Low-Speed PM Dynamometer (PMDY−LV220)

PM motor, Vehicle testing equipment, Constant-power characteristic, Torque ripples

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1. Preface

Meidensha Corporation has been striving to develop compact and low inertia drive motore (PCDY, PCDY−II 330) which can replace an engine in the powertrain test system. Besides, in regard to the load side dynamometer, the conventional FCDY has been replaced by PMDY to reduce total system size. Furthermore, the new system has been enabled to carry out a transient testing by giving a low inertia to the dynamometer on the load side.

This paper introduces a low-speed PM dynamometer (PMDY−LV220) which has compact and low inertia feature. It can be connected to an axle shaft to simulate tire idling and slipping phenomena. Fig. 1 shows an external view and Fig. 2 shows an example of the FWD transmission testing system in which new dynamometer is used.

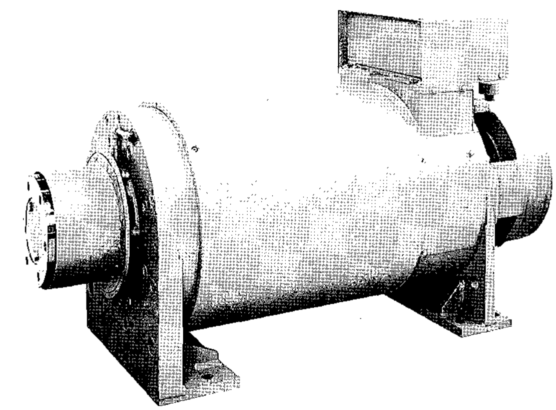

Fig. 1 External View of the Low-Speed PM Dynamometer (PMDY−LV220)

2. Features

The features of the testing system, incorporating PMDY−LV220, are as follows:

(1) Compact: PMDY−LV220 has the size which is 1/2.5 installation space that of a conventional PCDY.

(2) Small diameter: The outer diameter of the frame comes to only ϕ485mm – that is equivalent to or less than the size of a tire. Therefore, it is possible to make test layout similar to actual car.

(3) Low noise: The totally enclosed construction of the indirect liquid cooling type assures a low audible sound level. As such, it is possible to detect a faulty sound of a tested unit.

(4) Low inertia and high torque: Low inertia and a high torque make this dynamometer as high power rate dynamometer. Its Max. acceleration and deceleration rate is 20,674min^{-1}/s. By using electrical inertia simulation a tire wheel inertia can be reproduced. Therefore, a broad range of testing is possible, such as the reproduction of tire slippage.

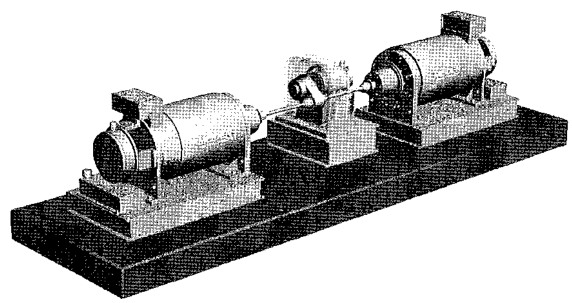

Fig. 2 Example of the FF Transmission Testing System

3. Equipment Explanation

The newly developed dynamometer for an axle shaft is a PMDY that uses permanent magnets. It is a compact and low-inertia dynamometer having an indirect liquid cooling construction. Table 1 shows the major specifications.

3.1 Constant Power Characteristic

PMDY−LV220 is connected to an axle shaft end. Therefore, it is required to have a constant power characteristic. In the case of a permanent magnet (PM) motor, it is difficult to produce a constant power characteristic because the magnetic flux is fixed. For this reason, a countermeasure is taken as described below.

Fig. 3 shows the equivalent circuit of the PM motor. The terminal voltage is defined as follows:

$$\begin{pmatrix} Vd \\ Vq \end{pmatrix} = \begin{pmatrix} Ra & -\omega Lq \\ \omega Ld & Ra \end{pmatrix} \begin{pmatrix} Id \\ Iq \end{pmatrix} + \begin{pmatrix} 0 \\ \omega \Lambda \end{pmatrix} \quad \cdots\cdots (1)$$

Table 1 Major Specification

Absorption capacity	Max. 2100N·m 2201176kW 1000~2500/3000min^{-1}
Driving capacity	Max. 1910N·m 2001160kW 1000~2500/3000min^{-1}
Time rating	Continuous
Excess torque	3000N·m for 1 munite; 1000min^{-1} or less
Moment of inertia	0.97kg·m^2
Max. acceleration1 deceleration capability	20,674min^{-1}/s
Engine torque	A separately furnished torque meter is directly coupled.
Direction of rotation	Reversible
Applicable standard	JEC-2100(1993)
Cooling water	35L/min, 32°C or below No freezing permissible
Ambient temperature	0~+40℃
Relative humidity	30~80%RH without dew condensation
Installation place	Altitude: 1000m or below, Minimal floating dust, Less corrosive gas content

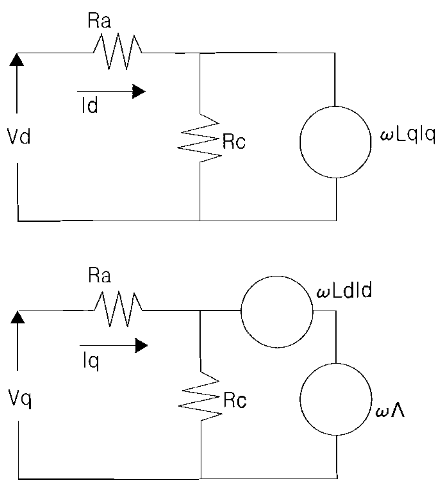

Fig. 3 Equivalent Circuit of the PM Motor

The torque is defined as follows:

$$T=Kt\cdot\{\Lambda Iq+(Ld-Lq)IdIq\} \quad (2)$$

The voltage generated by the effect of the magnetic flux is ω A and it rises together with the speed increase. Generally, this performance is dealt with by field weakening control (Id < 0). However, a high voltage is loaded to the inverter when control failure happens and dynamometer go into free run, and it may be failed. To avoid such condition a unique rotor shape, which will generate a proper magnetic reluctance in the direction of the magnetic flux (direction of Axis *d*) to suppress the intensity of this magnetic flux has been adopted. So that the inverter can be protected against

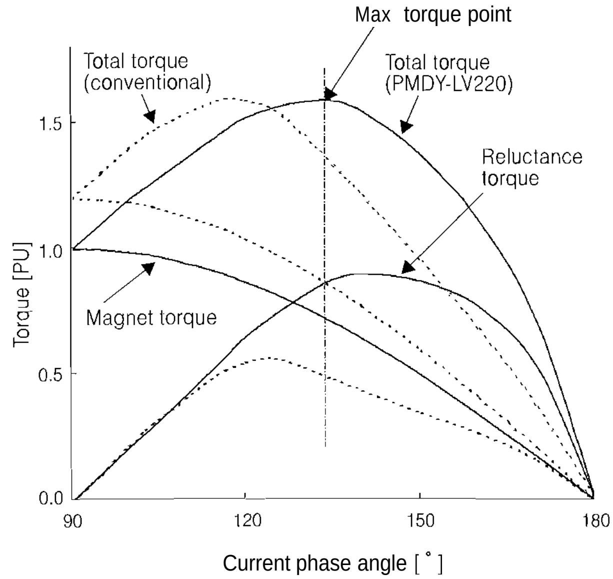

Fig. 4 Torque Characteristics

failure even during free-run. But if the magnetic flux is suppressed, the magnet torque (AIq) is decreased. To supplement the decreased magnet torque, PMDY−LV220 is designed to utilize the reluctance torque to attain the rated torque. Fig. 4 shows the torque changing with the phase angle between the magnetic flux and the current. The magnet torque gradually decreases according to the current phase angle is increased, but the reluctance torque has a peak in terms of the current phase. The motor torque is a total of this magnet torque and the reluctance torque and it has a peak value. PMDY−LV220 has a bigger current phase angle than that of conventional dynamometer and generate more reluctance torque, so that the total torque is not lowered.

3.2 **Low-Torque Ripples**

Since this equipment is directly connected to the axle shaft, it can be used from ultra-low speeds. And the dynamometer inertia is reduced, the drive shaft torsional vibration frequency tends to be raised. If a in shaft torque meter is used for torque measurement, torque ripple problem may be occured. In such case cogging torque, which is peculiar to the PM motor, reduction countermeasure should be required.

The torque can be expressed as follows:

$$T=-\frac{\partial W}{\partial \theta}$$

This torque is a differential of the magnetic energy (W) by the rotation angle (θ). Torque ripples are generated if there is any variation in the magnetic energy. There are open sections on the stator slots and they may create the magnetic energy variations in the gap area. This is the so-to-speak cogging torque and

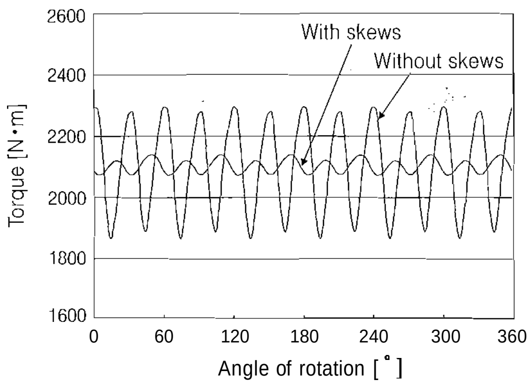

Fig. 5 Torque Ripple Simulation

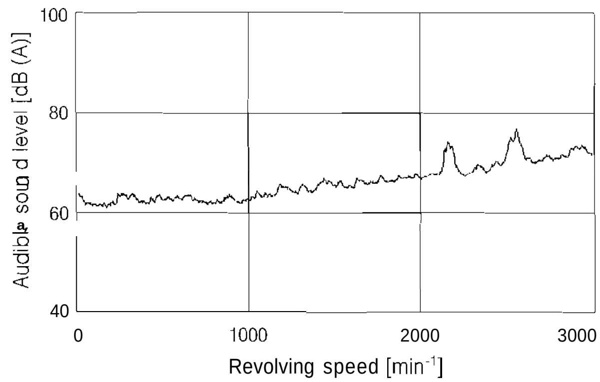

Fig. 7 Noise Data

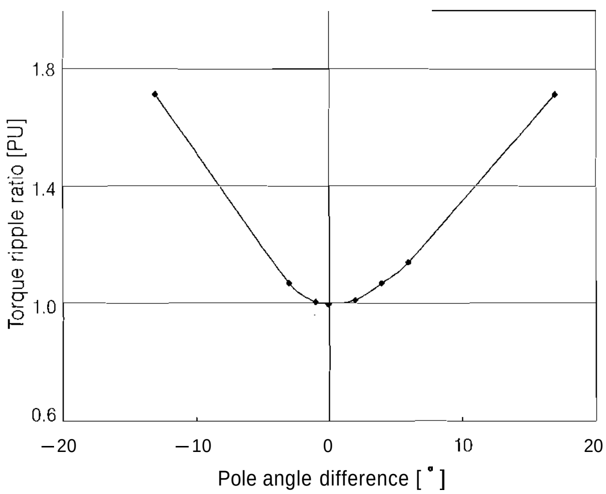

Fig. 6 Changes in Torque Ripples in Terms of Magnet Pole Angles

its frequency is defined by the Least Common Denominator (LCM) of the number of the stator slots and that of the poles.

To reduce the cogging torque, this magnetic energy has to be smoothed by adopting the skew structure of the slots in the stator. And a ferromagnetic material is used for the stator wedges, the cogging torque can also be reduced.

Recently, these reduction effects have been evaluated by simulation in the magnetic field analysis. Fig. 5 shows the result of simulation done for PMDY−LV220. Obviously, the effect of the skew slots seems to be substantial.

The torque ripples can be generated by another cause, other than the cogging torque. The ripple value can change even when the pole angle of the magnet is changed. Fig. 6 shows an example. PMDY−LV220 has been put into production after defining the pole angle that results in the least torque ripples.

3.3 Low Noise

Since the power train test system permits the simplification of utility, conventional engine driving systems have tended to be replaced by the electric motor driving systems. In addition, thanks to the use of electric motor driving, the audible sound (noise) level can be lowered and the detection of any unusual sound in the specimen can be detected. Since PMDY−LV220 is established in a totally enclosed construction with the indirect liquid cooling system, it interrupts the emission of noise generated inside the motor and the noise from auxiliary machines. Fig. 7 shows the noise level of the PMDY−LV220. Compared with a conventional machine, there is a reduction of more than 10dB (A).

4. Postscript

This paper has reported the characteristics of the load-side dynamometer used in the power train test system. As a result of being a small size and a low inertia, we consider that a substantial space saving can be achieved for the overall system. In addition, we think it possible to look for a new test evaluation method. We will make efforts in improving the equipment functions further in the future and to develop more improved products to satisfy the customers.