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ANALYZING LEAK DETECTION METHODS FOR ALUMINUM CAST COMPONENTS IN AUTOMOTIVE MANUFACTURING PROCESSES

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ABSTRACT

This study was conducted to detect leaks in aluminum casting components in the automotive manufacturing process, which is a significant issue because it can affect vehicle safety. The method used in this study is the Cosmo Air Leak Tester for leak testing using air pressure and differential methods, as well as bubble test testing as an alternative method. The results of the study show that the air leak tester machine has stable values but cannot detect leaks caused by deformation. Changes in parameters on the Cosmo Air Leak Tester do not significantly affect bubble detection. On the other hand, the water leak method proved effective in detecting early leaks with the appearance of bubbles in products experiencing deformation up to 40 microns.

KEYWORDS *Air Leak Tester, Water Leak, Deformation, Aluminum Casting, Leak.*

INTRODUCTION

In the automotive industry, there will always be several production issues related to the quality of the products produced, especially in components with very high precision levels, which have undergone machining processes such as CNC machines, one of which is in vehicle motion components such as transmissions, with its main material being aluminum casting. One of the significant problems in transmissions is leakage, as it involves many factors and will impact the safety level of the vehicle to be used by customers, thus requiring detection capabilities in the production area to ensure quality products. To ensure the quality of these leaks, the common method used in the automotive industry is to use an air leak tester machine (Ardi & Setyowati, n.d.). This machine works on the basic principle of applying air pressure into the product and then measuring the remaining pressure. If the remaining pressure is lower than the pressure applied, then the product is considered to have a leak.

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Essentially, leakage checking media are categorized into two types: Dry Testing and Wet Testing, while the testing methods vary greatly with their respective advantages and disadvantages (Bhosale et al., 2017). Japanese automotive companies generally use a component called the Cosmo Air Leak Tester as a calculation tool and system used in the Air Leak Tester machine. This machine is equipped with fixtures and other clamping components to maintain the position of the product accurately during the testing process. Therefore, products can be tested accurately without any disruptive shifts affecting the test results. Many studies confirm that the air leak tester method is an effective tool for ensuring the quality of leak detection in aluminum casting products. However, not all types of leaks can be guaranteed with this method.

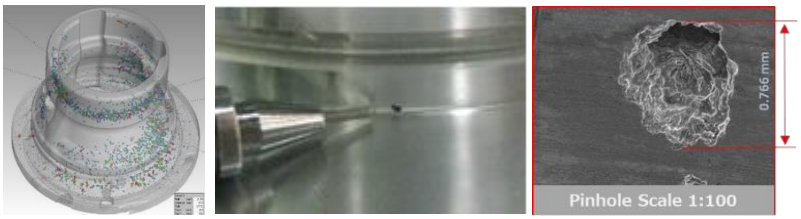

Figure (1) Porosity or Pin Holes in 3D Scan

The main cause of leakage in aluminum casting material is porosity, which can result in leaks. Porosity can decrease the strength, hardness, and ductility of the casting, thus reducing its mechanical properties (Kucharčík et al., 2014). This condition is currently occurring in the casting industry, with numerous defects emerging in the casting process (Wiryolukito, 2020). Porosity can manifest as small voids or holes on the surface or within the material of the casting, reducing the structural integrity of the component (Horváth et al., 2022). Essentially, air leak tester machines can detect leaks caused by porosity, but they have limitations in detecting low-level leaks such as bubble leaks. These bubble leaks are not well detected by air leak tester machines, especially if the pressure measurement intervals used are not sensitive enough to detect such leaks. Additionally, deformations resulting from assembly processes or the installation of other components on aluminum castings can also affect the leakage rate. Deformation occurring during assembly processes can exacerbate porosity and increase the level of porosity, which can lead to leaks. Products are tested to determine whether there are leaks within the components or not (Kala, S., Jadhav, A., Rohit Jadhav, A., & Professor, 2022). Leak testers are widely used in industries to prevent leaky products from being used by customers. In efforts to enhance effectiveness and strengthen quality assurance related to leaks, some companies seek solutions to prevent leaking parts from reaching customers. Besides addressing the causes of leaks, the primary focus should be on preventing the flow of leaks, as leak findings in cars are still prevalent, such as in PT. XYZ, a Japanese global automotive company.

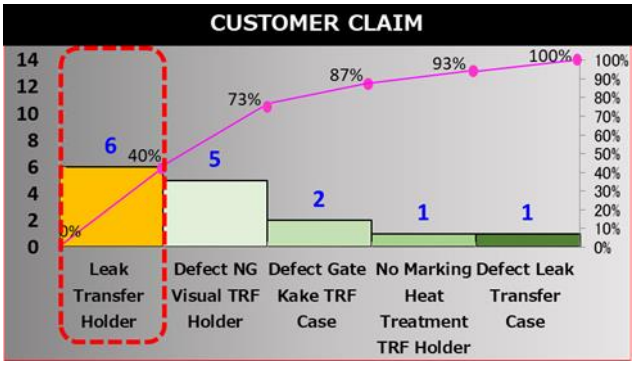

Figure (2) Porosity or Pin Hole on 3D Scan

There were six customer claims within one year of production, necessitating the strengthening of quality assurance by considering other aspects such as:

1. Repair costs and production costs (Cost)
2. Cycle Time (Delivery) of repair objects to support mass production,
3. Ease of use for users or operators (Man) in operation,
4. Safety in use (Safety) Improving quality

Function is considered the most important (Pop & Tîtu, 2016). Therefore, structured analysis and consideration of various aspects are needed to ensure that improvements do not create new problems. The quality assurance system for leak detection using the Air Leak Tester method has not been able to detect small-scale porosity leaks, as concluded by several researchers. It is necessary to combine testing methods to cover the shortcomings of the Air Leak Tester method. One such method, known as primitive by some researchers, is the Water Leak method. This wet method can detect small bubbles, commonly referred to in Japanese as kaniawa (crab bubbles). Therefore, the question arises whether the combination of these methods can be applied to mass production systems, or if the Air Leak Tester remains the best method, as mentioned by some previous researchers.

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RESEARCH METHOD

Cosmo Air Leak Tester

The use of Cosmo Air Leak Tester is already familiar in the industrial world, employing the air pressure method and conducting a comparison (differential) of air pressure between the object and the master chamber (machine). This method is most commonly used to test enclosed component (Deshmane, V., Sisode, R., Patil, A., Ghuge, S., & Vitnor, 2021).

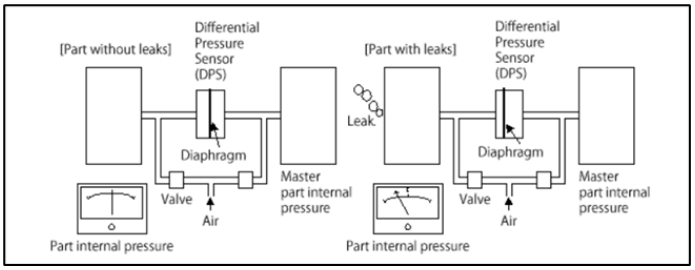


Figure (3) Differential Leak Test

The Cosmo Air Leak Tester's working system uses a differential pressure sensor method, comparing parts with a master, with the following flow:

1. Flow for OK Parts:

Air enters both the parts and the master with the same pressure value → after the specified cycle time, the air stops entering both objects → both objects apply pressure to the DPS installed between them → if the parts are OK, the pressure value received by the DPS will be the same as the pressure value from the master.

2. Flow for NG (Leaking) Parts:

Air enters both the parts and the master with the same pressure value → after the specified cycle time, the air stops entering both objects → both objects apply pressure to the DPS installed between them → if the parts are NG (leaking), the pressure value received by the DPS from the parts will be lower compared to the pressure value from the master, as the pressure in the parts decreases due to the leak.

Part Suspect Verification

The analysis of the cause of leaking suspect parts to customers involved 5 units by re-checking them using the air leak tester machine and comparing the data from when the parts lot was produced.

No	Part Claim (Suspect) Standard ±8cc /min	Hasil Leak Before (Masspro)	Judgement Leak Before (Masspro)	Hasil Leak After Claim	Judgement Leak After Claim	Noted
1	12112025	2.3 cc/min	OK	4.0 cc/min	OK	↑
2	12112032	5.5 cc/min	OK	6.2 cc/min	OK	↑
3	12112013	3.8 cc/min	OK	5.2 cc/min	OK	↑
4	12112012	4.5 cc/min	OK	5.3 cc/min	OK	↑
5	12012398	3.6 cc/min	OK	4.3 cc/min	OK	↑

Figure (4) Data re-check part claim

There were changes in the measurement results, but both before and after the suspect part claim, they were still judged as OK by the Air Leak Tester machine. Thus, the machine cannot conclusively guarantee the absence of leaks in those parts

Machine Repeatability

From the re-check data, verification of the stability of the air leak tester machine was performed by sampling 10 units of suspect parts, then two types of parts were compared: leaky (suspect) parts and OK parts, with a variability test conducted N:5 times.

REPEATABILITY										
No	No Lot	Part	Leak 1 cc/min	Leak 2 cc/min	Leak 3 cc/min	Leak 4 cc/min	Leak 5 cc/min	MAX	MIN	DIFF
1	12112025	NG (Claim)	0.56	0.47	0.31	0.16	0.34	0.56	0.16	0.40
2	12112032	NG (Claim)	0.29	0.71	0.63	0.80	0.42	0.80	0.29	0.51
3	12112013	NG (Claim)	1.63	1.75	1.96	1.76	1.91	1.96	1.63	0.33
4	12112012	NG (Claim)	1.18	0.72	1.07	0.25	0.58	1.18	0.25	0.93
5	12012398	NG (Claim)	1.85	1.77	1.68	1.49	1.82	1.85	1.49	0.36
6	11002010	OK	0.23	0.19	0.24	0.29	0.18	0.29	0.18	0.11
7	11002011	OK	0.33	0.39	0.42	0.22	0.21	0.42	0.21	0.21
8	11002012	OK	0.12	0.08	0.08	0.16	0.21	0.21	0.08	0.13
9	11002013	OK	1.34	1.38	1.39	1.22	1.54	1.54	1.22	0.32
10	11002014	OK	1.21	1.22	1.24	1.18	1.11	1.24	1.11	0.13

Figure (5) Repeatability data

The repeatability gap measurement result was <1cc/min, indicating that the air leak tester machine is stable and therefore deemed OK.

Machine Verification

Further verification was conducted regarding the machine's ability to detect NG parts, with three sample parts taken: suspect parts, OK parts, and NG parts.

No	No Lot	Part	Nilai Leak	
			Start	End
1	12112025	NG (Claim)	6.02	0.56
2	12112032	NG (Claim)	5.31	0.29
3	12112013	NG (Claim)	7.21	1.63
4	12112012	NG (Claim)	6.45	1.18
5	12012398	NG (Claim)	6.34	1.85
6	11002010	OK	5.29	0.23
7	11002011	OK	4.21	0.33
8	11002012	OK	4.98	0.12
9	11002013	OK	6.78	1.34
10	11002014	OK	6.87	1.21
11	11002111	NG Cosmo	30.2	12.8
12	11002198	NG Cosmo	26.5	12.2
13	11102112	NG Cosmo	18.8	9.8
14	11102398	NG Cosmo	39.1	16.6
15	11102423	NG Cosmo	66.2	30.9

Figure (6) Detection capability data

In the mechanism of cosmo air leak tester measurement, there are 2 parameters: purging and balancing during measurement, with initial purging numbers up to theend pressure calculation between the chamber and the part. The verification result showed no noticeable difference in start-end values in NG parts (Claim) and OK parts; significant differences only appeared in parts that were judged as NG by cosmo air leak tester (detected). From the 3 verification data, it was concluded that this air leak method cannot yet detect leaking parts that reach the customer.

Decision Analysis

In the manufacturing process, there are several methods to ensure the quality of product leaks, such as wet leak testing, dry leak testing, hydrogen leak testing, helium leak testing, and halogen leak testing (Kelkar, R., Sabale, P., Shinde, N., Tade, S. L., & Student, 2017). Further analysis is needed to find testing methods that can detect leaks in suspect parts. Leak testing methods are varied, including:

1. Technology → Ultrasonic
2. Media → Halogen, Helium, Hydrogen Check
3. Vacuum → Chamber or Decay
4. Air Leak → Differential or Without Differential
5. Bubble Test → Water Test or Soap

Leakage Method Decision Analysis

Mesin				Existing		New							
NO	項目 Item		重要度	Air Leak		Ultrasonic		Halogen, Helium Hydrogen Check		Vacuum Chamber or Decay		Bubble Test	
			Urgently	Check	Judge	Check	Judge	Check	Judge	Check	Judge	Check	Judge
1	Quality	Deteksi	W3	↑	3	↑	3	↑	3	↑	3	↑	3
2	Cost	Consumable	W3	↓	1	↓	1	↓	1	↓	1	↑	3
3	Delivery	Cycle Time	W3	↑	3	↓	1	↑	3	↑	3	↑	3
4	Man	Penggunaan	W3	↑	3	—	2	↑	3	↑	3	↑	3
5	Safety	Keamanan	W3	↑	3	↑	3	—	1	↑	3	↑	3
SCORE				13		10		11		13		15	

Figure (7) Decision Analysis

Determining categories based on the needs and limitations in the production line area, with categories Q, C, D, M, S to have multiple perspectives to maximize the selection of improvement themes. The bubble test method with water as the medium was chosen as the appropriate choice based on the DA score. Although this method is known to be primitive, when combined with the air leak tester method, it is expected to maximize quality assurance. This method involves immersing the product in water and applying air pressure.

RESULT AND DISCUSSION

Bubble Test

The fabrication of fixtures, jigs, and clamping is necessary for bubble checking, with the base touching soft material products to avoid scratching or damaging other products. The clamping jig system can ensure that no air leaks through the jig, ensuring maximum testing accuracy by holding air pressure inside the product. Thus, when immersed in water, the air pressure within the product follows standard specifications and can push out air if there is porosity in the product. Verification of bubble testing for suspect claim products is required to ensure correlation with the results of the air leak tester, which cannot detect these claimed parts.

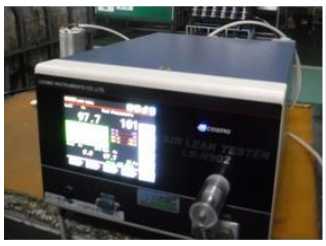
No	Sample	Waterleak				
		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1	NG A	Bubble	Bubble	Bubble	Bubble	Bubble
2	NG B	Bubble	Bubble	Bubble	Bubble	Bubble
3	NG C	Bubble	Bubble	Bubble	Bubble	Bubble
4	OK	No	No	No	No	No

Figure (8) Bubble Test Data for Suspect Parts

The testing results of all sampled suspect claim parts detected bubbles, correlating this bubble testing process with the leaks occurring in customers' hands. The bubbles that appeared were bursts with varying intervals, and the pressure applied to the product adhered to the specified standard drawing of 98Kpa.

Air leak & Bubble Test (Combination)

Seeking correlation between air leak test results and bubble tests by measuring air leaks simultaneously with the product immersion process in water or bubble testing.



No	Sample	Leak Test				
		Leak 1	Leak 2	Leak 3	Leak 4	Leak 5
1	NG A	3.07	2.82	3.03	2.97	2.86
2	NG B	3.13	2.86	2.91	3.03	2.56
3	NG C	3.76	2.78	3.03	2.82	2.82
4	OK	2.71	2.75	2.81	2.34	2.48

Figure (9) Data Combination of Air Leak & Bubble Test

No changes in part bubbles were found from the data; the air leak results still met standard specifications, while parts that did not produce bubbles had leak results similar to those that did.

Parameter Cosmo Air Leak Tester

Testing the bubble occurrence rate with several changes to cosmo air leak tester parametersas measures of leak results or product pressure levels, both in balancing, charging,and calculation.

No	Sample	Leak Test Pressure 0.2Mpa				
		Leak 1	Leak 2	Leak 3	Leak 4	Leak 5
1	NG A	3.02	2.98	3.03	2.97	2.96
2	NG B	3.02	2.8	2.9	3.03	2.98
3	NG C	3.52	2.72	3.02	2.82	2.81
4	OK	2.71	2.72	2.86	2.32	2.48

Figure (10) Pressure 0.1 Mpa → 0.2 Mpa

No	Sample	Leak Test Charging 20sec				
		Leak 1	Leak 2	Leak 3	Leak 4	Leak 5
1	NG A	2.87	2.82	2.87	2.72	2.76
2	NG B	2.81	2.96	2.82	2.69	2.91
3	NG C	2.76	2.72	2.69	2.67	2.61
4	OK	2.52	2.46	2.52	2.54	2.58

Figure (11) Cycle Time 13 sec → 20 Sec

Changes in cycletime balancing, charging parameters in cosmo air leak tester, or additional pressure did not affect the bubble detection capability of the product.

Figure (12) Bubble Cylinder Scale

The measurement results of the number of bubbles coming out of the product corresponded to the levels shown in the cosmo air leak tester; however, the bubbles had intervalsor increased levels, while in the cosmo air leak tester, the pressure levels were the result of calculations of the leak rate differentiation between the chamber and the product.

Leak Method Verification

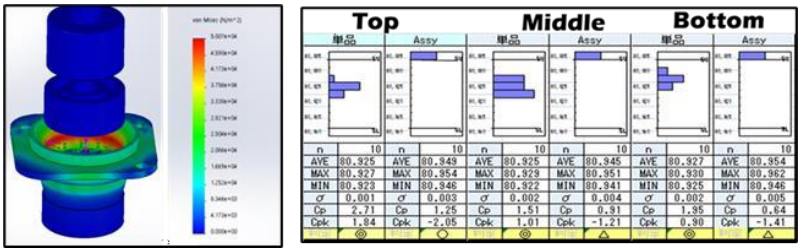
The bubble check detection process with immersion systems on suspect parts was compared using manual bubble check with Test Soap on the Air Leak Tester machine, with similar results of detected bubbles, although the values from the cosmo air leak tester machine still showed OK.

No	No Lot	Part	A. Waterlak	B. Bubble Check	C. Leak Tester	Note
1	12112025	NG (Claim)	Bocor	Bocor	1.37 cc/min	
2	12112032	NG (Claim)	Bocor	Bocor	0.28 cc/min	
3	12112013	NG (Claim)	Bocor	Bocor	2.75 cc/min	
4	12112012	NG (Claim)	Bocor	Bocor	2.09 cc/min	
5	12012398	NG (Claim)	Bocor	Bocor	1.62 cc/min	

Figure (13) Comparison of Leak Methods

Deformation

The Transfer Holder part condition, when becoming child parts, although bubbles appeared, the cosmo air leak tester always showed OK values. However, when it became a unified Transmission Assy unit, the cosmo air leak tester detected leakage val-ues, prompting deformation analysis by measuring using a 3D CMM (Coordinate Measuring Machine) both before and after assembly.



No	Diameter		N1	N2	N3	N4	N5	AVE
1	∅81 -0.068 -0.088	Before	80.922	80.926	80.928	80.924	80.924	80.925
		After	80.961	80.968	80.971	80.968	80.956	80.965
		GAP	0.039	0.042	0.043	0.044	0.032	0.040
2	∅98 -0.053 -0.073	Before	97.938	97.935	97.938	97.934	97.937	97.936
		After	97.967	97.967	97.975	97.968	97.969	97.969
		GAP	0.029	0.032	0.037	0.034	0.032	0.033

Figure (14) Parts Dimension Table

From the data, in the two areas where the diameter received press bearing treatment during the assembly of the taper bearing, there was a dimensional change. The diameter showed enlargement due to deformation, approximately 33~40 microns. This is concerning as it may increase porosity in the material, leading to leaks when the bearing is installed.

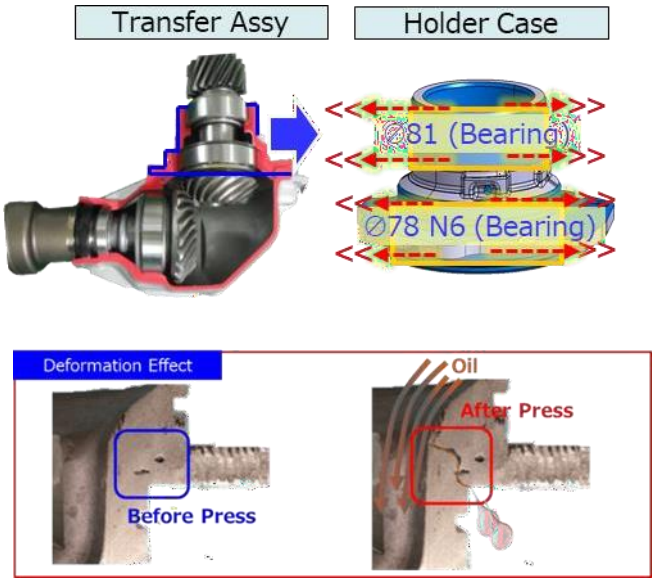


Figure (15) Deformation Illustration

Based on the dimensional changes, parts measurement trials were conducted with the bearing installed condition, and air leak tester testing was performed.

No	Part Trial Bearing Standard ±8cc /min	Hasil Leak Before (Tanpa Bearing)	Judgement	Hasil Leak After (Terpasang Bearing)	Judgement	Noted
1	14114045	2.7 cc/min	OK	8.2 cc/min	NG	Internal
2	14114034	3.5 cc/min	OK	9.3 cc/min	NG	Internal
3	14114013	3.8 cc/min	OK	9.1 cc/min	NG	Internal
4	14114014	3.5 cc/min	OK	8.3 cc/min	NG	Internal
5	14014398	4.6 cc/min	OK	8.3 cc/min	NG	Internal

Figure (16) Installed Bearing Trial Table

The cosmo air leak tester can detect leaks when parts have bearings installed; however, this condition cannot be applied in the production system because bearing installation is done in a different area and would incur very high costs.

Merging Leak Test Processes

Several factors influence the occurrence of leaks in aluminum casting, whether as child parts, during assembly, or when used in a vehicle. Quality assurance for leaks cannot guarantee 100% effectiveness when external factors are involved. Strengthening quality assurance can be done by considering QCDMS

factors, especially cost, which is a crucial item in the manufacturing process due to mass production.

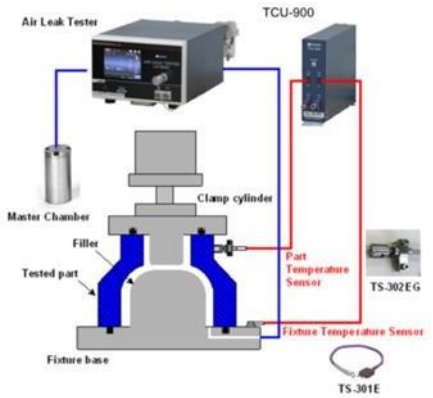


Figure (17) Instrument LS-R902 (Https://www.cosmo-k.co.jp/, n.d.)

The common quality assurance method used in the automotive industry employs the air leak tester method with cosmo air leak tester as the measuring tool for every produced product's value. A value becomes crucial as production history data and refers to the drawing, which sets the leakage value for each product. Based on trial results and considering QCDMS values, the water leak method with immersion systems can be merged with the existing air leak tester process in mass production.The water leak process can minimize deformations that may cause leaks, enabling early detection by sorting products that produce bubbles as an indication of NG (Not Good) leaks during assembly into assembling units.

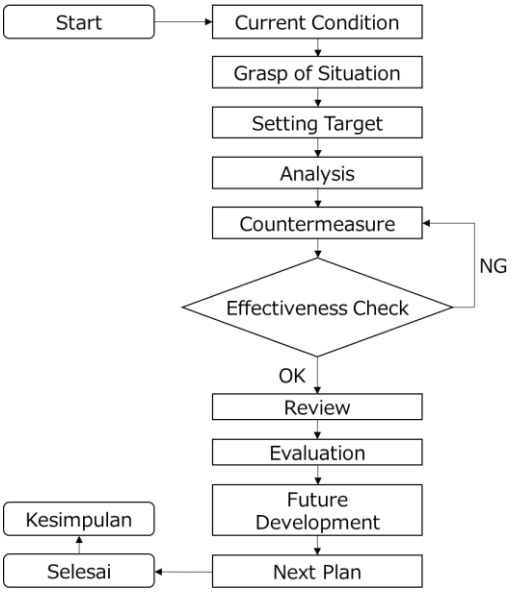


Figure (18) Research Methodology Stages

Various stages of research methodology have been conducted, including comparing cosmo air leak tester testing with Arduino as a testing tool comparison against cosmo air leak tester.Regarding sensitivity and stability values for using Arduino in mass production, it is less efficient compared to cosmo air leak tester. Operational factors in mass production, durability, and cycle time are taken into consideration in its application.

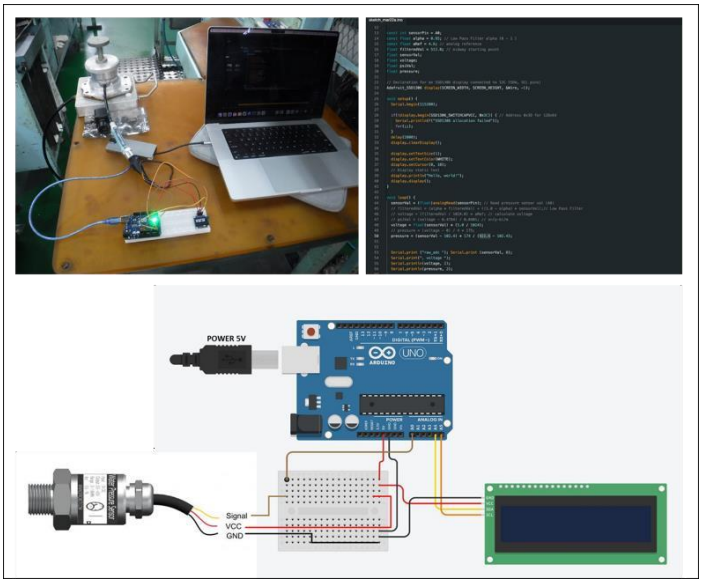


Figure (19) Arduino Leak Test

Quality assurance methods will merge wet and dry methods to be used for quality assurance in mass production at PT.XYZ. The addition of the bubble test method with water immersion essentially follows the existing system in the previous machine, using automation to match the mass production flow at PT. XYZ. Parameters and references from the previous Air Leak Tester machine include:

1. Use of Cosmo Air Leak Tester
2. Cylinder Clamp System
3. Machine Cycle Time 55"
4. Keyence Safety Sensor
5. Mitsubishi Fx Series PLC Machine
6. Maximum Air Pressure 0.5 Mpa Facility
7. Existing Machine Dimensions
8. Production Capacity
9. Maximum Machine Modification Cost < $10,000;
10. Safety Declaration Manual Book

The above items are to be incorporated using equipment from the previous air leak tester machine, reflecting the addition of items in the water leak process. Safety is a concern in the mass production machine category to ensure safe use by production operators.

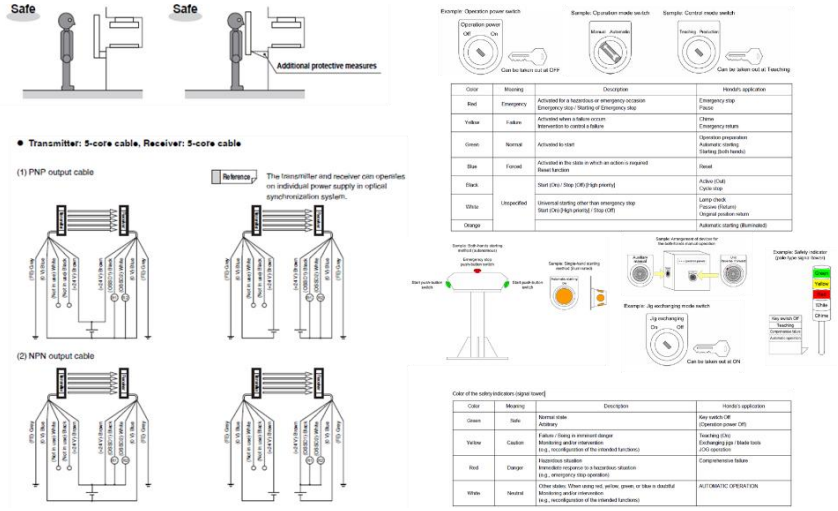


Figure (20) Safety Specification Sheet
(Https://www.keyence.co.id/, n.d.; PT.XYZ, n.d.)

CONCLUSION

The air leak tester method has not been able to identify leaks caused by deformation during the assembly of parts, with a deformation value reaching up to 40 microns. Even with an increase in cycle time from 13 seconds to 20 seconds or an increase in pressure from 0.1 Mpa to 0.2 Mpa, there is no significant change in the results. On the other hand, the water leak method provides an early indication of potential leak positions in a vehicle transmission by detecting bubbles. Essentially, not all products that show bubbles will necessarily have a leak in the transmission because of the difference in viscosity between the fluid used in the water leak test and the oil in a transmission. However, the air leak value from the Cosmo Air Leak Tester is similar to the bubble magnitude that appears, and it can be confirmed that all products experiencing leaks at the customer showed bubbles during the water leak process. Thus, the water leak process can be a solution for ensuring early detection of potential leaks.

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