Torque-Speed 기울기를 통한 PWM 구동 DC 모터의 토크 측정

Torque Measurement of PWM Driven DC Motor Using Torque-Speed gradient

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Key words : Torque Feedback, Torque-Speed, PWM, DC Motor

1. Introduction

Motor torque is one of main concerns for mobile robots especially for outdoor or uneven terrain robots. But torque is not directly measurable with simple feedback devices like an encoder or tachometer. There has been various researches to measure torque. In previous researches, direct and indirect torque measurement methods are introduced[12]. Direct method uses torque transducers such as dynamometer and torque meter. It gives much accurate result compare to indirect methods, but it needs expensive torque transducer which takes space, too. Indirect method gives relatively inaccurate result but it is much cheaper and simple way, which is more applicable to a mobile robot. In this study, we introduce an experiment system to measure thrust force applied to a linear guide block from a wheel driven by motor. The thrust force can be easily transformed into torque. The system is used to verify torque of PWM(Pulse Width Modulation) driven brushed DC motor acquired from indirect method using motor torque-speed gradient.

2. Parameters for indirect torque measurement

Indirect torque measurement methods uses motor parameters and the relation between parameters to evaluate torque. We can easily consider voltage, current and angular velocity of motor as the parameters which are not to difficult to get. An ideal PWM effective voltage can be represented as below.

$$V_{eff} = V_s \times \frac{P.W}{P.P} \quad (1) \qquad V_s : Supply\ \ Voltage$$

$$P.W : Pulse\ \ Width \qquad P.P : Pulse\ \ Period$$

Hence, we can expect pseudo analog voltage effect with an ideal PWM voltage supply. But when we apply PWM voltage into a DC motor, we can not get effective voltage, which linearly depends on pulse width, due to inductance of coil element. The effect of inductance is shown in motor electric part KVL(Kirchhoff's Voltage Law) equation (2).

$$V = L\frac{di}{dt} + Ri + K_b w \quad (2) \qquad L : inductance\ \ of\ \ wire$$

$$K_b : Back\ \ EMF\ \ constant \qquad w : motor\ \ speed(angular\ \ velocity)$$

Motor torque and current has linear relation as equation (3) below. The force induced on a wire in magnetic field is proportional to the current flows through the wire.

$$f_{ind} = Bil \qquad (3)$$

$$B = Magnetic\ \ flux\ \ density \qquad l : \ wire\ \ length$$

Torque induced on a rotor of motor is n/r times of force induced on the rotor wire. 'n' is the number of turns of wire, and 'r' is the effective rotor wire radius.

3. Relation between torque and speed

We can derive an equation between motor torque and speed, under constant voltage induced, from equation (2) & (3) as an linear equation as below.

$$\tau = K_r i \quad (4) \qquad V = Ri + K_b w \quad (5) \quad \left(\frac{di}{dt} = 0\right)$$

$$\tau = \frac{K_r}{R}V - \frac{K_r K_b}{R}w \qquad (6)$$

The linear relation of torque and speed[2] on equation (6) is the key of indirect torque measurement in this study. We made an test equipment and verified the relation by experiments.

4. Test equipment

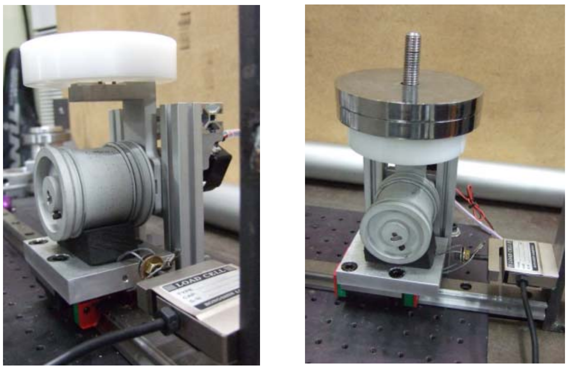

Fig. 1 Test equipment

Maxon RE26 18W DC brushed motor is used with 84:1 planetary gearbox and 500ppr encoder. It is one of the 6 independently driven wheels of mobile robot named TAMRY[3]. The tire is removed to make radius of wheel fixed to 28mm. High tension sponge is located between a linear guide block and the wheel, transfer thrust force to the linear guide block connected to a load cell with 500N capability.

Normal force is adjusted using mass block of 10N/ea, making different friction force works as an external torque to the wheel. The motor is driven by L6203 D-MOS H-Bridge driver with PWM velocity command. Angular velocity is acquired by time sampled encoder value and armature current is measured by the voltage induced on the series resistor of 5W 0.05ohm. The current feedback voltage is averaged by lowpass filter twice at before and after 20 times voltage amplifier.

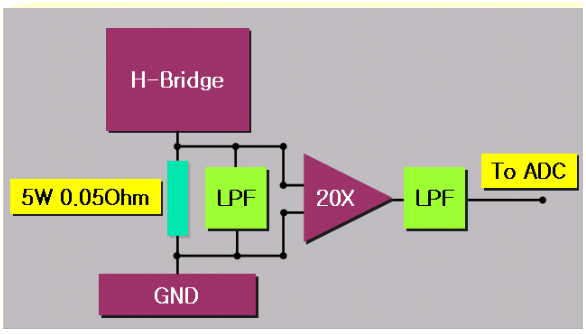

Fig. 2 Lowpass filtered effective current acquisition from PWM driven H-Bridge motor driver

5. Test result

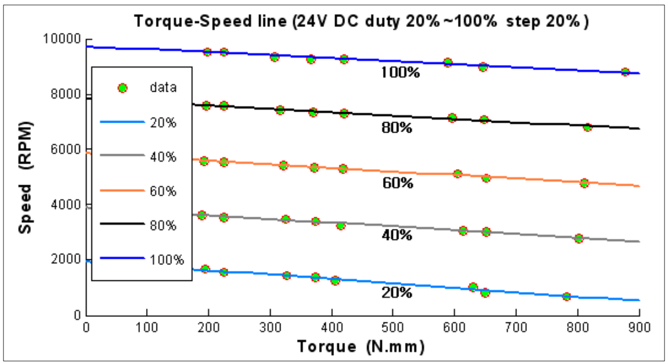

Fig. 3 Measured Torque-Speed data & its 1st order polyfit result

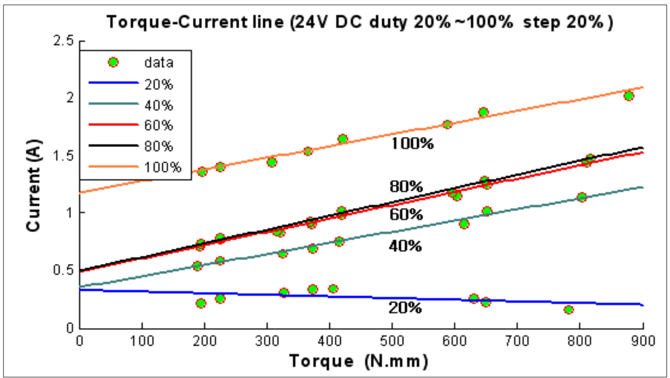

Fig. 4 Measured Torque-Current data & its 1st order polyfit result

Table 1 Torque-Speed & Torque-Current gradient

Duty	20%	40%	60%	80%	100%
$\Delta w/\Delta\tau$	-1.5927	-1.3602	-1.2996	-1.1949	-1.0697
$\Delta i/\Delta\tau$ (x 10-3)	-1.3564	9.6829	11.576	11.974	10.185

The input voltage from 24V regulated DC power supplier was used as Vs and 0 to 110N of normal forces are applied to the test equipment during the PWM duty varying from 20% to 100%. Torque, angular velocity and low pass filtered current are measured by USB type DAQ made by National Instruments Inc with 2kHz sampling rate. Fig. 3 shows the relation of torque and speed of motor. It shows that the relation follows equation (6) within acceptable error range. Fig. 4 shows the relation of torque and current. In case of duty over 40%, it also shows the tendency following equation (4), but the error and nonlinear aspect toward the duty ratio make it impossible to use current information to decide the torque. Even it shows totally wrong result on 20% duty case.

In ideal case, the gradient of torque-speed line should be same in any constant voltage case. It is because the gradient is decided by armature resistance, current-torque constant and back EMF constant. All three parameters are constants, but in experiment result it shows change of gradient as the duty changes. It can have various sources of error, but in practical usage of the relation to decide motor torque transferred to the external environment, it is enough to know the gradients for whole duty range with enough steps and it's RPM axis intercept only.

6. Conclusion

We have introduced an experiment equipment to measure motor torque represented by it's linear thrust force and combined the measured torque with motor speed(angular velocity). We could verify the predefined equation explaining relation of torque and speed. The result is acquired as an linear function has different gradient and RPM axis intercept for different duties. The experiment results meets the expected tendency with desirable accuracy even though it has some non-constant gradient for duties. It could be a good solution for simple and cheap approach to torque measurement of DC motor.

Torque-current relationship was also under interest, but even though it showed partially acceptable result, still it is not so effective as torque-speed relation, and has difficulties to use for a mobile robot.

In conclusion, we can measure torque of motor by measuring speed and effective voltage applying various external force with known value. It doesn't need additional equipment on the motor system, encoder is the only device for this method, but it need to perform some tests to decide the motor's parameter such as armature resistance, current-torque constant and back EMF constant, prior to use in mobile environment.

7. Future works

In this study, we measured the torque and angular velocity at constant speed after some time later changing duty, which means an static relation. To apply this method into real platform and use it to get torque as an feedback input, we need to perform the same test in dynamic condition, and see if the angular velocity dynamically follows the torque. It will be performed and will be applied to platform TAMRY later if successful.

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