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The Vibration Analysis of Diesel Engine with Hydrogen-Diesel Dual Fuel

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ABSTRACT

The diesel engine vibration is one of the main problems of engine damage. When the hydrogen-diesel dual fuel is used, it may affect the engine vibration. Therefore, it is necessary to study the effect of hydrogen-diesel dual fuel. The regression analysis is used to find the relations between hydrogen percentage and the engine vibration. The results for all cases found that the relation between the Average Peak Acceleration (APA) and hydrogen percentage (%H_2) can predict by using linear equation with average coefficient of determination (R^2) = 0.8973 or 2nd polynomial equation with R^2 = 0.9592. All graphs are the decreasing function. APA can decrease by increasing %H_2. The relation between the average peak acceleration and hydrogen percentage can predict by using linear equation or 2nd polynomial equation. The average peak acceleration can decrease by increasing hydrogen percentage. In the other word, the engine vibrations can decrease by increasing hydrogen percentage.

Keywords: Engine Vibration, Hydrogen-Diesel Dual Fuel, Diesel Engine, Hydrogen, Accelerometer

1. INTRODUCTION

The engine vibration is one of the main factors in engine design and engine maintenance (Cheng *et al*., 2012; Taghizadeh-Alisaraei *et al*., 2012). The engine vibration can measure by using the displacement sensor, the velocity sensor (Cheng *et al*., 2012), the accelerometer (Taghizadeh-Alisaraei *et al*., 2012; Barelli *et al*., 2009; Carlucci *et al*., 2006), the engine acoustic pressure (Barelli *et al*., 2009). We can decrease it by using springs and dampers to support the engine.

In diesel engine, the alternative fuels are using to mix with diesel oil as the dual fuels for decreasing diesel oil consumption (Lata *et al*., 2011; Escalante and Fernandez, 2010; Selim, 2001; Banapurmatha *et al*., 2008; Huzayyin *et al*., 2004). The hydrogen-diesel dual fuel is one of the main choices because hydrogen can be produced from various sources such as water (Korakianitis *et al*., 2010; Miyamoto *et al*., 2011; Saravanana *et al*., 2007; Shin *et al*., 2011; Wu and Wu, 2012). However, addition of hydrogen in diesel engine affect to the engine vibration (Barelli *et al*., 2009).

2. MATERIALS AND METHODS

2.1. Test Engine

In the present study, a single cylinder, direct injection, Kubota "RT100 plus" diesel engine is used. The engine details are summarized in **Table 1 and Fig. 1** shows its setup with the engine test bed.

Table 1. Test engine specification

Maker	Kubota
Model	RT100 DI
Number of cylinder	1
Bore × Stroke	88 mm × 90 mm
Displaced volume	547 cm^3
Compression ratio	18:1
Maximum power	7.4 kW @ 2,400 rpm
Maximum torque	3.4 kg·m @ 1,600 rpm

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Fig. 1. Kubota "RT100 plus" setup with the engine test bed

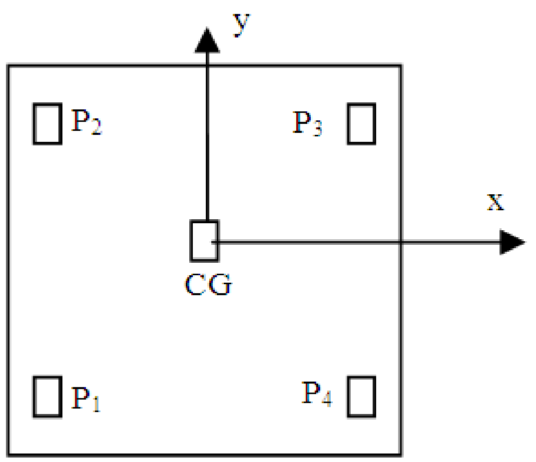

Fig. 2. The accelerometer mounting allocations (top view)

Table 2. Instrumentation specifications

Instrumentation	Characteristics
Glink	Sample rate 2048 samples per channel per second Measuring acceleration X, Y and Z axes Rage: ±2G or ±10G On-board flash memory: 2 MB
WADA base	Power: usb Frequency: 2.405 GHz to 2.480 GHz.

2.2. Accelerometer

Five "G-Link" wireless accelerometers are use to measure the engine vibrations at the engine support. **Figure 2 and 3** show accelerometer mounting points.

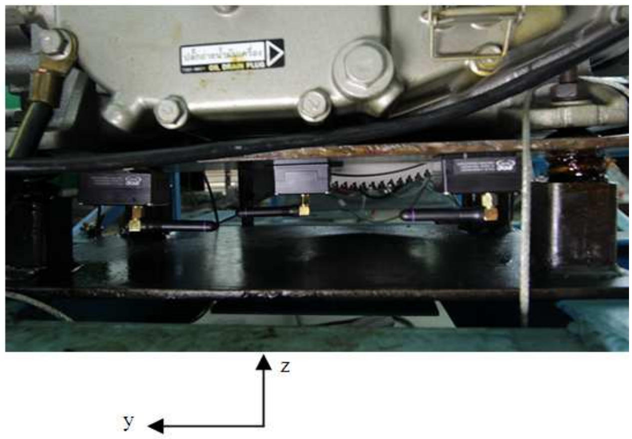

Fig. 3. The accelerometer mounting allocations (front view)

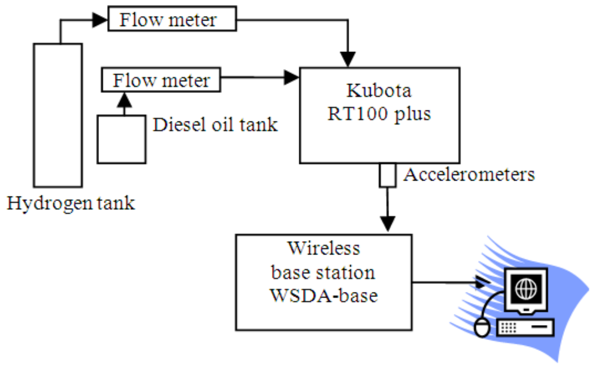

Fig. 4. Schematic of the experimental setup

Table 3. The experimental details

Experiment	N	T
Exp. 1	2,000	25%
Exp. 2	2,000	50%
Exp. 3	1,600	15%
Exp. 4	1,600	25%

The accelerometers are controlled by "Node Commander" software through base station "WADA base". The main technical specifications are show in **Table 2**.

2.3. Measuring System Layout

The schematic diagram of the experimental is shown in **Fig. 4**.

The hydrogen flows across the flow meter with the pressure of 1 bar before flow into the cylinder. Hydrogen flow rates are controlled by a valve with the values of 0, 5, 10, 15 and 20L pm.

Hydrogen percentage (%H2) is percentage of mass fraction between hydrogen consumption and diesel oil consumption Equation 1:

$$\%H_2 = \frac{m_{H_2}}{m_f} \times 100 \quad (1)$$

m_{H_2} = hydrogen mass flow rate (kg/s)
m_f = diesel oil mass flow rate (kg/s)

The engine speed and the engine torque details are shown in **Table 3**.

From the experiment design, we have total 20 study cases for each accelerometer.

3. RESULTS

Examples of the engine acceleration graphs at the Center of Gravity (CG) with engine speed (N) 1,600 rpm, Torque (T) 25% and $\%H_2 = 0.50\%$ are shown in **Fig. 5-7**.

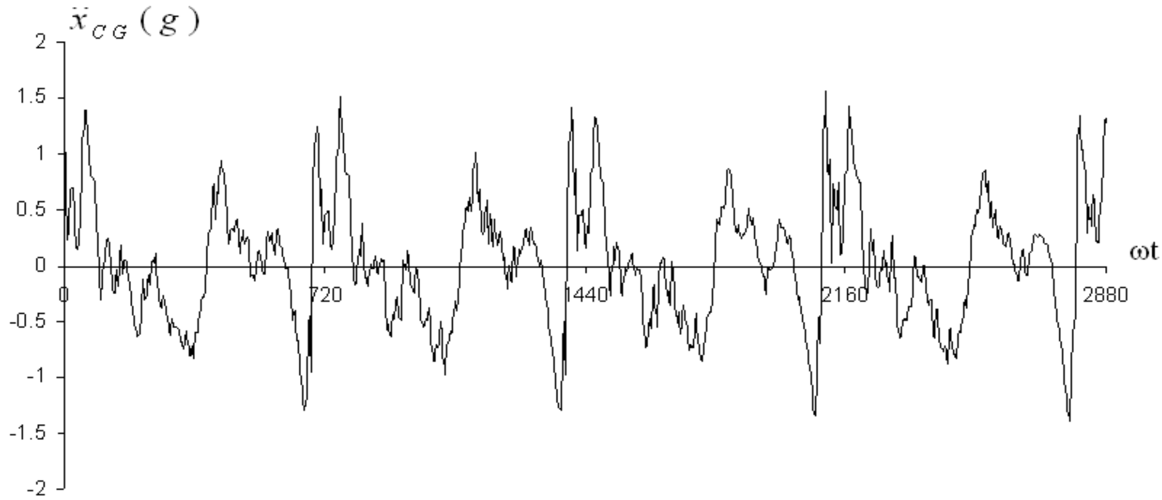

Fig. 5. The engine acceleration at CG in x direction ($\ddot{X}_{CG}$)

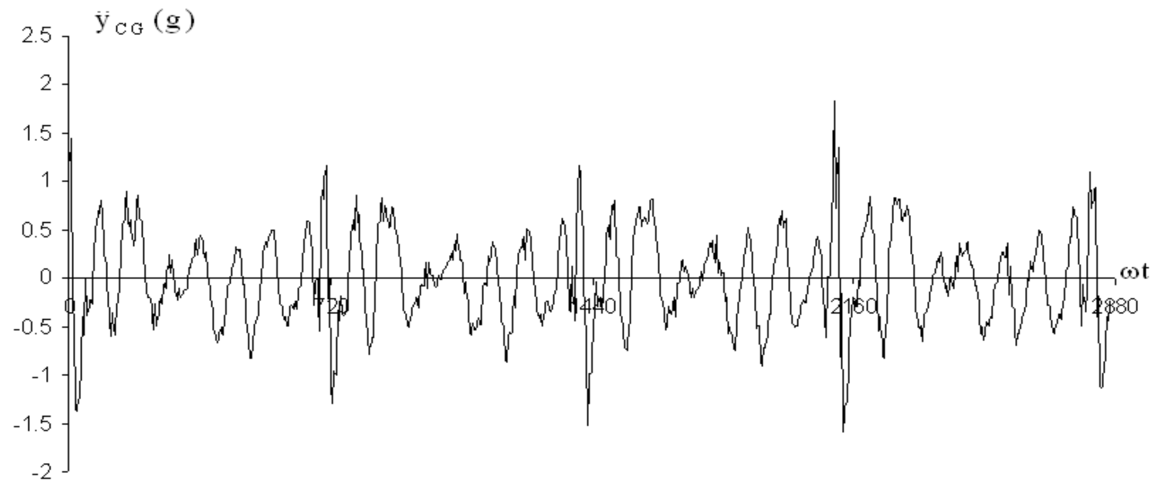

Fig. 6. The engine acceleration at CG in y direction ($\ddot{Y}_{CG}$)

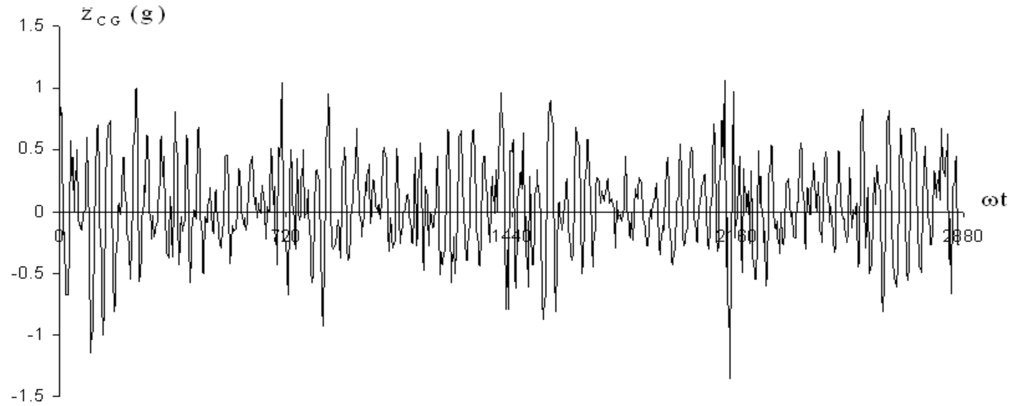

Fig. 7. The engine acceleration at CG in z direction ($\ddot{z}_{CG}$)

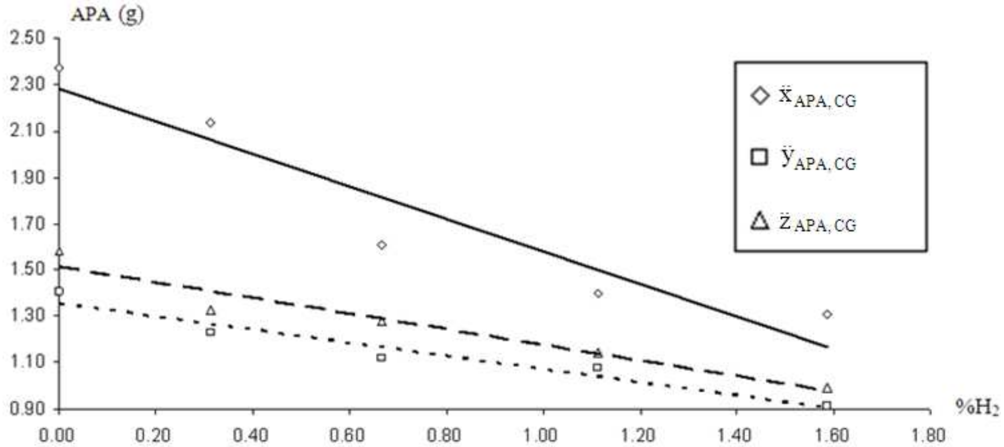

Fig. 8. The average peak acceleration at CG (Exp. 1, N = 2,000 rpm, T = 25%, n = 1)

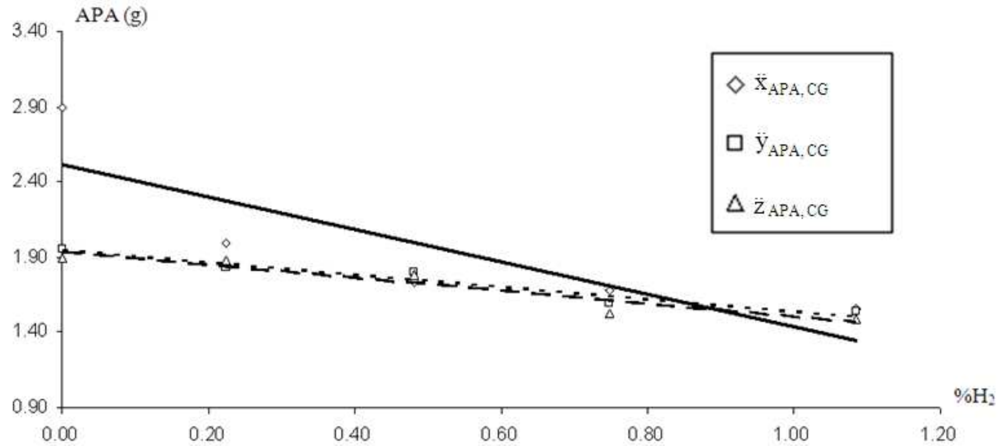

Fig. 9. The average peak acceleration at CG (Exp. 2, N = 2,000 rpm, T = 50% and n = 1)

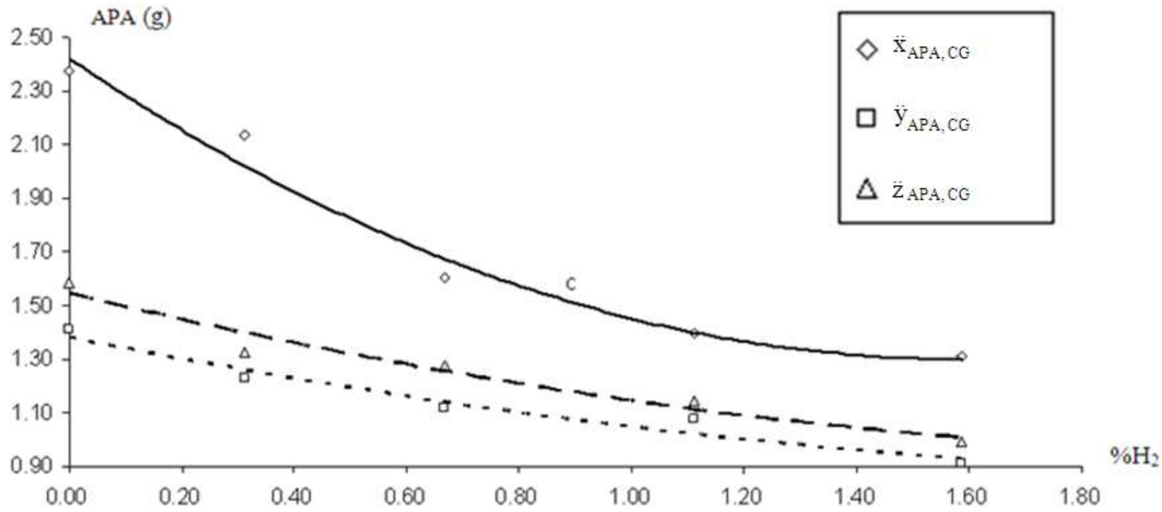

Fig. 10. The average peak acceleration at CG (Exp. 1, N = 2,000 rpm, T = 25%, n = 2)

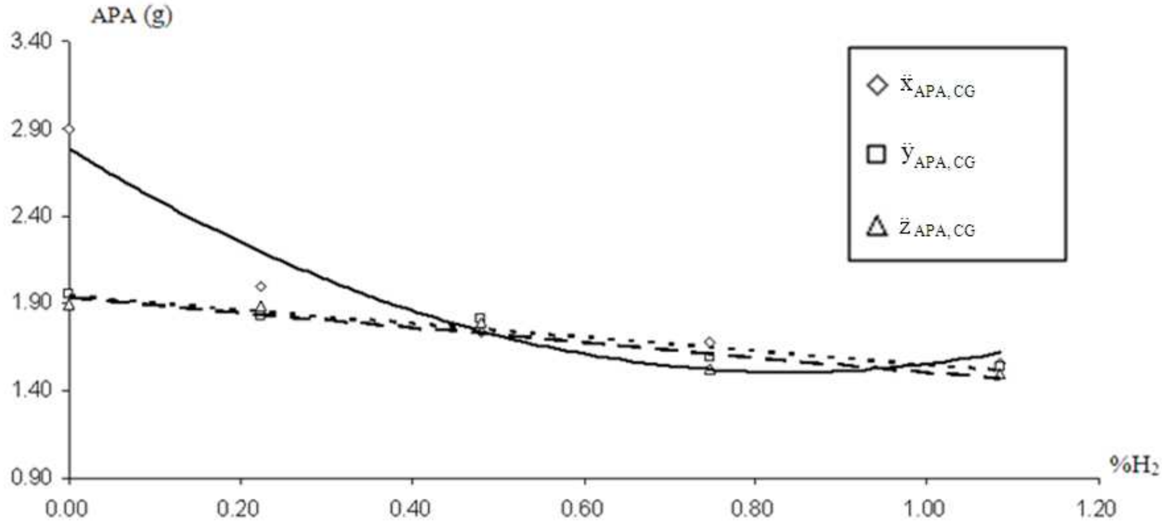

Fig. 11. The average peak acceleration at CG (Exp. 2, N = 2,000 rpm, T = 50% and n = 2)

Table 4. The average peak acceleration APA at CG (Exp. 1, N = 2,000 rpm and T = 25%)

	%H_2				
	0	0.31	0.67	1.11	1.59
$\ddot{x}_{APA,CG}$	2.37	2.13	1.60	1.40	1.31
$\ddot{y}_{APA,CG}$	1.41	1.23	1.12	1.08	1.91
$\ddot{z}_{APA,CG}$	1.58	1.33	1.28	1.14	1.99

Table 5. The average peak acceleration APA at CG (Exp. 2, N = 2,000 rpm and T = 50%)

	%H_2				
	0	0.31	0.67	1.11	1.59
$\ddot{x}_{APA,CG}$	2.90	2.00	1.73	1.68	1.55
$\ddot{y}_{APA,CG}$	1.83	1.83	1.81	1.59	1.53
$\ddot{z}_{APA,CG}$	1.88	1.88	1.79	1.52	1.49

Table 6. APA equations at CG

Order	Condition	a	b	c	R^2
	Exp.1				
	$\ddot{x}_{APA,CG}$	-0.7019	2.2799		0.8988
	$\ddot{y}_{APA,CG}$	-0.2835	1.3563		0.9410
	$\ddot{z}_{APA,CG}$	-0.3385	1.5146		0.9395
1	Exp.2				
	$\ddot{x}_{APA,CG}$	-1.0728	2.5158		0.7160
	$\ddot{y}_{APA,CG}$	-0.3984	1.9453		0.9397
	$\ddot{z}_{APA,CG}$	-0.4312	1.9354		0.8970
	Exp.1				
	$\ddot{x}_{APA,CG}$	0.4489	-1.4178	2.4206	0.9772
	$\ddot{y}_{APA,CG}$	0.0829	-0.4158	1.3823	0.9582
2	$\ddot{z}_{APA,CG}$	0.1032	-0.5031	1.5466	0.9581
	Exp.2				
	$\ddot{x}_{APA,CG}$	1.8152	-3.0472	2.7852	0.9325
	$\ddot{y}_{APA,CG}$	0.0509	-0.4537	1.9529	0.9414
	$\ddot{z}_{APA,CG}$	-0.0407	-0.3869	1.9294	0.8978

The results show that the engine accelerations are the periodic function for all experiments and all directions with the period of 720° per revolution. Examples of the Average Peak (APA) of 100 revolutions of the engine are show in **Table 4 and 5**.

The relation between APA and $\%H_2$ can find by using the regression analysis with n^{th} polynomial Equation 2 and 3:

$$(n-1)APA = a(\%H_2) + b \quad (2)$$

$$\begin{aligned}(n-2)APA &= a(\%H_2) + bAPA \\ &= a(\%H_2)^2 + b(\%H_2) + c\end{aligned} \quad (3)$$

Example of APA graph at CG with linear equation (n = 1) are shown in **Fig. 8-9** and APA graph with 2nd polynomial equation (n = 2) are shown in **Fig. 10-11**.

Table 6 shows APA equations and R^2 of the APA graphs at CG.

4. DISCUSSION

The results for all cases (show some cases in this study) found that the relation between APA and $\%H_2$ can predict by using linear equation with average R^2 = 0.8973 or 2nd polynomial equation with R^2 = 0.9592. All graphs are the decreasing function. APA can decrease by increasing $\%H_2$.

5. CONCLUSION

The relation between the average peak acceleration and hydrogen percentage can predict by using linear equation or 2nd polynomial equation. The average peak acceleration can decrease by increasing hydrogen percentage. In the other word, the engine vibrations can decrease by increasing hydrogen percentage.

6. ACKNOWLEDGMENT

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