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Operating performance of a simple hydraulic dynamometer using vane pump

Iman Kasih Telaumbanua[1], Yoshihiko Oishi[*1], Kosuke Imai[1], Yogie Probo Sibagariang[2], Hideki Kawai[1]

[1]Division of Production Systems Engineering, Muroran Institute of Technology, 27 -1 Mizumoto, Muroran, Hokkaido, 050-8585, Japan
[2]Research Center for Energy Conversion and Conservation, National Research and Innovation Agency (BRIN), Indonesia
[*]Corresponding Author: oishi@muroran-it.ac.jp

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ABSTRACT

To investigate engine performance in detail, a high-precision power-loading device is required. Many regions and countries need to develop sustainable engines and fuels, and so there is a demand for simple engine performance investigations. In this study, a simple hydraulic dynamometer using a vane pump for engine testing was developed and its operational performance was investigated. A single-cylinder diesel engine was used as the prime mover. The load on the prime mover was controlled by controlling the discharge flow rate. All tests were performed with the prime mover rotation speed set at 2400 rpm. Torque was obtained from the measured value of load cell value and an equation with the discharge flow rate and discharge pressure of the vane pump. The experimental results showed that the torque was calculated by absorbing the power of the prime mover. However, there was a discrepancy between the experimental results and numerical calculations. This difference could be compensated for by considering the moment generated in the device. In addition, it successfully applied torque for diesel operated in different fuel such as diesel and emulsified diesel fuel. Time series data for torque using different fuels has been presented and showing the clear fluctuations difference for each fuel sample.

Keyword: Dynamometer, Hydraulic power, Vane pump, Diesel engine, Torque

1. Introduction

The increase in global temperature is one of the indicators of global warming caused by the increase of greenhouse gases (GHGs) in the atmosphere. Fossil fuels, which have been used as an energy source since the industrial revolution, are the primary source of GHGs emissions. As global warming intensifies, it poses a serious threat to environmental stability and human well-being, as illustrated in Table 1. The Glasgow Climate Pact [1, 2] that adopted at COP26 decided to pursue the "1.5°C target" to limit the global temperature increase to 1.5°C. To achieve this target, it is important to reduce GHG emissions over a 10-year until 2030. Moreover, achieving net-zero greenhouse gas emissions by 2050 is critical in addressing global warming, according to the International Energy Agency [3]. One potential solution lies in further research on internal combustion engines, which can focus on advancing fuel technology and combustion methods, as well as integrating these engines into advanced systems.

The dynamometer, as part of the braking system, requires development to enhance the loading capability of the power engine. It plays a crucial role in simulating real driving conditions. The most widely used type today is the electric dynamometer, but its complex structure tends to result in high design costs [4]. Therefore, the hydraulically driven dynamometer, with its simple design and excellent load accuracy, advances engine research in environments lacking sufficient engine development resources. As shown in Table 2, a comparison with other dynamometers highlights that the basic hydraulic dynamometer has attracted researchers because of its straightforward structure and its use of a working fluid that is compatible with engine components. Additionally, transitioning to a hydraulic dynamometer can reduce the engine's specific fuel consumption. With advancements in the applied load mechanism, we can expect an increase in output torque, which in turn can decrease the amount of fuel required [5].

The technology related to hydraulic dynamometers is currently in a continuous development phase, focusing on both system and design aspects [4, 6, 7]. The more severe the environmental issues become, the greater the need to continue using internal combustion engines. However, environmental problems tend to be more severe in regions where engine development environments are inadequate. To establish an engine development environment that more readily solves environmental issues such as exhaust emissions, it is essential to develop a power test bench that is affordable and has a simple structure. Therefore, the objective of this research is to develop a low-cost, simple hydraulic power test bench system suitable for diesel engine operation. The hydraulic dynamometer designed in this study operates based on the mechanism of a vane pump, which absorbs power using oil as the working fluid. This approach leverages the characteristics of fluids, making it easier to maintain accuracy in performance based on thermodynamic and hydrodynamic principles. The feasibility of using a hydraulic dynamometer to apply load torque to the engine is assessed by comparing the torque measurements from the load cell with the torque generated by the working fluid.

Table 1. Predicted Impacts of global warming on the environment [8].

Affect	Raised temperature	
	1.5℃	2℃
Flood (population affected)	100% increase	170% increase
Summer sea ice in the Arctic Ocean (possible disappearance)	Once in 100 years	Once in 10 years
Sea level rise (average sea level rise through 2100)	0.28-0.55m	0.33-0.61m
Drought (population affected)	950 million people	1.15 billion people
Food (cost of crop response)	63 billion US dollar	80 billion US dollar
Ecosystem (coral reef decline)	70-90%	99%

Table 2. Brake dynamometers [9].

Friction Dynamometers	Proni dynamometer
	Rope Dynamometer
Hydro Dynamometer	Disc type dynamometer
	Junkers type dynamometer
	Flood type dynamometer
Electric Dynamometer	DC dynamometer
	AC dynamometer
	Eddy current dynamometer
Air Dynamometer	Lunar Air Dynamometers

2. Experimental apparatus and methods

In this study, we conducted torque measurement experiments on a prime mover using a simple hydraulic dynamometer that is based on a vane pump. The experiments aimed to investigate the operational characteristics of the hydraulic dynamometer. A schematic diagram of the device is presented in Fig. 1. The dynamometer system comprises a balanced vane pump (YUKEN Kogyo, PV2R1-6-F), a load cell (Tokyo Sokki Research Laboratory, CLS-200NB), a flow control valve (TAIYO, 8F1200S), a prime mover, and a pressure gauge. The system utilizes the mechanical power from the prime mover, which is applied to the rotating shaft of the vane pump to allow the rotor of the vane pump to rotate. As the rotor turns, it drives the vanes along its circumference, drawing in and discharging hydraulic fluid. The rotation of the rotor generates shear stress in the rotational direction. The shear stress acting on the casing of the vane pump causes it to rotate. The torque generated by the prime mover can be calculated by measuring the reaction force using a load cell. This load on the prime mover can be adjusted by controlling the discharge flow rate with a flow control valve. The data recorded by the load cell was collected using a data logger (Graphtec, GL900-4). A single-cylinder diesel engine (Fuji Heavy Industries, DY27D) served as the prime mover, with specifications outlined in Table 3. The engine's maximum torque is 12.8 Nm at 2400 rpm.

To measure fluid pressure, a pressure gauge is installed on the hydraulic oil discharge side, and a coupled gauge is placed on the hydraulic oil suction side. The specifications of the dynamometer are detailed in Table 4. The dynamometer is classified as a brake dynamometer, capable of absorbing a maximum power of 15.3 kW at a maximum permissible speed of 1800 rpm. It has a maximum working pressure of 14 MPa and a theoretical pump displacement of 5.8 cm^3/rev. The arm length from the dynamometer's rotating shaft to the load cell measures 0.135 m.

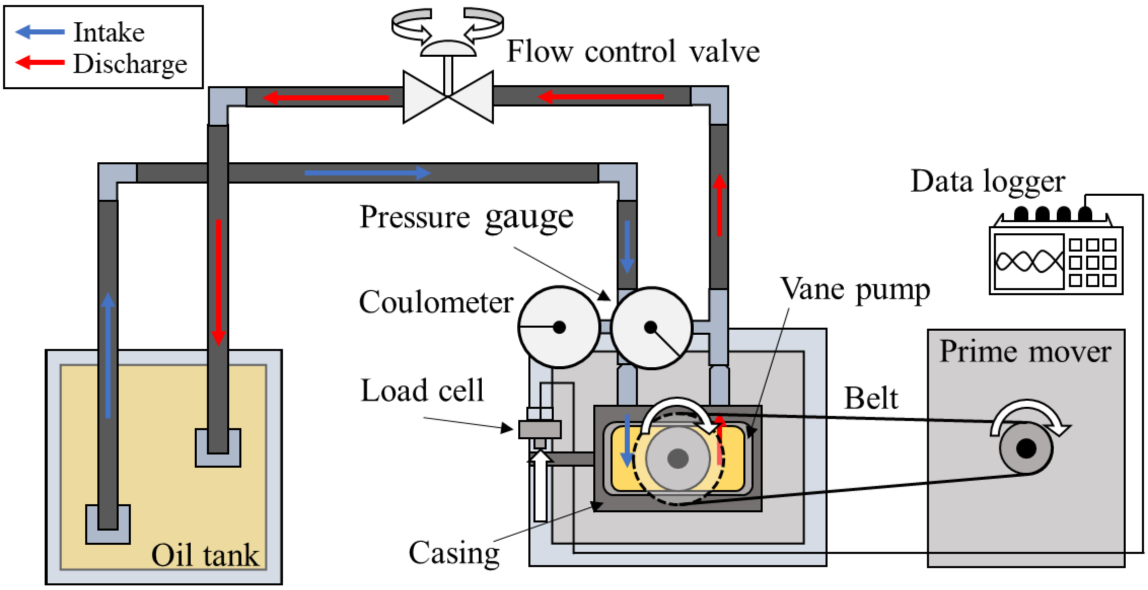


Figure 1. Simple hydraulic dynamometer schematic.

Table 3 Prime mover specifications

Type	Air-cooled, 4-Cycle, Vertical, Overhead Valve, Single Cylinder Diesel Engine
Bore × Stroke	75×60 mm
Piston Displacement	265 cc
Compression Ratio	21
Maximum Torque	12.8 Nm (2400 rpm)

Table 5 presents the experimental conditions for torque measurement. The rotation speed of the prime mover was set at 2400 rpm, while the dynamometer's rotation speed was adjusted to 1080 rpm, reflecting a pulley ratio of 0.45 between the engine and the dynamometer. The prime mover was powered by diesel and emulsified diesel contains 20 vol.% and 30 vol.% of waters. Each measurement was conducted three times. In the outcomes section, we illustrate the correlation between the produced torque and variations in discharge pressure, along with the validation of torque measurements obtained from both the load cell and the hydraulic dynamometer.

Table 4 Simple hydraulic dynamometer specifications

Type	Brake dynamometer
Working fluid	Oil
Maximum absorbing power	15.3 kW/1800rpm
Maximum absorbing torque	81.2 Nm
Maximum allowable rpm	1800 rpm
Minimum allowable rpm	750 rpm
Maximum working pressure	14 MPa
Theoretical push-off volume	5.8 cm^3/rev
Moment arm	0.135 m

Table 5 Experimental conditions

Prime mover rotation speed	2400 rpm
Dynamometer rotation speed	1080 rpm
Pulley ratio	0.45
Fuel	Diesel, W20/D, and W30/D

3. Results and discussions

Figure 2 illustrates the relationship between the flow rate and pressure of the discharged hydraulic fluid of the vane pump. The vertical axis represents the discharge pressure, while the horizontal axis indicates the discharge flow rate. Each measurement was conducted three times; the plotted data represent the average values, and the error bars indicate the standard deviation from the number of trials conducted.

This dynamometer regulates the load on the prime mover by adjusting the discharge flow rate of the hydraulic fluid. As the outlet flow rate increases, the outlet pressure decreases. Specifically, the discharge pressure starts at 0 MPa when the discharge flow is 125 cm^3/s and rises to 6 MPa at a flow rate of 100 cm^3/s. This behaviour is closely linked to the dynamics of the moving fluid. When the cross-sectional area of the flow increases, leading to a higher flow rate, the pressure decreases further. These results reflect the performance of the vane pump and demonstrate that the experiment has high reproducibility, confirming that the flow is operating normally.

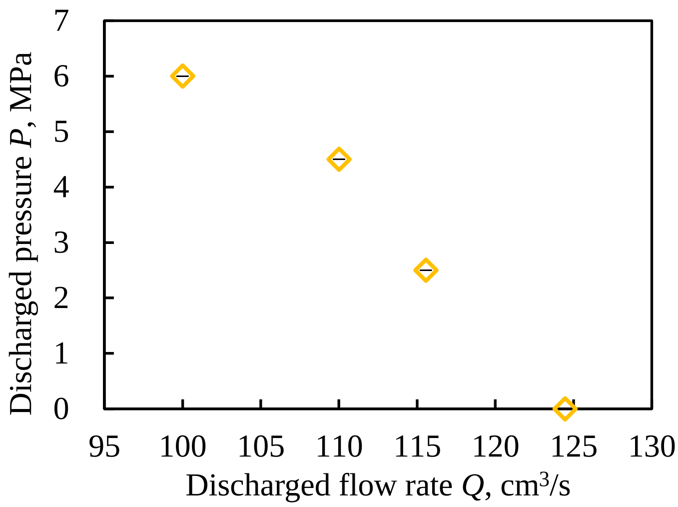


Figure 2. Relationship between discharged flow rate Q and discharged pressure P.

3.1 Relationship between Output torque and discharge pressure

In this section, we will derive the output torque and discharge pressure to estimate the torque of the simple dynamometer we have developed. Since the output torque is measured using a load cell, we can express the calculation of the output torque T_{out} as shown in Eq (1).

$$T_{out} = FL \tag{1}$$

where, the force produced by the rotating vane pump, denoted as F [N], is measured by the load cell, while L [m] represents the distance between the center of the rotation axis of the dynamometer and the load cell. Figure 3 illustrates the measurement results of the T_{out}. Similar to the previous figure, the plotted data shows the average values, and the error bars indicate the standard deviation from three trial measurements. The vertical axis represents the T_{out}, while the horizontal axis represents the discharge pressure P. The results indicate that the T_{out} increases as the discharge pressure P increases. This increase suggests that the power absorbed by the dynamometer from the prime mover also rises.

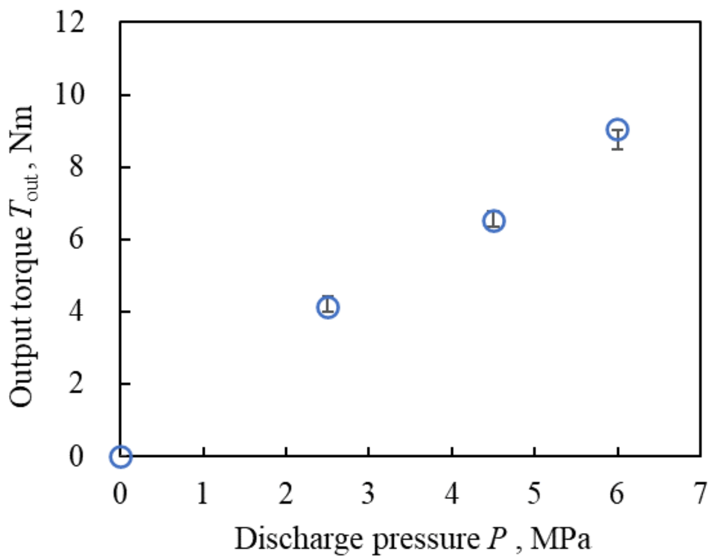


Figure 3. Relationship between Output torque T_{out} and Discharge pressure P.

3.2 The actual driving torque

The theoretical torque T_{th} can be obtained using Eq. (3) under ideal conditions at the input and output of the vane pump. Where push-off volume V_{th} [cm^3/rev] is the volume of working fluid pushed off per unit revolution of the vane pump [10].

$$T_{th} = \frac{V_{th}}{2\pi} P \tag{2}$$

Using the above equation, the relationship between T_{th} and P in Fig. 4. The change in P is directly proportional to the increase in T_{th}. The actual driving torque stands for the total of the theoretical torque T_{th} combined with the ΔT which is the total of frictional torque, viscous torque, and device-specific torque. Therefore, it can be expressed as shown in the following Eq. (3).

$$T_d = T_{th} + \Delta T \tag{3}$$

For friction torque ΔT is the force that occurs due to contact between the vane tip and cam contour on the vane pump. ΔT is a combination of friction torque at the vane tip T_n, viscous torque T_v, and device specific torque T_{as} as stated in Eq. 4.

$$\Delta T = T_n + T_v + T_{as} \tag{4}$$

Due to the dynamometer setup, T_{as} is given by the Eq. 5.

$$T_{as} = m_p g L_g \sin\theta \tag{5}$$

Where the $m_p$is the mass of the pipes, g is the acceleration of gravity, $L_g$stands for the distance between center of gravity (CoG) and a center axis of the vane pump, and θ is the displacement centre of gravity due to the rotation of vane pump. The mass of the pipe mp is 10 kg according to the specification, and the gravitational acceleration g is 9.81 m/s^2. The distance L_g from the CoG of the device to the center of rotation is 0.2216 m according to the 3D CAD model. The diagram of 3D model can be seen in Fig. 5. The CoG itself can be obtained automatically in the model based on the mass distribution of the system.

Thus T_d can be written as follows:

$$T_d = \frac{V_{th}}{2\pi} P + m_p g L_g \sin\theta \quad (6)$$

Because their values are very small, an exception is made for T_n and T_v. Based on the calculation, the relationship between T_{as} and θ values are shown in Fig. 6.

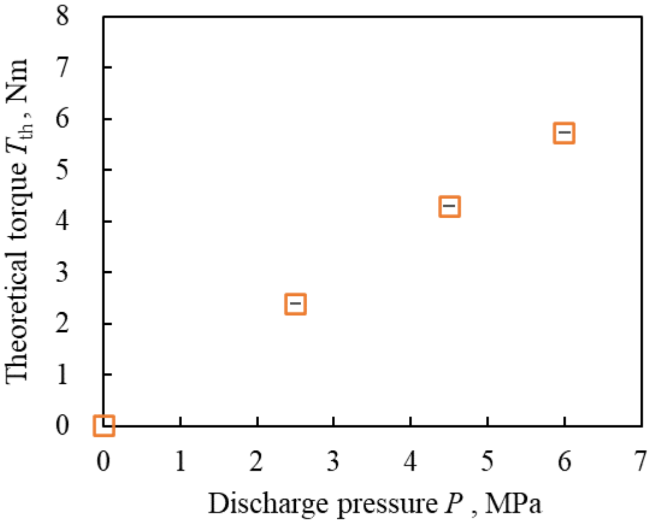
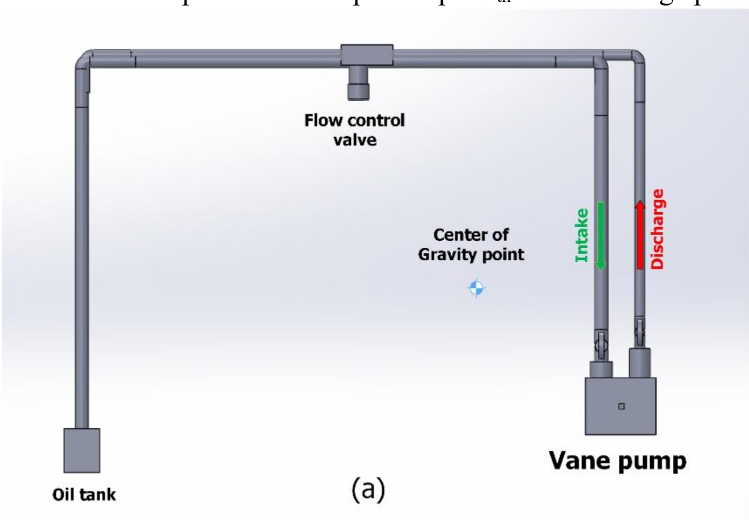


Figure 4. Relationship between Output torque T_{th} and Discharge pressure P.



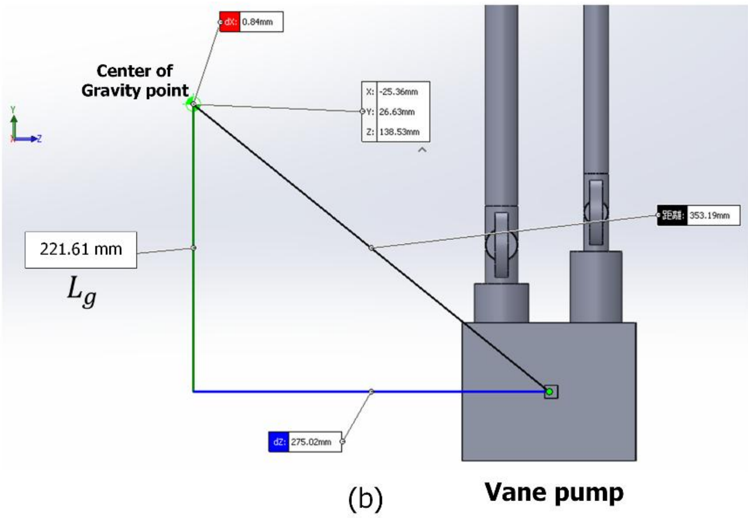


Figure 5. 3D Model of the Hydraulic Dynamometer System: a) Overall View, b) CoG View.

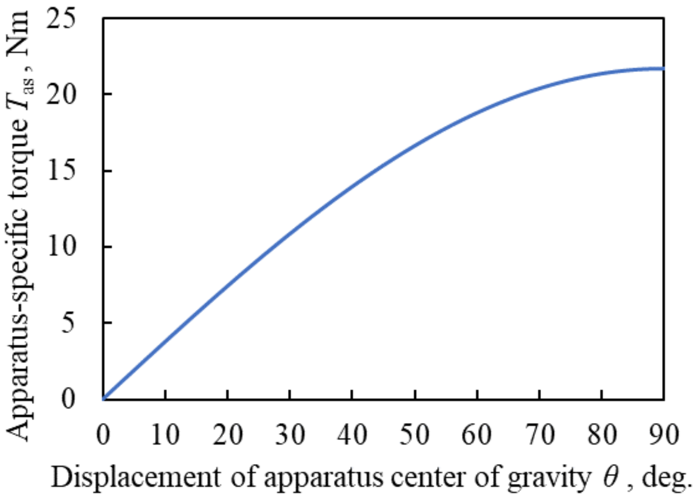


Figure 6. Relationship between T_{as} and θ.

The displacement of the center of gravity due to the force absorbed by the dynamometer causes the value of T_{as} to increase as θ increases. This is, of course, due to the temporary change in the center of gravity of the system when the dynamometer is running. Thus, when combined with P, a linear graph is also obtained, as shown in Fig. 7. Finally, the book calculates T_d by inputting the value of T_{as}. The relationship between these values is shown in Fig. 8. These values exhibit a trend similar to that shown in Fig. 3. This indicates that the apparatus system is reliable, as it produces close values when these trends are compared. A comparison of the actual torque value with the measured torque is shown in Fig. 9. There is a slight gap between the trend of the T_{out} and T_d graphs, but the difference is still acceptable.

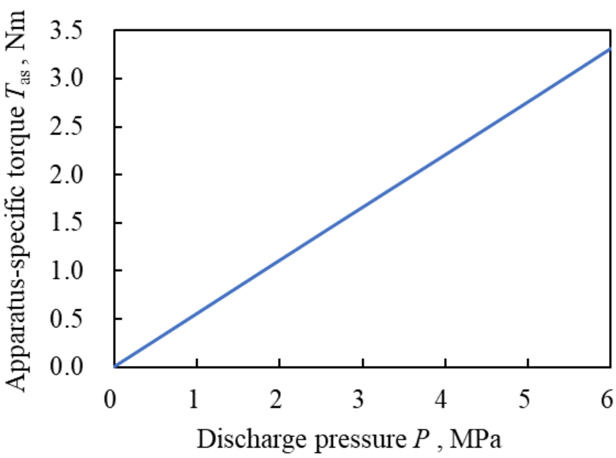


Figure 7. Relationship between T_{as} and P.

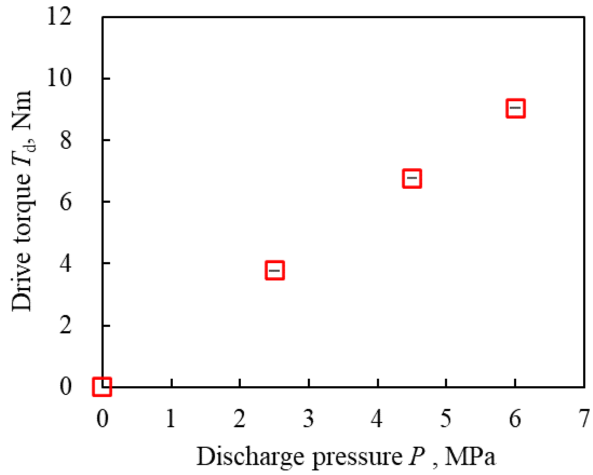


Figure 8. Relationship between Output torque T_d and Discharge pressure P.

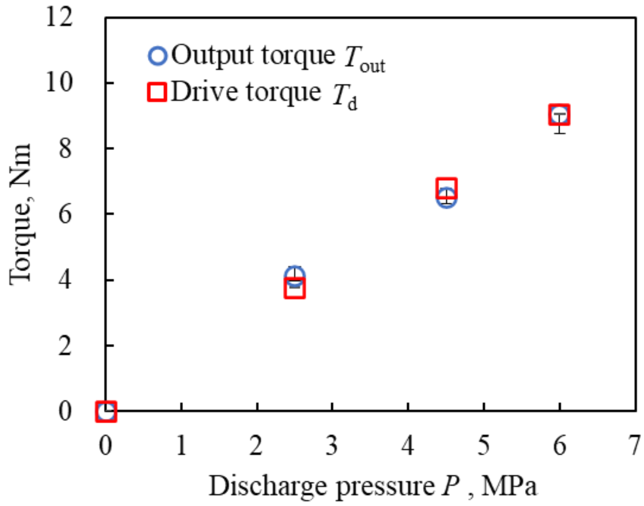


Figure 9. Comparison of Output torque T_{out} and Drive torque T_d.

To evaluate the accuracy of the measurement, we compare the measured value to the value reduced by the absorbed torque, as illustrated in Fig. 10. Since the difference between these two values is minimal, we can conclude that the power absorbed by the dynamometer is nearly equal to the power generated by the prime mover.

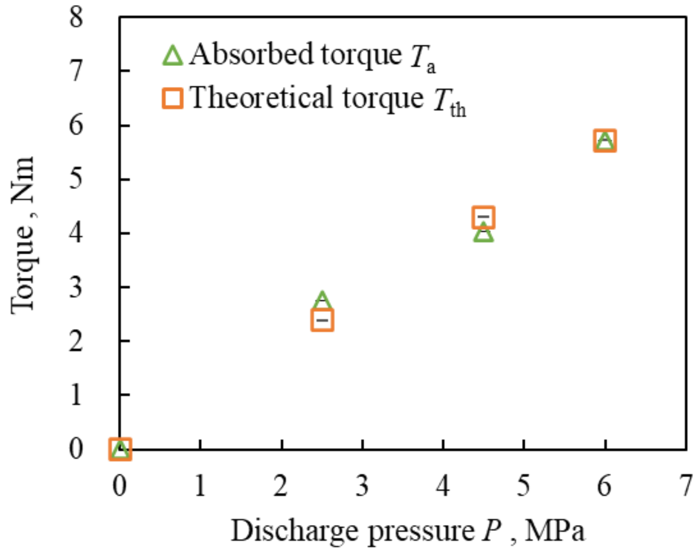


Figure 10. Comparison of Output torque T_a and Theoretical torque $T_{th.}$

3.3 Evaluation of time series torque data

Time series data is an important evaluation parameter of the dynamometer in this study. To identify fluctuations in the measurements, a comparison of the torque data over time between diesel and emulsion fuels was conducted. The test conditions are outlined in Table 6. The engine speed was set at 2400 rpm, while the dynamometer speed was 1080 rpm. The fuels used in the tests were conventional diesel, W20/D and W30/D emulsion fuels. Emulsion fuel was chosen based on the hypothesis that it could significantly influence torque fluctuations due to potential instability in combustion. Figure 11 illustrates the time series data for the torque output (T_{out}) calculated from Equation (1). The solid line represents the actual time series data, while the dashed line indicates the average values. The measurements were conducted to ensure that the average torque value remained around 4 Nm. As shown in Fig. 11(a), the amplitude fluctuations for diesel fuel are stable. This stability is attributed to the consistent combustion of the diesel oil used as fuel. In Fig. 11(b), the torque fluctuations for W20/D are observed to be more stable than those of diesel fuel. This could be due to the contributions of micro-explosions during combustion that enhance firing in the combustion chamber. However, W30/D in Fig. 11(c) exhibits significant fluctuations, although the amplitude changes are smaller during the intervals from 0.3 to 0.5 seconds and from 0.8 to 1.0 seconds compared to other intervals. This may be caused by abnormal combustion, such as ignition triggered by the high-water content in the emulsion fuel used, which leads to an instantaneous decrease in rotational speed and power output.

Since this dynamometer can measure instantaneous torque fluctuations, it enables the evaluation of each combustion cycle in experiments with prime movers. This capability allows for the examination of cycles influenced by secondary atomization, which is a characteristic of emulsion fuel.

Table 6 Experimental condition of time-series data measurement

Prime mover rotation speed	2400 rpm
Dynamometer rotation speed	1080 rpm
Pulley ratio	0.45
Fuel	Diesel, W30/D

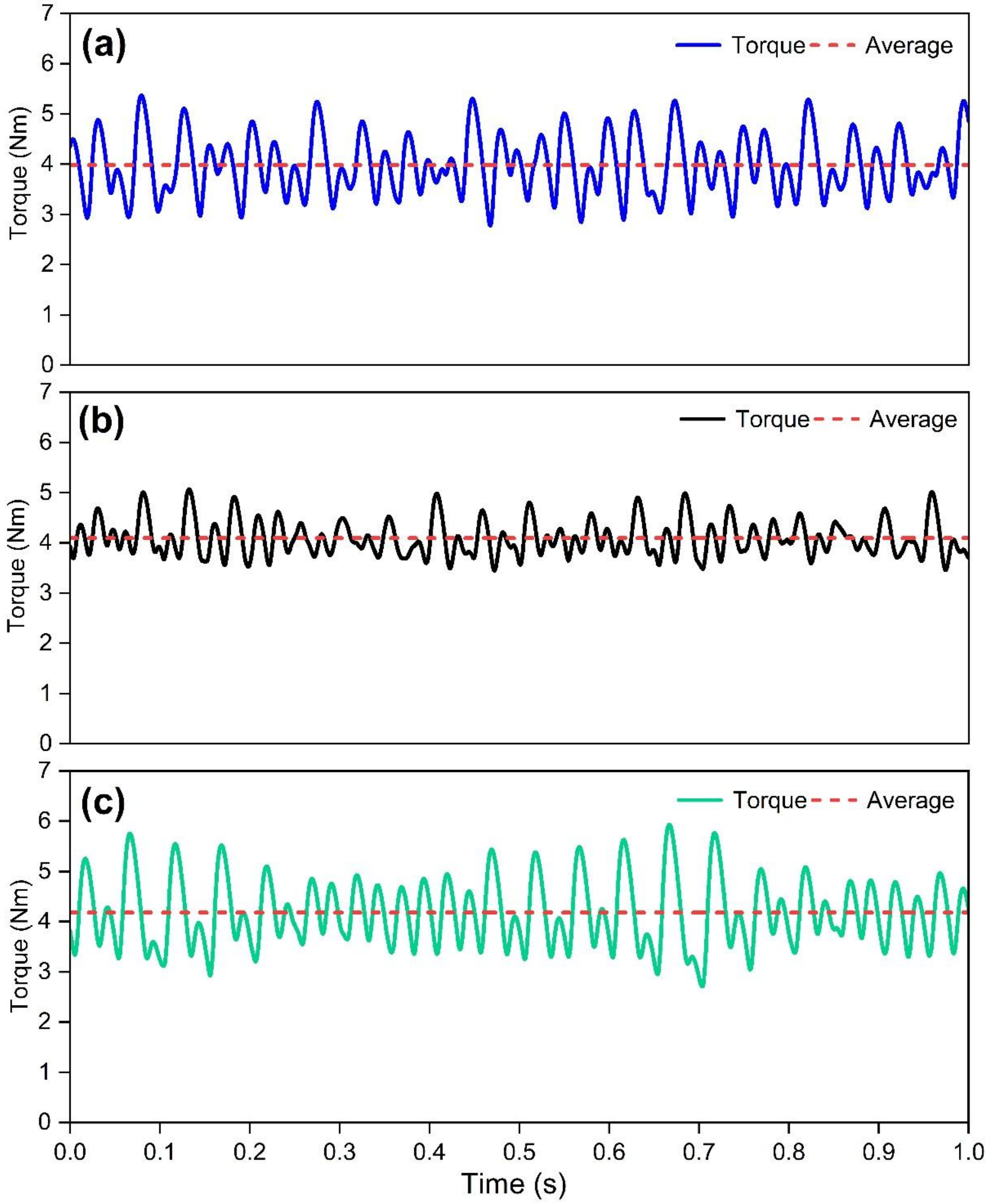


Figure 11. Time-series data of torque T_{out}: (a)Diesel, W20/D and (c)W30/D

Conclusion

This study focuses on the development of a simple vane pump hydraulic dynamometer specifically designed for engine testing, followed by an analysis of its operational performance. The hydraulic dynamometer, which utilizes a vane pump, effectively provides a load to the prime mover and measures the absorbed torque. Based on the evaluations of the experimental data, the following conclusions were drawn:

1. The applied load T_{out} will increases linearly as the discharge flow rate Q decreases due to the increasing discharge pressure P when the valve channel area is reduced.
2. When comparing the torque read on the load cell T_{out} with the torque calculated from the discharge flow rate and discharge pressure of the vane pump, the moment of gravity of the pipe must be considered. This will result in an acceptable gap between torque measured by the load cell and the torque calculated from the flow rate and vane pump pressure.
3. The evaluation of torque applying into the diesel engine has been conducted with different fuel such a diesel and emulsion fuel. This clearly shows the different trend for the different fuels used, with the trend for diesel fuel being more stable than for emulsion fuels.

The development of hydraulic dynamometers is essential and requires improvements in efficiency. Additionally, the working fluid must be cooled during operation to prevent a decline in power transfer caused by changes in oil temperature.

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References

[1] United Nations, Report of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement on its third session, (2022)

[2] UK Government. COP26 Presidency Outcomes. 2022. https://www.gov.uk/government/publications/cop26-presidency-outcomes).

[3] IEA, WorldEnergyOutlook2022, (2022)

[4] Ammar Alfaiz, M. A., Tahir Musthafah, M. T., Abu Baker Rosli, Shahir Ali, M., & Muhaimin, A., New design of a low cost small engine dynamometer for engine testing. *Appl. Mech. Mater.* 2015; *699:*642-647. doi:10.4028/www.scientific.net/AMM.699.642.

[5] Bramer, J.; Sattler, E.; Michael, P. Dynamometer Testing of Energy Efficient Hydraulic Fluids and Fuel Savings Analysis for US Army Construction and Material Handling Equipment. *Lubricants* 2022; 10: 216. https://doi.org/ 10.3390/lubricants10090216

[6] Kachanov, P., Lytviak, O., Derevyanko, O., & Komar, S. Development of an automated hydraulic brake control system for testing aircraft turboshaft gas turbine engines. *East.-Eur. J. Enterp. Technol.* 2019; 6 (2): 52-57.

[7] Shaha, S. S., Chaturvedia, S., & Agustin, S. A. Design, Development and Validation of Engine Dynamometer for FSAE. *Turk. Online J. Qual. Inq.* 2021:*12*(6).

[8] IPCC, AR6, (2022)

[9] Killedar, Jyotindra S. Dynamometer: theory and application to engine testing. Xlibris Corporation, (2012).

[10] Inaguma, Y.: Theoretical of analysis of mechanical efficiency in vane pump, JTEKT Engineering Journal No. 1007, 28-35, (2010)