

## A COMPARISON OF PURELY STATIC AND CONTINUOUS TORQUE CALIBRATION PROCEDURE

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**Abstract:** This paper presents the results of calibration procedure comparison in pure torque measurement with a synchronous system between the purely static (step-by-step) and continuous (quasi-static) facilities in order to prove the influence of the procedural conditions on the uncertainty of calibration. The filter setting (Low pass Bessel: 0.2 Hz, 1.25 Hz, 5 Hz and 10 Hz) and speed of applying torque ( $\approx 0.7\%$  of full scale/sec to  $\approx 2.8\%$  of full scale/sec) were varied to examine the effects of both parameters on the measurement results and to optimize the continuous procedure. The measurement was made by a torque calibration machine (TCM) with a reference torque transducer and the HBM MGCplus amplifier system using a comparison method.

The results of this experiment show the deviation between the purely static and continuous procedure within  $\pm 0.01\%$  of reading that was enough for class 0.2 torque measuring devices (DIN 51309) and torque transfer wrench (DAkkS-DKD-R 3-7) calibration. For the step-by-step measurement, the duration time in each torque step (from applying torque to data record) must be adequate for steady state of filter setting. For the continuous measurement, the speed of applying torque and filter setting should be optimized for best measurement capability.

**Keywords:** Torque measurement, purely static and continuous facilities, synchronous system.

### 1. INTRODUCTION

Previous research on the calibration of torque measurement using the continuous procedure [1, 2] has shown that this procedure has many advantages over the step-by-step calibration. While a comparison method using the continuous procedure can be used with the calibration in accordance with Class 0.2 of the EA guideline EA-10/14 Guideline [2, 3], the following factors need to be taken into consideration: transducer creeping, data transfer rate and data processing. Andreas Brüge and Rudolf Konya [4], in their study, selected a torque transducer for a continuous torque and calibration. The National Institute of Metrology Thailand (NIMT) is interested in this continuous procedure and wants to examine if it can be used with the institute's existing machines.

In addition to the factors mentioned above, there are other factors that have the effects on the precision of the

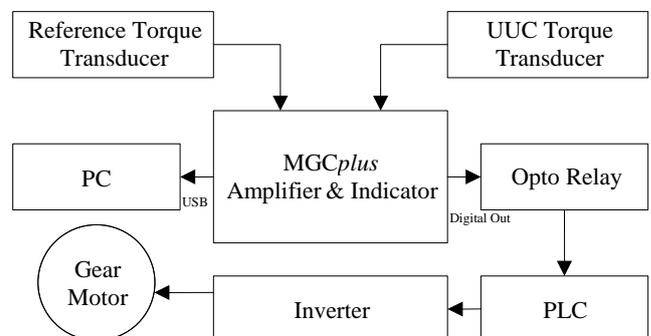
continuous calibration. NIMT wants to examine the effects of the filter setting and speed of applied torque, including an optimization of two parameters, in order to obtain the best results of calibration that is close to the step-by-step procedure.

### 2. TORQUE CALIBRATION MACHINE

Figure 1 shows the 10 N·m torque calibration machine (TCM) [5], which was used in the experiment. The 10 N·m TCM was built to support the workload of class 0.2 torque transducer calibration according to DIN 51309: 2005 [6] and class 0.2 torque transfer wrench according to DAkkS-DKD-R 3-7 [7], with an uncertainty of measurement of the system is 0.04% at  $k = 2$ .



**Figure 1:** 10 N·m Torque calibration machine



**Figure 2:** Open loop control system

The machine was controlled by the open loop system (see Figure 2). The torque transducer with 0.025% expanded uncertainty (calibrated by the step-by-step

procedure with a dead weight torque standard machine and 0.2 Hz filter setting) and 0.01 % creep constant were selected as a reference. The MGCplus (2 channels ML30B) synchronized measuring system was used to amplify and indicate the output signal. Automatic data were recorded by the computer software program via USB interfacing. The gear motor was controlled by programmable logic control to applied torque value.

### 3. EXPERIMENT

#### 3.1 STEP-BY-STEP PROCEDURE

To show the effect of varied filter setting on the measurement results and select the best measurement value for being the reference value comparison, the experiment was performed as follows:

The step-by-step calibration was carried out in each low pass filter setting with the same value of STD and UUC at 0.2 Hz, 1.25 Hz, 5 Hz and 10 Hz Bessel. The maximum torque value was preloaded three times. A waiting time for zero creeping after the last preloading was 3 minutes. The torque transducer was calibrated in the same mounting position with torque step (0.5, 1, 2, 3, 4 and 5) N·m and 3 cycles of repeatability (see Figure 3). A duration time in each torque step calibration started from applied torque until recording the data was 60 seconds. A waiting time after finishing each measurement cycle was 3 minutes. The calibration of torque transducer was reproduced three times (once a week) by re-mounting in the same position and using the same procedure to confirm the stability of artifact and results' reliable.

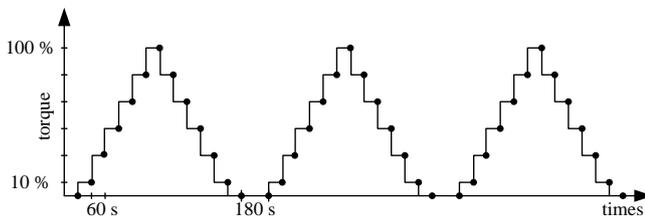


Figure 3: Step-by-step procedure

#### 3.2 CONTINUOUS PROCEDURE

To show the effect of varied filter setting, speed of applying torque to the measurement results and system optimization for selecting the best measurement value for a comparison, the experiment was performed as follows:

The continuous calibration was carried out in each low pass filter setting with the same value of STD and UUC at 0.2 Hz, 1.25 Hz, 5 Hz and 10 Hz Bessel. The maximum torque value was preloaded three times. A waiting time for zero creeping after the last preloading was 3 minutes. The torque transducer was calibrated in the same mounting position with automatic data record torque value (50 ms sampling rate and 10 Hz data transfer rate) from 0 N·m to 5 N·m with computer software program via USB

interfacing. Three cycles of repeatability were observed; this is shown in Figure 4. A speed of applying torque varied (0.7, 1.4, 2.1 and 2.8) % of FS./sec for every filter setting. A waiting time after finishing each measurement cycle was 3 minutes. The calibration of torque transducer was reproduced three times (once a week) by re-mounting in the same position and using the same procedure to confirm the quality of artifact and results' reliable.

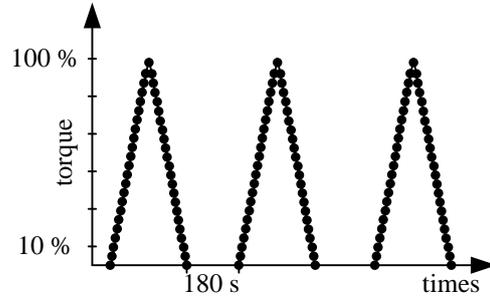


Figure 4: Continuous procedure

### 4. EXPERIMENT RESULTS AND DISCUSSION

#### 4.1 STEP-BY-STEP PROCEDURE AND SELECTED DATA TO COMPARISON

Figure 5 shows the relative interpolation deviation of the measurement results of the step-by-step procedure in each filter setting. Almost a non-linearity agreement of each measurement point is  $\pm 0.0025$  % except at 0.5 N·m and 1 N·m of 10 Hz filter. The deviation possibly resulted from poor resolution and high fluctuation of indicating devices due to a high filter value.

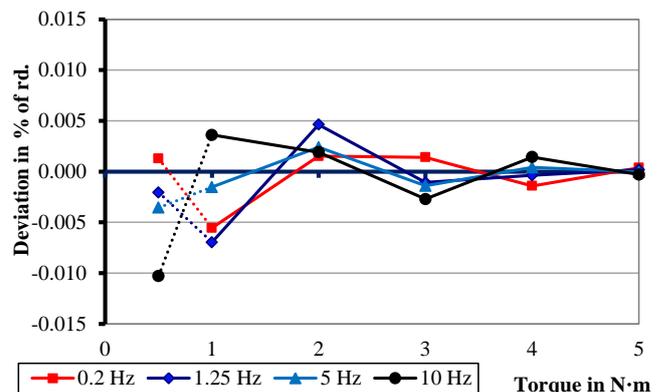
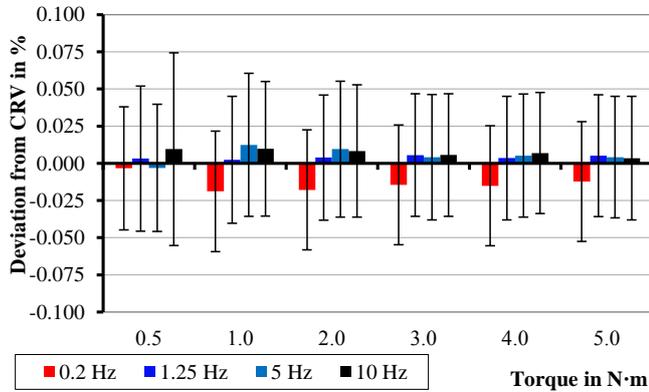


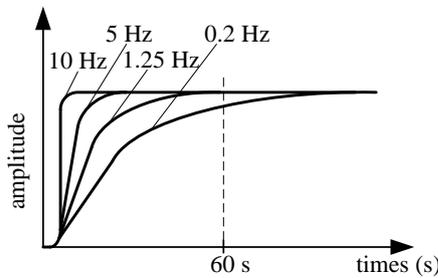
Figure 5: Relative interpolation deviation of each filter

Considering the deviation of measurement results and uncertainty of measurement (concerning repeatability, reproducibility, resolution and uncertainty of calibration torque) of each filter setting (see Figure 6), the measurement results of 0.2 Hz filter deviated from the comparison reference value (CRV) [8] in the different direction. The value of all measurement point was less than other filter value; this was possibly due to an inadequate time for steady state of 0.2 Hz filter as shown in Figure 7.

The uncertainty of the measurement point 0.5 N·m of 10 Hz filter was larger than the uncertainty of other filter setting. The main influence was repeatability of measurement that had high fluctuation of indicating devices (poor resolution).



**Figure 6:** Relative deviation of measurement results



**Figure 7:** Impulse response

The selected measurement results, which were at 1.25 Hz filters setting and considered to be the best degree of equivalence ( $|E_n|$  numbers  $< 0.15$  all of measurement points), were compared with the continuous calibration procedure.

## 4.2 CONTINUOUS PROCEDURE

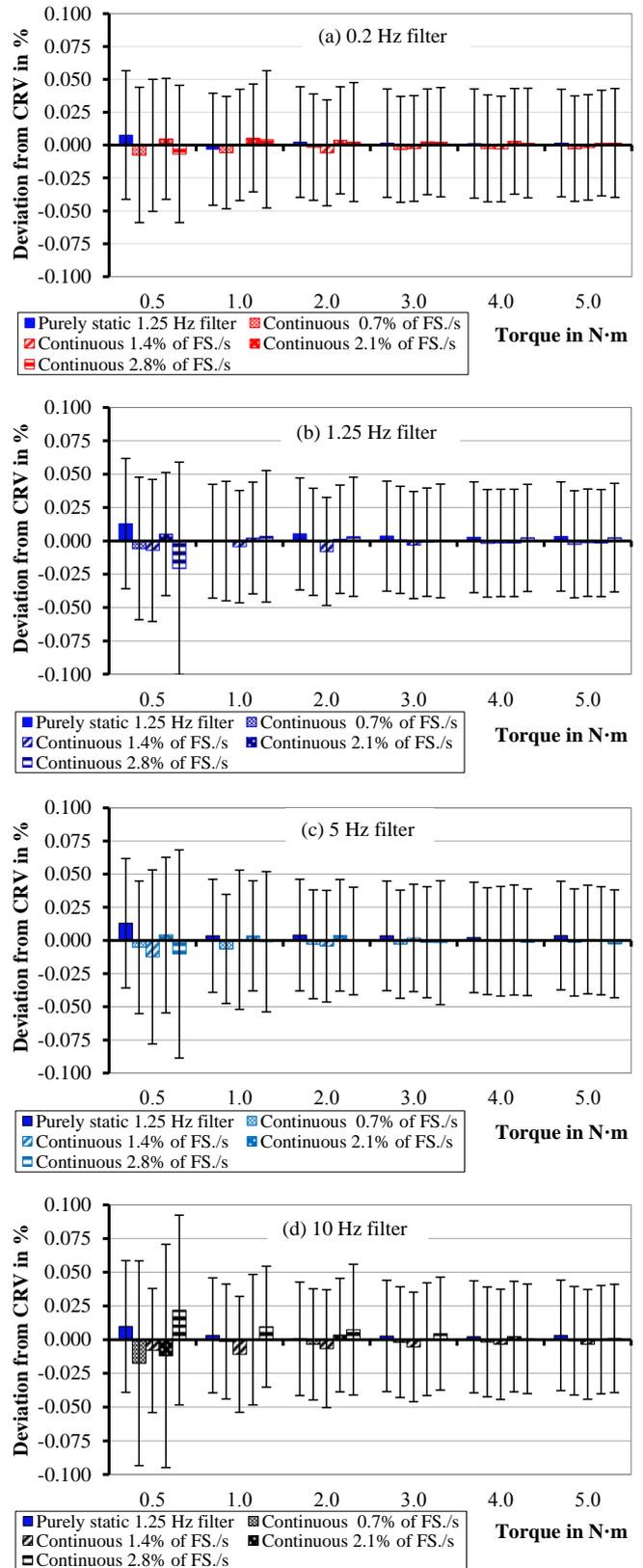
### 4.2.1 Comparison of Measurement Results

The comparison results between the step-by-step procedure and continuous procedure in each filter setting and all applying torque speed are shown in Figures 8(a) - 8(d).

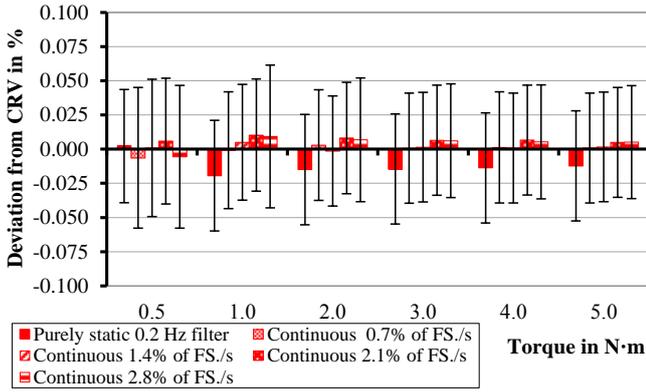
The uncertainty value of 0.5 N·m measurement point of 5 Hz and 10 Hz filter setting in every speed tended to be large. For 1.25 Hz filter shows large uncertainty only 2.8 % of FS./sec applying torque speed. This demonstrated that the high filter settings and high speed of applying torque had the effects on the uncertainty of the measurement. Also, degree of filter setting value affected the measurement uncertainty more than the speed of applying torque. However, the measurement results were still under the CMC.

From the comparison results in Figures 8(a) - 8(d), we were not able to determine the appropriate filter setting and

speed of applied torque for continuous measurement system. Therefore, other effects were analysed.



**Figure 8:** Relative deviation of measurement results with uncertainty between purely static and (a) 0.2 Hz, (b) 1.25 Hz, (c) 5 Hz and (d) 10 Hz filter setting of continuous procedure in each applied torque speed.



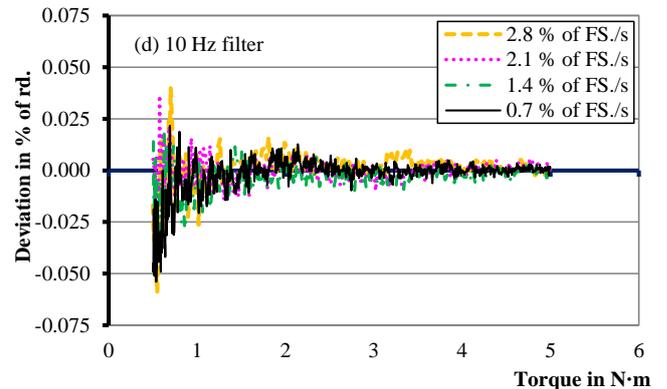
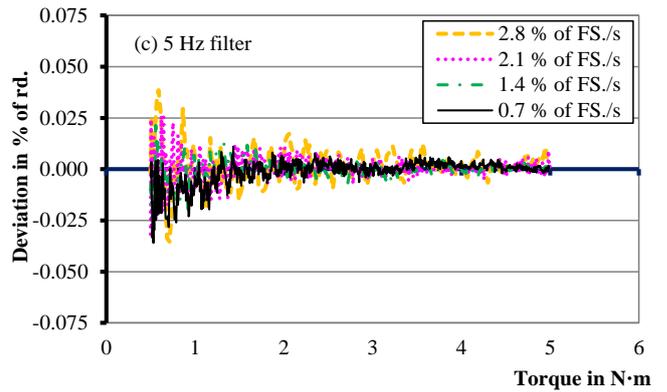
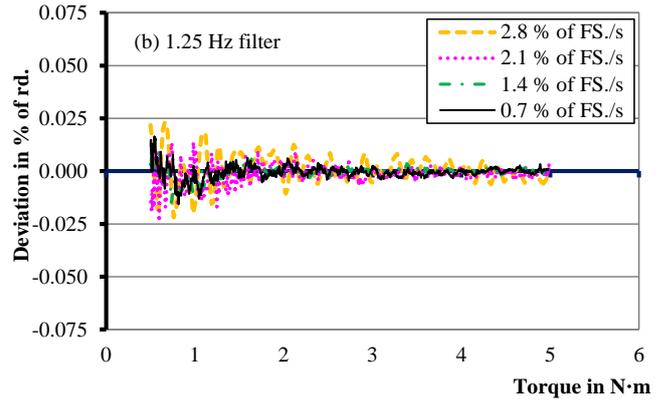
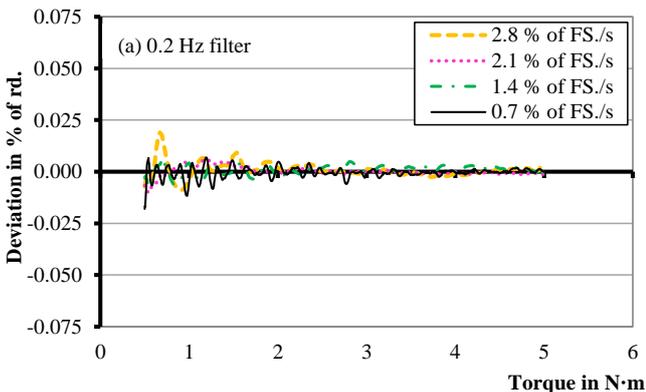
**Figure 9:** Relative deviation of measurement results with uncertainty between 0.2 Hz filter of step-by-step procedure and 0.2 Hz filter of continuous procedure in each applied torque speed

To confirm that the measurement value from 1.25 Hz filter was the best reference value (representative of step-by-step calibration procedure), it was tested by the measurement value from other filter setting. For example, bringing the measurement value from 0.2 Hz filter of the step-by-step procedure to compare with 0.2 Hz filter of continuous procedure. Almost all of the values of measurement points was less than the value from the continuous procedure; this is shown in Figure 9.

#### 4.2.2 Interpolation Deviation Characteristic

Figures 10(a) - 10(d) show the relative interpolation deviation characteristic of each filter setting and its speed of applying torque. As shown in Figures 10(a) - 10(d), the non-linearity interpolation graph tended to raise the following filter settings value (In the range of about  $< 0.02\%$  to  $\approx 0.06\%$ ). Considering the speed of applying torque of each filter settings, at speed 2.8 % of FS./sec, the non-linearity characteristic differed from the other speeds, except for the filter 10 Hz that offered the same characteristic; yet its deviation seemed to be larger than other filter.

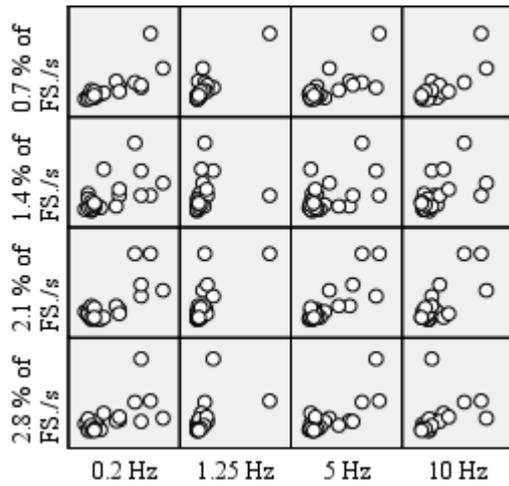
By considering the relative interpolation deviation, it was found that the continuous procedure works well with the filter 0.2 Hz and 1.25 Hz, and the speed (0.7, 1.4 and 2.1) % of FS./sec. Therefore, the optimized parameters were the 0.2 Hz and 1.25 Hz filter and speed of applying torque (0.7, 1.4 and 2.1) % of FS./sec.



**Figure 10:** Relative interpolation deviation of cubic polynomial regression of (a) 0.2 Hz filter, (b) 1.25 Hz filter, (c) 5 Hz filter and (d) 10 Hz filter

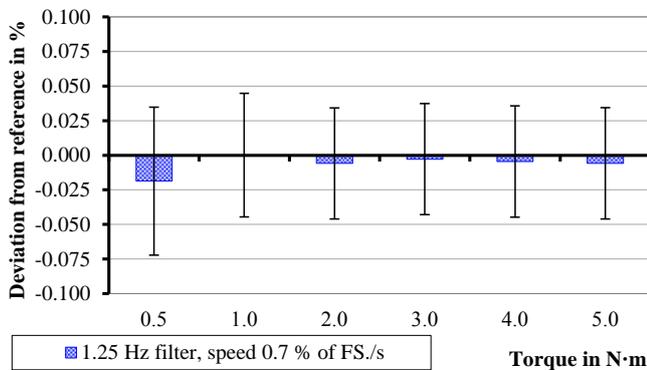
#### 4.2.3 Repeatability of measurement

Another parameter that should be taken into consideration was repeatability of measurement. The correlation of repeatability of all measurements setup and all measurement points is shown in Figure 11. From correlation of repeatability of measurement, it was found that the results from 1.25 Hz filter and at speed of applying torque 0.7 % of FS./sec gave a good repeatability (small and uniformity). There was only one isolation from the group; it possibly resulted from the poor resolution at low torque measurements.

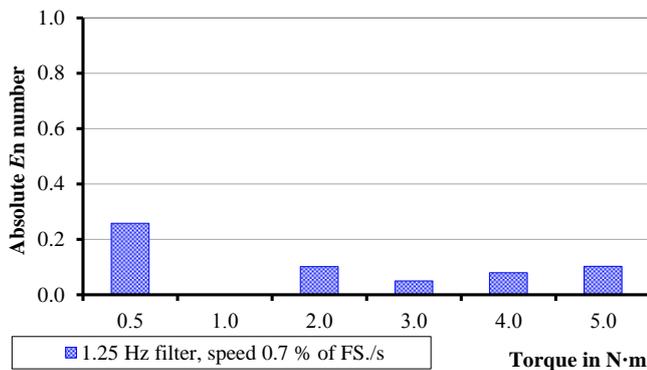


**Figure 11:** Correlation of repeatability of measurement between filter setting and speed of applied torque

From all information, the optimized filter and speed of applying torque was 1.25 Hz and 0.7 % of FS./sec, respectively. The comparison results between the step-by-step and continuous procedure by using the step-by-step as a reference demonstrated the deviation with uncertainty of measurement; these are shown in Figure 12. The deviation from reference value within  $\pm 0.01$  % and the degree of equivalence ( $|E_n|$  numbers [9, 10]) in Figure 13 was less than 0.3, which was subject to confirm the calibration and measurement capability.



**Figure 12:** Relative deviation of continuous procedure from purely static procedure



**Figure 13:** Degree of equivalence expressed as  $E_n$  numbers

## 4. CONCLUSION

1. The pure static or step-by-step calibration can perform with a wide range of filter settings (0.2 Hz to 10 Hz), but the duration of time (from applying torque to data recording) in each torque step should be taken into consideration. The duration of time should be adequate for the steady state of each filter setting value. Also, a high filter value will make more fluctuation, and it affects repeatability of measurement.

2. The filter setting value and speed of applying torque have the effects on the results of the continuous calibration procedure, measurement results, linearity, and uncertainty of measurement. Therefore, it is essential that the parameters be set up appropriately in order to get the best measurement results, which are close to the step-by-step calibration results.

3. The optimized filter and speed of applying torque for our system were 1.25 Hz Bessel low pass filter and 0.7 % of FS./sec speed, respectively. It resulted from a limitation of 10 Hz data transfer rate. The deviation of measurement results of the continuous procedure from step-by-step procedure was less than  $\pm 0.01$  % and  $|E_n|$  numbers  $< 0.3$  of all measurement points. This confirms the calibration and measurement capability.

4. The advantage that receives from the continuous procedure for our system is that it can reduce the calibration time interval about four times; this is satisfying.

5. In the future work, we want to experiment with asynchronous amplifiers and include image processing capture data.

## 5. ACKNOWLEDGEMENTS

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