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DEVELOPMENT OF A SIMPLIFIED METHOD FOR MEASURING ENGINE MOTORING FRICTION AND ITS APPLICATION TO VALVE TRAIN FRICTION MEASUREMENT

Kohei Nakashima, Tatsuya Kato, Kenta Goto, Yoshio Murakami

Meijo University, Department of Vehicle and Mechanical Engineering
1-501 Shiogamaguchi, Tempaku-ku, Nagoya 468-8502, Japan
tel.: +81 52 832 1151, fax: +81 52 832 1235
e-mail: nakasima@meijo-u.ac.jp

Abstract

We developed a simpler and less expensive method for measuring friction. Our equipment floats the double-end shaft motor by supporting both sides of the motor shaft with bearings, allowing the stator within the motor case to swing on the rotor with the shaft. Two arms were installed in the motor case; one is attached to a load meter; the other to a balance weight. The motor shaft is connected to the engine shaft, and when the engine is operated by the motor, torque is exerted on the stator with the motor case in the direction opposite to the motor shaft rotation, with engine friction acting as the reaction force. Torque is calculated by multiplying the arm length by the load as measured by the load meter in the arm. As an application of our new motoring friction test method, we measured valve train friction. The cylinder head of a single cylinder gasoline engine was clamped on a test bed, and its camshaft was connected to our friction measuring equipment. Utilizing various follower configurations of the rocker arms, we investigated the friction loss between the rocker arms and the cam. We thus clarified the effect of the valve-opening period and the valve lift on friction loss under various camshaft rotation speeds, and understood the lubricating conditions between the rocker arms and the cam.

Keywords: *engine friction, motoring friction method, valve train, rocker arm, follower configuration*

1. Introduction

Reducing engine friction loss is an effective measure to improve fuel consumption in automobile engines. An engine motoring test is widely used to quantify this engine friction loss. However, motoring lubrication conditions are different from firing lubrication conditions [4]. In motoring operation, firing pressure does not act on the piston, piston rings, and bearing; piston and cylinder bore temperatures are lower, and piston-cylinder clearances are greater, than in firing operation. However, the rubbing friction in firing operation at a lower load is roughly equal to that in motoring operation. The motored engine breakdown tests are useful for assessing the relative importance of individual friction components [4, 5].

Two methods are conventionally used to test friction while motoring. In the first, the engine is connected to an electric dynamometer (as a generator), which measures the power needed to drive the engine [5]. In the second, an electric motor drives the engine, and a torque sensor is installed between them [7]. In this research, we developed a simpler method for measuring friction. We measure the torque, which is exerted on the stator, with the motor case in the direction opposite to the motor shaft rotation, with engine friction acting as the reaction force, while floating the double-end shaft motor by supporting both sides of the motor shaft with bearings.

As an application of our new motoring friction test method, we measured valve train friction. The camshaft in OHC type single cylinder gasoline engine with a centre pivot rocker arm was connected to our friction measuring equipment. Previous study analysed the oil film thickness and the friction between the rocker arm follower and the cam, using fixed follower configuration with centre pivot rocker arm [2]. However, no study addressed the friction loss using various follower configurations. Utilizing various follower configurations produced for our eco-mileage vehicle engine [3], we investigated the effect of the valve-opening period, and the valve lift, on the friction loss between the rocker arms and the cam.

2. Motoring friction test method with engine friction acting as reaction force

Figure 1 shows our motoring friction measurement principle. Our equipment floats the double-end motor shaft by supporting both sides of the shaft with bearings, allowing the stator within the motor case to swing on the rotor with the shaft. The motor shaft is connected to the engine shaft, and when the engine is operated by the motor torque is exerted on the stator, with the motor case in the direction opposite to the motor shaft rotation, with engine friction acting as the reaction force. Friction torque is calculated by multiplying the arm length by the load as measured by the load meter in the arm.

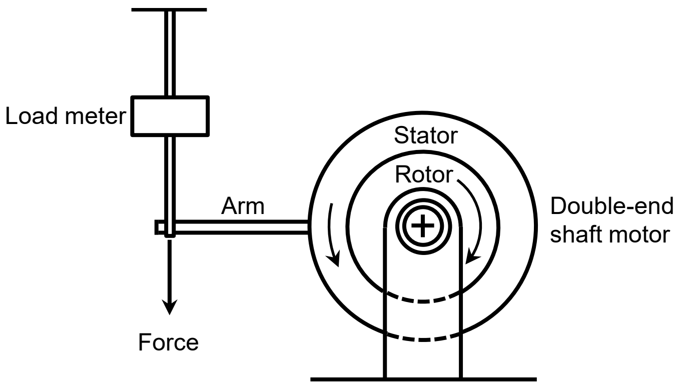

Fig. 1. Motoring friction measurement principle

3. Application to valve train friction measurement with friction acting as reaction force

3.1 Experimental equipment and method

Figure 2 shows our experimental equipment for measuring valve train friction. A three-phase AC induction motor (1.5 kW) with a double-end shaft was supported with pillow blocks (with an inner diameter of 20 mm) at both sides of the motor shaft. Two arms were installed in the motor case; one was attached to a load meter at a distance of 250 mm from the centre of the motor shaft; the other, to a balance weight (with a mass of 0.9 kg).

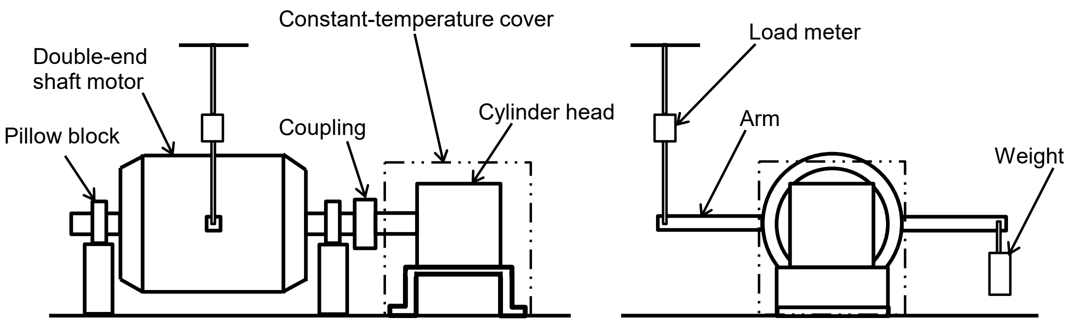

Fig. 2. Experimental equipment

The cylinder head of a single cylinder gasoline engine of OHC type with centre pivot rocker arms of (as shown in Tab. 1) was clamped on a test bed, and its camshaft was attached to a shaft, which was then coupled to the motor shaft of our friction measuring equipment. To maintain the temperature in the cylinder head, we covered it with a constant-temperature cover equipped with thermocouples, heaters, and stirrer fans.

Tab. 1. Engine specifications

Number of cylinders	1
Displacement [mL]	49.5
Bore x stroke	39 x 41.4
Compression ratio	10
Valve train	OHC, centre pivot rocker
Number of valves	Intake 1 & Exhaust 1
Fuel	Gasoline (Premium)
Maximum power [kW/rpm]	3.3 / 7000
Maximum torque [Nm/rpm]	5.1 / 4500

Table 2 shows the experimental follower configurations at the sliding side on the cam. Using these followers, we set the valve-opening period and valve lift, as shown in Fig. 3. These conditions match our previous research, which improved engine torque and specific fuel consumption in an eco-mileage vehicle engine [3]. We used commercially available cam, valves, and valve springs. Simulating operating an eco-mileage vehicle engine, we tested at camshaft speeds of 1000 to 2000 rpm (at engine speeds of 2000 to 4000 rpm). We also used lubricating oil SAE 10W-30. The temperature of the cylinder head and the inside of its constant-temperature cover was maintained at 40°C.

Tab. 2. Experimental follower configurations at sliding side on the cam

Commercially-available follower (std.)	
Modified follower In intake	 a b c d e
Modified follower In exhaust	 f g h

In our experiment, we set a predefined valve-opening period and valve lift, by assembling intake and exhaust followers. We set the temperature of the cylinder head and the inside of our constant-temperature cover at 40°C, then started the motor, and broke in the valve train at camshaft speeds between 1000 and 2000 rpm. Then the motor was stopped, and the load meter was calibrated to zero. After lubricating oil (at 40°C) was put on the followers and the cam, the motor was started again. Camshaft speed was increased to 2250 rpm, and then decreased to 2000 rpm. Then the load (reaction force) was recorded every 250 rpm as the camshaft speed decreased from 2000 to 1000 rpm. Here the measured load was accurate to within ±6.5%. Friction between the followers and the cam was obtained by subtracting the load when driving without rocker arms, from the load when driving with assembling rocker arms. Friction torque (friction loss) was also obtained by multiplying the friction by an arm length of 250 mm.

	Followers	Open [deg]	Close [deg]	Valve lift [mm]
Commercially-available follower (Std.)	Intake	TDC 0	ABDC 2	2.31
a	Intake	TDC 0	ABDC 46	3.29
b	Intake	BTDC 34	ABDC 3	3.68
c	Intake	BTDC 1	ABDC 4	3.09
d	Intake	ATDC 1	BBDC 38	1.99
e	Intake	ATDC 20	ABDC 24	2.66
Commercially-available follower (Std.)	Exhaust	BBDC 12	TDC 0	2.77
f	Exhaust	BBDC 42	ATDC 1	3.06
g	Exhaust	ABDC 3	ATDC 32	3.62
h	Exhaust	BBDC 6	ATDC 3	2.88

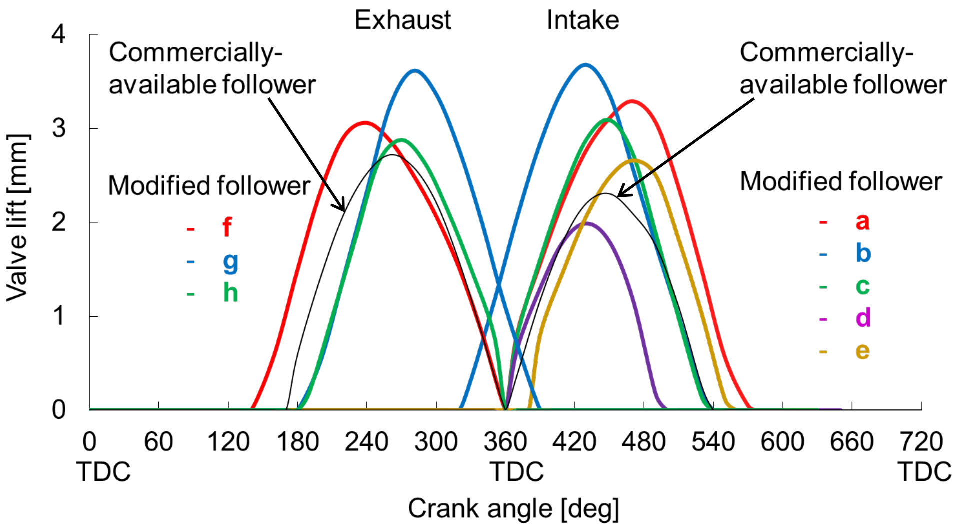

Fig. 3. Valve opening period and valve lift

3.2 Results and consideration

Figure 4 shows friction torque in various combinations of intake and exhaust followers. In Fig. 4, as camshaft speed decreased, friction torque increased. It appears that, when camshaft speed decreases, the lubricating oil does not form a film between the followers and the cam, and the predominant lubrication between them becomes boundary lubrication. Then when the valve-opening period and the valve lift increased, friction torque increased. We examined which factor contributed the most friction torque: the valve-opening period or the valve lift. Fig. 5 and 6 show friction torque vs. the total valve opening period, and friction torque vs. the total valve lift, respectively. For each camshaft speed, the contribution from the total valve-opening period exceeded that from the total valve lift. It seems that, when the total valve opening period increases, the followers receive a larger force sliding on the ramps of the cam, where the friction coefficient is higher [6].

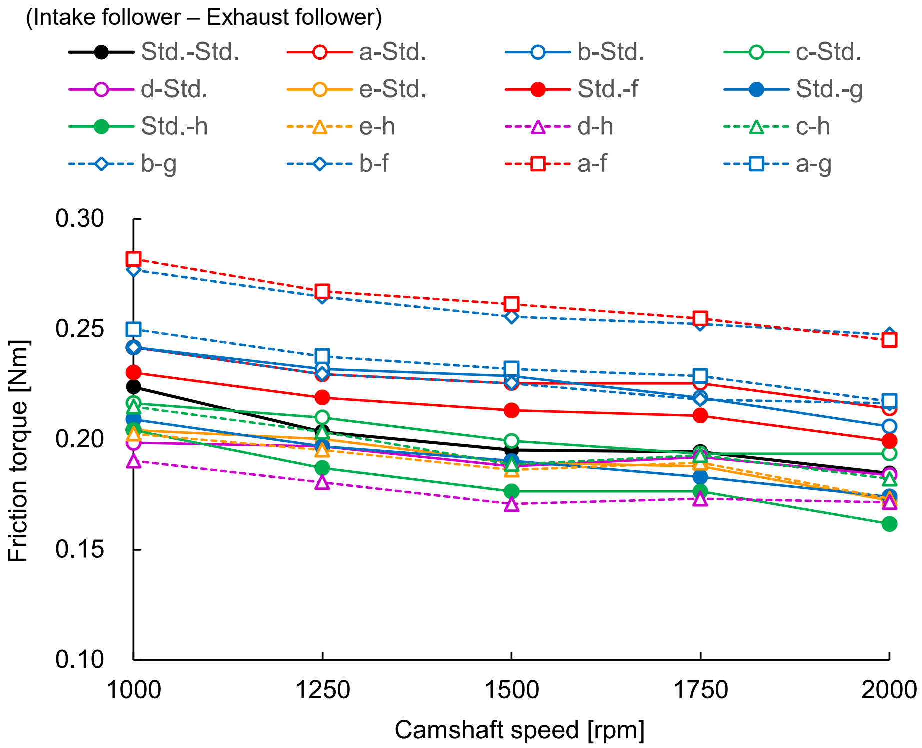

Fig. 4. Friction torque in various combinations of intake and exhaust followers

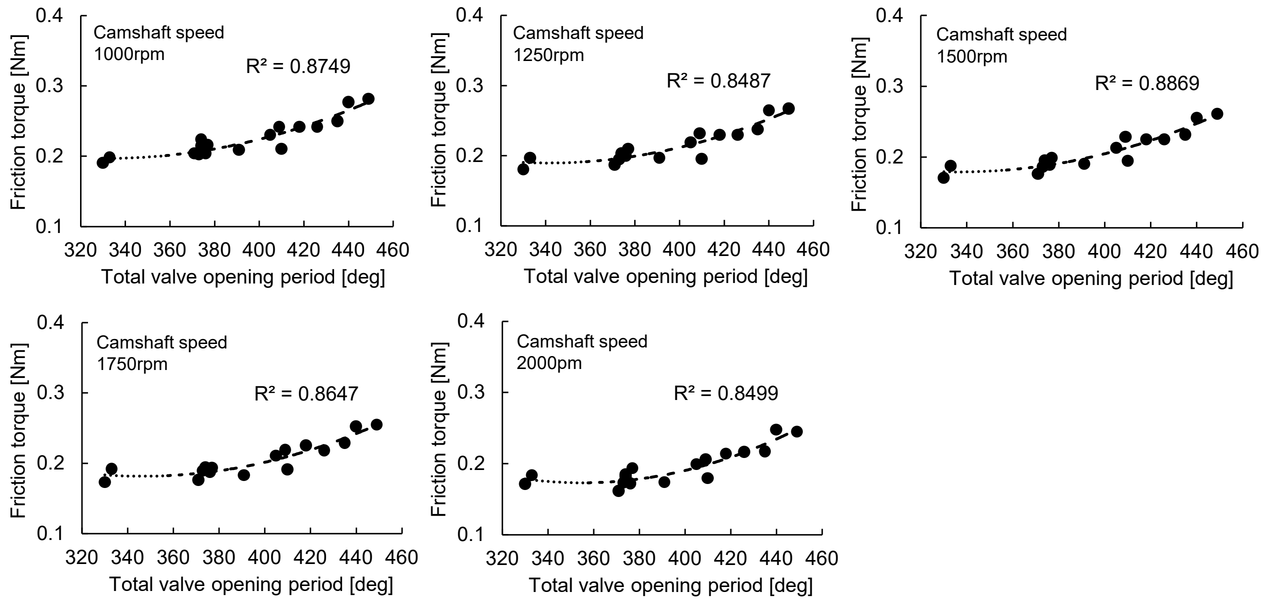

Fig. 5. Friction torque vs. total valve opening period

In our previous research on an eco-mileage vehicle engine, the combination of a commercially-available follower in the intake and a follower of ‘f’ (‘Std.’-‘f’ in Fig. 4) improved engine torque and specific fuel consumption, compared with the combination of commercially-available followers in the intake and exhaust without overlap (‘Std.’-‘Std.’ in Fig. 4) [3]. In Fig. 4, the friction torque with the combination of a commercially-available follower in the intake and a follower of ‘f’ (‘Std.’-‘f’) increased 0.006 to 0.018 Nm, compared to that with the combination of commercially-available followers in the intake and exhaust without overlap (‘Std.’-‘Std.’). Because this increment in friction torque is quite small in comparison to engine torque (3.3 Nm at an engine speed of 4000 rpm), it has a minimum effect on engine performance.

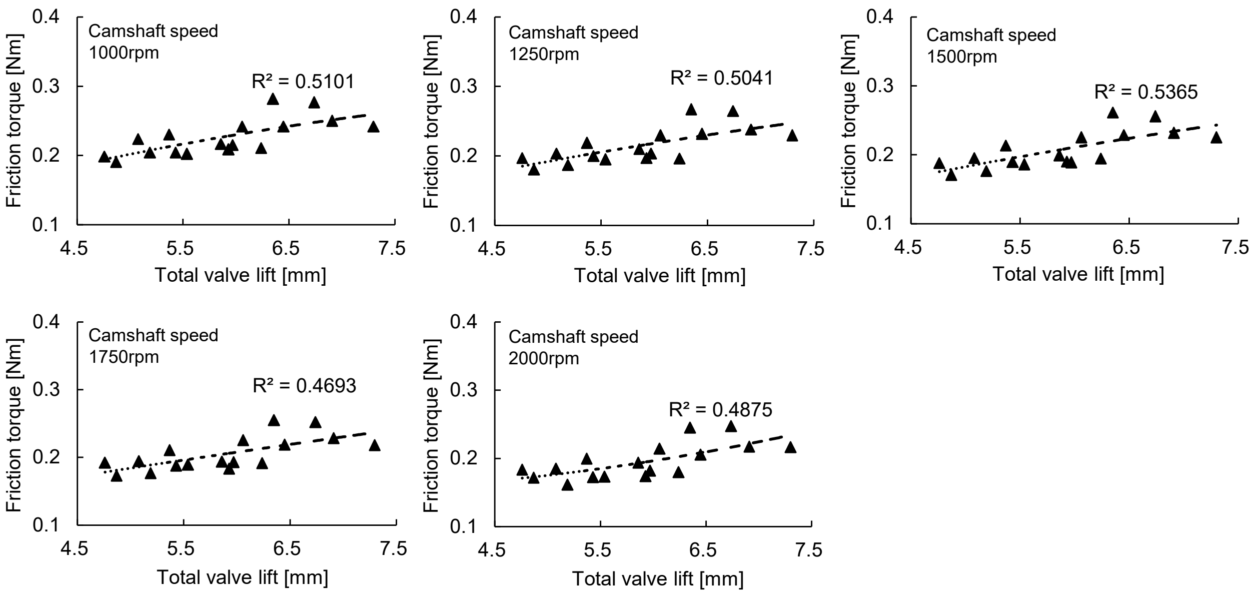

Fig. 6. Friction torque vs. total valve lift

Next, we investigated whether our friction torque results agreed with the well-known empirical equation of valve train friction. Bishop [1, 4] showed the friction mean effective pressure (FMEP, F_{mep}) of valve train (which excludes camshaft-bearing loss) as Eq. (1).

$$F_{mep} = \frac{C[1-0.133(N/1000)]n_{iv}D_{iv}^{1.75}}{B^2 L}, \tag{1}$$

where:
n_{iv} – number of inlet valves per cylinder,
D_{iv} – inlet valve head diameter [mm],
B – cylinder bore diameter [mm],
L – stroke [mm],
N – engine speed [rpm],
C – 1.2×10^4 [kPa].

We calculated our FMEP by substituting the dimensions of our experimental engine into Eq. (1). The calculated FMEP was 24.2 kPa at an engine speed of 2000 rpm (corresponding to a camshaft speed of 1000 rpm) and 15.4 kPa at an engine speed of 4000 rpm (camshaft speed of 2000 rpm). Our experimental results with the combination of commercially available followers in the intake and exhaust without overlap (‘Std.’-‘Std.’ in Fig. 4) indicated that FMEP was 56.9 kPa at a camshaft speed of 1000 rpm, and 47.0 kPa at a camshaft speed of 2000 rpm. Therefore, our experimental results were 2.4 to 3.1 times as large as the calculations using Eq. (1). When the temperature of lubricating oil increases, the friction coefficient of the valve train increases [6]. Taking into account the temperature of lubricating oil for our experimental results, the differences between our experimental results and calculated results with Eq. (1) increase. This discrepancy arises because Eq. (1) was obtained from the experimental results with a larger-displacement OHV-type engine. Therefore, Eq. (1) does not apply to a smaller OHC type single-cylinder engine.

4. Conclusions

We developed a motoring friction test method with engine friction acting as reaction force, and applied it to valve train friction measurement. We verified that the friction torque between the rocker arm followers and the cam could be measured precisely by our motoring friction method. Friction torque increased with increasing valve opening period and valve lift. For this friction torque, the contribution from the total valve-opening period exceeded that from the total valve lift.

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