making informed adjustments based on the experimental results, we have successfully defined a new vacuum pressure output requirement that does not compromise the product's reliability and performance on the end-user's side.

In Figure 29, it represents a graph showing the low vacuum pressure reading defect occurrence from January 2021 to July 2023 and its linear trends. In 2023, a noticeable decreasing trend in defects is clearly observed, primarily attributed to the

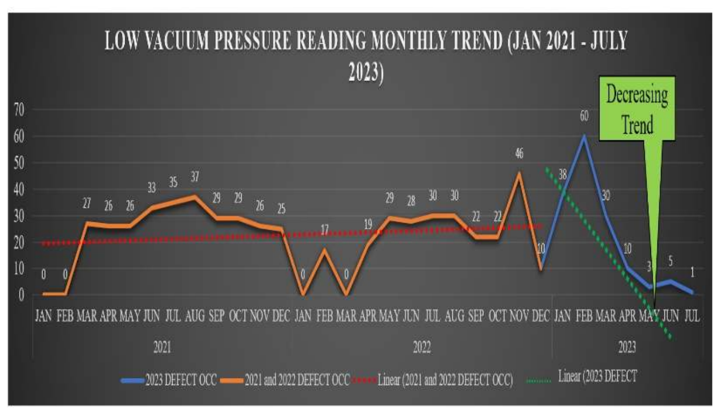

Figure 29. Low Vacuum Pressure Reading Defect Occurrence from Jan. 2021 to July 2023.

enforcement of new vacuum pressure standards commencing in May 2023. By comparing the defect occurrences from May to July 2023, encompassing the last three months after the implementation, with the data from February to April 2023, representing the three months prior to the new requirement enforcement, **a significant relative change of -91% is evident.**

5.0 CONCLUSION

The introduction of the new vacuum pressure requirement in the vacuum pressure test step for the vacuum processor assembly has resulted in a declining trend of defect occurrences. This, in turn, has led to a reduction in downtime and the scrap rate of materials. Importantly, these changes have had no adverse effects on the end product's reliability and performance. The implementation of the new requirement has proven to be beneficial, enhancing the overall efficiency and quality of the manufacturing process without compromising the final product's integrity and functionality.

6.0 RECOMMENDATIONS

It is essential to conduct in-depth analyses of both vacuum Venturi and vacuum processor assembly designs and their interoperability to ensure both components are compatible and efficient. The manufacturer and customer should be actively involved in providing their expertise and support for analyzing their respective components. Through this collaborative effort, the cause of inconsistencies in vacuum pressure reading can be identified, and appropriate measures can be implemented to achieve a complete elimination of the issue.

7.0 ACKNOWLEDGMENT

The success of this work will never be realized without the support and contributions of the following: To Sir Jermie De Mesa, for providing valuable insights and expertise during the course of this project. His contributions have been instrumental in shaping and enhancing the outcome. To my co-author, Mr. Leonardo Sarmiento, who primarily leads all of the experimentations and gathering of data. To Mr. Ronne-Mier Combalicer, for providing continuous support in testing setup. To Ms. Carla Aday, for providing process-related support during experiments.

8.0 REFERENCES

1. https://www.blowervacuumbestpractices.com/system-assessments/vacuum-generation/utilizing-venturi-vacuum-generators-efficiently
2. Technical Datasheet of Vacuum Venturi
3. Customer's Product Technical Manual

9.0 ABOUT THE AUTHORS

About the Author

DARWIN B. ALCANTARA is a graduate of Bachelor of Science in Electrical Engineering from the Philippines-Maragondon Campus and is a Registered Electrical Engineer. He has been currently working at P.IMES as Product Engineer under Automation and Technology Solutions-Engineering Department

About the Co-Author

LEONARDO Z. SARMIENTO is a graduate of Associate in Micro-Computer Technology from Philippine Science and Technology. He has been working at P. IMES Corp., under ATS-Engineering. He came from Alpha Techno Precision Toolings Inc. where has experienced being a Process Engineer before becoming part of ATS-