

# UNCERTAINTY EVALUATION METHOD OF A DYNAMIC TORQUE GENERATING MACHINE USING ELECTROMAGNETIC FORCE

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## Abstract:

This study investigated the uncertainty evaluation procedure in the dynamic torque realised by a dynamic torque generating machine (DTGM) based on an electromagnetic force under development at NMIJ. The dynamic torque can be generated by changing the applied current. The generated torque can be traceable to the International System of Units (SI) by referring to the national standards of voltage, current, angle, and frequency.

**Keywords:** torque; dynamic torque; electromagnetic force; Kibble balance; uncertainty

## 1. INTRODUCTION

In recent years, the importance of precise measurement of dynamic torque has been recognised to improve the performance of motors and engines and contribute to saving energy. Studies have been conducted in some countries to measure dynamic torque accurately [1], [2]. NMIJ has been advancing research on the precise measurement of dynamic torque by using electromagnetic force based on the principle of Kibble balance [3]. This method measures dynamic torque by comparing the time-varying electric current and the torque generated thereby. In this study, the uncertainty evaluation method for the dynamic torque generation machine (DTGM) using electromagnetic force was investigated for the establishment of the dynamic torque calibration method.

## 2. PRINCIPLE OF A DYNAMIC TORQUE GENERATION

There is a relationship between the torque  $T$  generated when current  $I$  is applied to a rectangular coil in a uniform magnetic field  $B$  (case 1) and the induced electromotive force  $V$  generated when the rectangular coil is rotated at a constant angular velocity  $\omega$  in a uniform magnetic field  $B$  (case 2), as shown in equation (1), [4]

$$T \omega = V I . \quad (1)$$

At the angular position of the rectangular coil where the torque becomes the maximum value  $T_{\max}$  with respect to the rotating axis in case 1, the induced electromotive force also becomes the maximum value  $V_{\max}$  in case 2. Here,  $\frac{V_{\max}}{\omega}$  is a device-specific constant called the magnetic flux passing through the rectangular coil. Therefore, the torque is expressed as a function of current, as given in equation (2)

$$T_{\max} = \frac{V_{\max}}{\omega} I . \quad (2)$$

Here,  $I$  can be changed over time  $t$  and is expressed by equation (3)

$$I(t) = I_0 + I_m \sin(\theta t) . \quad (3)$$

Dynamic torque can be generated by evaluating  $\frac{V_{\max}}{\omega}$  in advance and changing the current over time.

## 3. A DYNAMIC TORQUE GENERATING MACHINE

Figure 1 shows a photograph of the DTGM. The DTGM is a vertical machine driven by servo motors with reduction gear on both ends. Reduction gears enable precise angular position manipulation. The upper servo motor is connected to a magnetic circuit consisting of two neodymium magnets and a yoke. It can rotate the magnetic circuit. The lower servo motor is connected in the order of torque transducer, aerostatic bearing, and coil. It can rotate them. A total of five rotary encoders (REs) are installed, and the angular position of the shaft can be measured. Arbitrary current can be applied by source measure unit of eXtensions for Instrumentation (PXI). A rubidium oscillator is connected to the PXI system, as shown in Figure 2, to synchronise each measurement. The output of the transducer, current, and angular position can be measured simultaneously since the torque transducer, coil, and three rotary encoders are connected to the PXI system for simultaneous measurement.

The device-specific constant  $\frac{V_{\max}}{\omega}$  was evaluated by the following method. When  $\omega$  was changed in

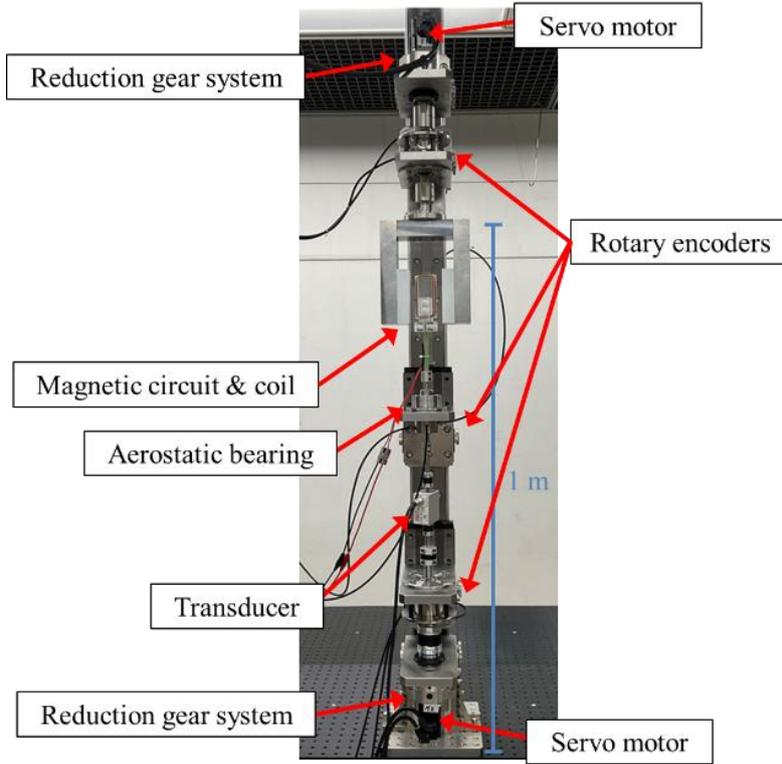


Figure 1: Photograph of the dynamic torque generation machine

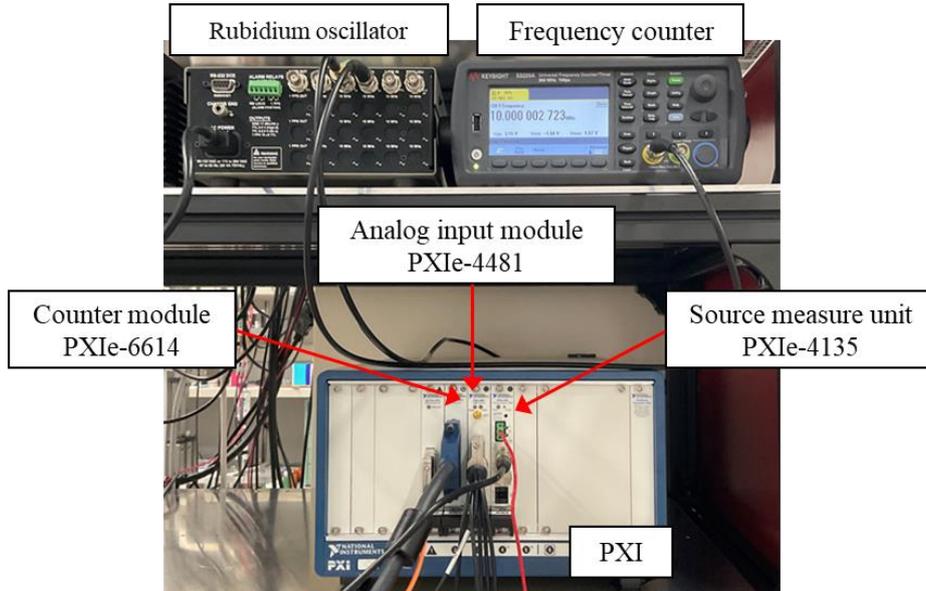


Figure 2: Photograph of the rubidium oscillator with frequency counter and the PXI system

case 2 of section 2,  $V_{\max}$  can be obtained at each  $\omega$ . As a result, the slope  $\frac{V_{\max}}{\omega}$  can be obtained from the plots.

#### 4. UNCERTAINTY OF THE DYNAMIC TORQUE GENERATING MACHINE

The uncertainty evaluation procedure of the torque realised by the DTGM using the electromagnetic force is shown as follows [5]. The

relative expanded uncertainty  $W_{\text{DTGM}}$  of the torque realised by this machine is expressed by equation (4)

$$W_{\text{DTGM}} = k \cdot w_{\text{DTGM}} = k \cdot \sqrt{w_V^2 + w_{\text{RE}}^2 + w_{\text{time}}^2 + w_{p_0}^2 + w_{\frac{V_{\max}}{\omega}}^2 + w_{I_{\text{dyn}}}^2}, \quad (4)$$

where  $k$  is a coverage factor,  $w_V$ ,  $w_{\text{RE}}$ ,  $w_{\text{time}}$ ,  $w_{p_0}$  and  $w_{\frac{V_{\max}}{\omega}}$  are the relative combined uncertainties ascribable to the analogue input module of the PXI system, the RE, the frequency, the measurement of

angular position  $p_0$  at which the induced electromotive force becomes maximum value  $V_{\max}$ , and the relative standard uncertainty ascribable to the first-order regression equation by the least-squares method in the  $\frac{V_{\max}}{\omega}$  evaluation, respectively.  $w_{I_{\text{dyn}}}$  is planned to be evaluated as the relative combined uncertainties ascribable to the source measure unit of the PXI system and time variation of the current.

## 5. SUMMARY

This paper introduces the outline and uncertainty evaluation procedure for a dynamic torque generation machine developed in NMIJ.

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