Experimental Test of Simultaneously Compression Tester to Detect Compression Pressure Leakage on Gasoline Engines

I Wayan Marlon Managi[1], I Putu Darmawa[2], and I Komang Rusmariadi[3]

[1,2,3] Mechanical Engineering Department, Politeknik Negeri Bali, Bali, Indonesia
marlon_managi@pnb.ac.id

Abstract. The use of vehicles in Indonesia is currently dominated by motorized vehicles, and not all of these land vehicles are in optimal condition regarding their combustion engines. This situation can lead to exhaust gases from vehicles that do not burn fuel completely, which can increase air pollution. Residual combustion exhaust gases include Carbon Monoxide (CO), Carbon Dioxide (CO_2), Nitrogen oxide (NO or NOx), and Hydrocarbons (HC). An important factor in motorized vehicles to achieve exhaust gas quality standards is the complete combustion process. If any of these supporting components experience issues, it will result in incomplete combustion, leading to vehicle exhaust emissions below standards. In addressing this issue and diagnosing combustion system malfunctions, misdiagnoses frequently occur. Therefore, a compression pressure leakage detection tool for gasoline engines is a suitable alternative as a Special Diagnostic Tool (SDT) to minimize diagnostic errors. Regarding this matter, the author proposes research on the Design and Experimental Testing of a compression leakage detection tool to measure pressure in the cylinders. This research is important because compression pressure measurement can be conducted simultaneously, saving diagnostic time before further repair steps are taken. The method applied in the research is experimental, starting with the Design and Development of the tool using CAD (Computer Aided Design) software assistance. This includes creating 3D working drawings, manufacturing and assembling the tool, preparing the research equipment, and collecting pressure data and analyzing using paired t-test. The sampling time will be compared with the test car's data sheet for reference.

Keywords: CAD Design, Combustion Motor, Compression Leakage, Paired t-test, Pressure Gauge, Simultaneously Compression Tester

1 Introduction

In Indonesia, the use of vehicles is currently predominantly by motorized vehicles. The total number of motorized vehicles in the country was recorded at 159,365,883 units (Statistik Transportasi Darat, 2023). Among those vehicles registered in

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transportation statistics, not all have optimal condition for their combustion engines. This situation can lead to incomplete combustion, resulting in high emission of exhaust gases that contribute to increased air pollution (Machmud, 2021). The exhaust gases from the incomplete combustion process include Carbon Monoxide (CO), Carbon Dioxide (CO_2), Nitrogen oxide (NO or NOx) (Momani, 2017), and Hydrocarbons (HC). Carbon Dioxide (CO_2) is a significant contributor to global warming, particularly in areas with insufficient vegetation to convert CO_2 into Oxygen (O_2). The emissions from vehicle exhaust gases cause several dangers, including 1) damage to the respiratory system, and 2) carcinogenic properties.

A critical factor for achieving emission standards in motorized vehicles is a good combustion process inside the combustion chamber (Machmud, 2021). A complete and good combustion process is achieved when the combustion system operates effectively (Mormon & Astuti, 2020). The system components involved in the combustion process included the fuel, the fuel supply system (whether carburetor or injection), the ignition system, and the combustion chamber. For motorized vehicles using pistons as part of the combustion system, several components are involved: the engine block, piston (cylinder), piston rings, cylinder head, and valve seals. Any issues with these supporting components can result in incomplete combustion. It leads to exhaust emissions below standard (Mormon & Astuti, 2020). Diagnosing problems in this system often leads to incorrect diagnoses. For example, a common mechanical error involves diagnosing when a vehicle emits excessive smoke. Incorrect diagnosis can lead to inflated repair costs, as the problem may not be solely attributable to piston ring damage. There are two types of piston rings: compression rings and oil rings (Turnbull et al., 2020).The condition of excessive smoke may not only result from compression leakage (Junipitoyo, 2017) in the piston cylinder but also originated from valve seals and valves (Turnbull et al., 2021).

Based on these problems, a compression tester that can measure pressure simultaneously for gasoline engines is needed as a Special Diagnostic Tool (SDT) (Berthome et al., 2021). However, compression testers in the industry only can measure the pressure of one piston (Wilantara & Rahardjo, 2019). This method has several disadvantages, including the time required to check all pistons, the inability to display measurement data concurrently, and suboptimal measurement precision. Therefore, this study proposes the design and development of a simultaneous compression tester, along with an experimental evaluation of the device. With four digital gauges, the device can be used to check the compression pressure of engines with three to four pistons. It is compatible with various piston configurations, including inline, V-engine, and boxer types. This simultaneous compression tester tool enhances diagnostic efficiency by allowing simultaneous installation on all spark plug locations, using digital indicators, and requiring only one operator. In comparison, standard compression testing tools typically require two operators for installation and result reading, along with an additional operator for engine starting. The designed tool can provide accurate measurement results, it makes the research process more practical and efficient.

2 Methodology

In this study, the test car is a 1990 Mazda 626 SOHC 12-valve inline 4-cylinder 2000cc. Detailed specifications are provided in Table 1 (Mazda, 1988). The methodology used in this research is an experimental approach that involves observing instruments designed to measure compression pressure simultaneously. The device will be designed to accommodate four pressure gauges with a pressure reading range of 0-20 bar. Mazda 626 was selected as the test vehicle due to its age already 34 years (Asa et al., 2019). This allows for the assumption that material fatigue has likely occurred in both the compression rings and oil rings (Machmud, 2021). The research used four digital pressure gauges with a pressure reading range of 0-20 bar. The design of the device will be executed using CAD (Computer-Aided Design) (Łukaszewicz, 2017). The CAD design will be analyzed to determine the optimal design with the lowest displacement, based on the stress analysis of the frame, as shown in Figure 1. The selected frame design will be manufactured using a 3D printer using PLA+ as a filament to hold the pressure gauges and equal-angle iron as a frame. Collected data from pressure measurement and then analyzed using paired t-test. Paired *t-test* is a statistical test used in hypothesis testing to determine whether a process or treatment has an effect.

Table 1. In-depth details on the specifications of the car test unit

Engine model		FE 2000 12 valve
Type		Otto engine four strokes
Cylinder type		Inline 4
Valve		SOHC timing belt
Capacity (cc)		1,998
Compression Ratio		9.5 : 1
Pressure Compression	Standard	14.5
(kg/cm3)	Minimum	10.2
Firing Order		1 – 3 – 4 - 2

Table 2. Pressure gauge specification

Pressure gauge type	Digital pressure gauge
Type	Gauge pressure
Accuracy	1%
Power	3V (2 pieces AAA battery)
Screen	4-digits LCD Screen
Data Memory	Permanent EEFROM
Units	kPa, PSI, Kgf/cm2, Bar

3 Result and Discussion

3.1 3D Design And Simulation Result

Based on the results of the frame analysis simulation conducted in the CAD program, a 5-kilogram load was applied in the stress analysis to determine the displacement along the Z-axis. The optimal frame design was identified as design Version 2 due to its smaller displacement result on the Z-axis.

Table 3. Displacement along the axis of the frame

Axis	Design version 1	Design version 2
X-axis	0.134 mm	0.207 mm
Y-axis	0.209 mm	0.541 mm
Z-axis	1.263 mm	1.041 mm

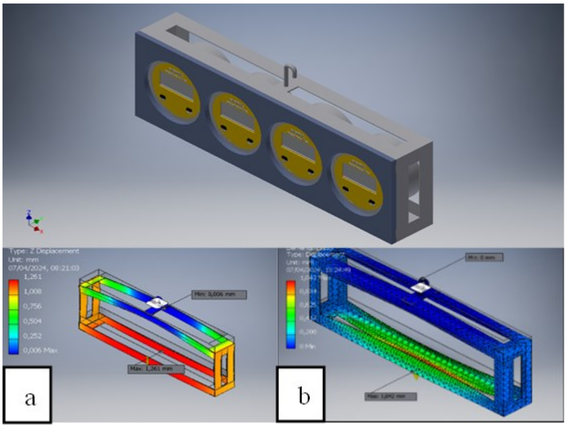

Figure 1. (a) Frame design version 1. (b) Frame design version 2

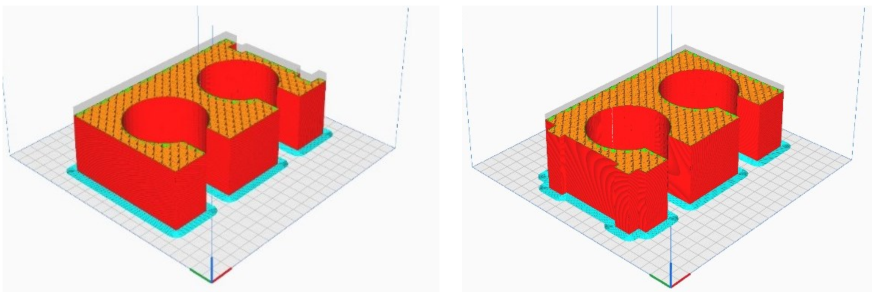

Figure 2. Frame generated from CAD and exported to Cura Program to Print on 3D printer

3.2 Paired samples t-test

A paired samples t-test is used to compare the means of two samples of time required and pressure measurement between manual compression tester using manual/analog with simultaneously compression tester device.

$$T = \frac{\bar{d}}{\left(\frac{S_d}{\sqrt{n}}\right)} \tag{1}$$

$$d_f = n - 1 \tag{2}$$

where,

$\bar{d}$: sample mean of the differences

S_d : sample standard deviation of the differences

n : sample size

d_f : degree of freedom

Two-Sample T Test Hypotheses used in this study are :

a. Null hypothesis (H0) : no significant effect between manual and simultaneously measurement.
b. Alternative hypothesis (H_A) : there is a statistically significant difference between manual and simultaneous measurement

For industrial purposes significant level α = 0.10 for two-tails test

Table 4. Measuring result

No of Piston	Manual (psi)	Simultaneously compression (psi)	differences (d)
1	130.5	131.9	1.4
2	137.7	137.7	0
3	130.5	133.4	2.9
4	130.5	131.9	1.4
Average	132.3	133.725	1.425
Standard deviation (S_d)	3.6	2.742	1.184

From Equation (1) and (2) calculation result for "t value" based on Table 4 is t= 2.406 compared to "t table" at purposes significant level α = 0.10 is 2.353 we can reject Null hypothesis (H0). That indicates there is a statistically significant difference in pressure measurements between using simultaneously compression tested compare to manual compression tester, alternative hypothesis (H_A) accepted.

Table 5. Time required for measurement

No of piston	Manual (seconds)	Simultaneously compression (seconds)	differences (d)
1	90	61	-29
2	78	60	-18
3	69	60	-9
4	61	59	-2
Average	74.5	60	-14.5
Standard deviation (S_d)	12.449	0.816	11.676

Same result of calculation from Equation (1) and (2) calculation result for "t value" based on Table 5 is 2.483 compared to "t table" at purposes significant level $\alpha = 0.10$ is 2.353 we can reject Null hypothesis (H0). That indicates there is a statistically significant difference in time required to measure the pressure between using simultaneously compression tested compare to manual compression tester, alternative hypothesis (H_A) accepted.

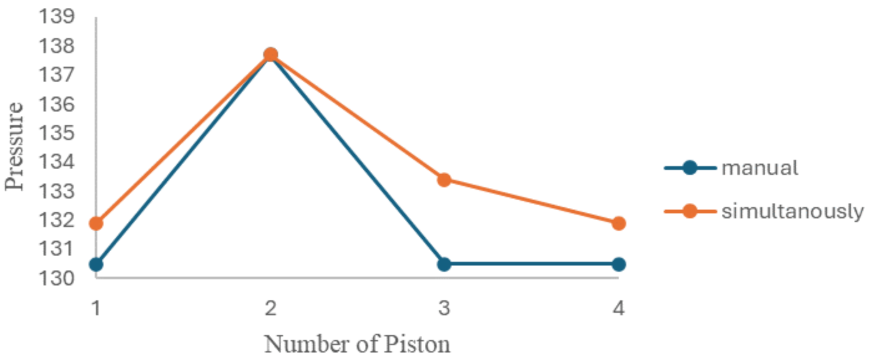

Figure 3. Comparison of pressure measurement result

As illustrated in Figure 3, the simultaneous compression tester provided more accurate measurement results compared to manual compression tester. The used of a simultaneously compression tester for measuring compression leakages in internal engines allows for a shorter diagnostic time. Specifically, while the manual compression tester required 298 seconds and the simultaneously compression tester it required 240 seconds.

4 Conclusion

After completing the design in the CAD program, the optimal frame design identified as Design Version 2 based on smaller displacement result on Z-axis This design has displacement values of 0.207 mm along the X-axis, 0.541 mm along the Y-axis, and 1.041 mm along the Z-axis, as detailed in Table 3. Paired t-test result indicated that simultaneously compression tester can measure pressure in piston chamber more acurate compared to manual compression tester in range 130.5 psi - 137.7 psi. Compared to data sheet engine in good condition the compression pressure should be around 145.03 psi -210.30 psi. Based on these analysis device has successfully detected compression pressure leakage in the gasoline engine. Compared to the manual compression tester, the simultaneous compression tester demonstrates an improvement in measurement time efficiency of 19.46%.

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