MOTOR CONTROL CENTER (MCC) BASED TECHNOLOGY STUDY FOR SAFETY-RELATED MOTOR OPERATED VALVES

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It is necessary to monitor periodically the operability of safety-related motor-operated valves (MOVs) in nuclear power plants. However, acquiring diagnostic signals for MOVs is very difficult, and doing so requires an excessive amount of time, effort, and expenditure. This paper introduces an accurate and economical method to evaluate the performance of MOVs remotely. The technique to be utilized includes electrical measurements and signal processing to estimate the motor torque and the stem thrust, which have been cited as the two most effective parameters in diagnosing MOVs by the US Nuclear Regulatory Commission. The motor torque is calculated by using electrical signals, which can be measured in the motor control center (MCC). Some advantages of using the motor torque signature over other signatures are examined. The stem thrust is calculated considering the characteristics of the MOV and the estimated motor torque. The basic principle of estimating stem thrust is explained. The developed method is implemented in diagnostic equipment, namely, the Motor Operated Valve Intelligent Diagnostic System (MOVIDS), which is used to obtain the accuracy of and to validate the applicability of the developed method in nuclear power plants. Finally, the accuracy of the developed method is presented and some examples applied to field data are discussed.

KEYWORDS : Motor Control Center, Motor-Operated Valve, Motor Torque, Stem Thrust, At-the-Valve Test, NEST, NEET

I. INTRODUCTION

A motor-operated valve (MOV) is an essential element to control the piping flow in a nuclear power plant. In fact, the operational failure of a safety-related MOV can have catastrophic results. Therefore, it is necessary that the operability of safety-related MOVs should be ensured in the design basis conditions. The US Nuclear Regulatory Commission (NRC) issued Generic Letter 89-10 regarding safety-related MOV testing and surveillance. Subsequently, in South Korea, the Korea Institute of Nuclear Safety (KINS) required similar testing and verification, as follows:

- Reviewing and documenting the design basis for the operation of each MOV
- Establishing the correct switch settings
- Demonstrating an MOV to be operable at the design basis differential pressure and/or flow

To perform the above requirements, several sensors have been directly attached to MOVs in nuclear power plants. Doing so has required workers to spend hours in radioactively contaminated environments and has involved very high expenses for testing.

Once the operability of each MOV was proven, the need arose to preserve the operability of every tested MOV to maintain the safety of nuclear plants. The US NRC issued Generic Letter 96-05, which specifies periodic verification of the operability of MOVs. In case that the testing at the valve is used to implement periodic verification of MOVs, an excessive amount of labor is required.

To overcome the disadvantages of testing at the valve, many efforts have been made to develop a new and effective approach to verify the condition of MOVs. The Oak Ridge National Laboratory studied diagnosing MOVs by using the current signature and by estimating the stem thrust at the control switch trip using the power signature. Since the stem thrust at the torque switch trip indicates the condition of valve seating and the switch, it is one of the most important parameters. In addition, the Crane Nuclear Co. developed a method to estimate motor torque via measured voltages and currents utilizing motor information supplied by the motor manufacturer and to estimate the stem thrust from the correlation between the estimated motor torque and the measured stem thrust of the baseline data. [1]

However, each of these methods is inadequate for application to all MOVs due to problems with accuracy and limited application to specific MOVs, despite the advanages of remote monitoring via signals measured in the Motor Control Center (MCC). Because the MCC is located in a safe and clean location apart from the valves, it is effective for remote monitoring. Therefore, in this paper, a new method is introduced to estimate the motor torque and the stem thrust at the MCC more accurately, thus enhancing the applicability of remote monitoring of MOVs.

1.1 Operational Principles of an Mov

An MOV consists of a motor, an actuator, and a valve. Figure 1 shows a schematic diagram of an MOV. A motor that is bolted to the actuator housing drives the actuator. The pinion gear, which is attached to the motor shaft, drives a gear train. The gear train drives a worm that is splined onto the opposite end of the worm shaft. This worm assembly is capable of moving axially as it revolves with the worm shaft. The axial movement is a means of controlling the output torque of the operator. The worm drives a worm gear that rotates the drive assembly. As the drive sleeve rotates, the stem nut raises or lowers a valve stem. When the valve is seated or obstructed, the worm gear can no longer rotate, and the worm slides axially along its splined shaft compressing a spring pack. This axial movement operates a torque switch, causing the motor to be de-energized.

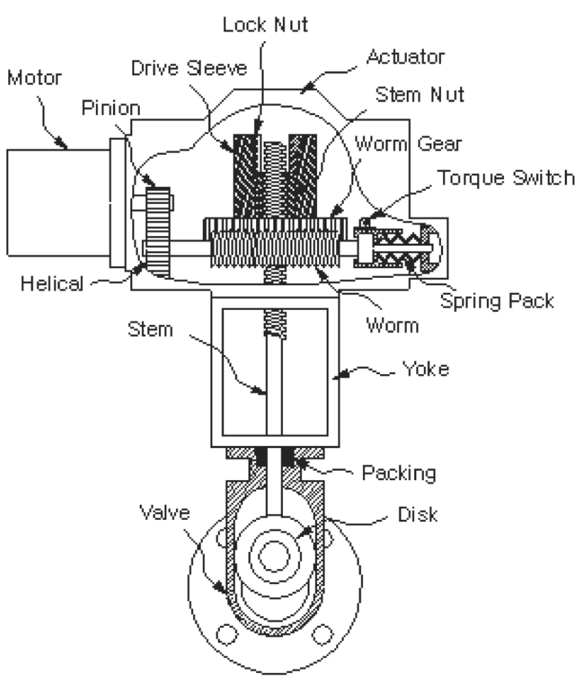


Fig. 1. Schematic Diagram of MOV

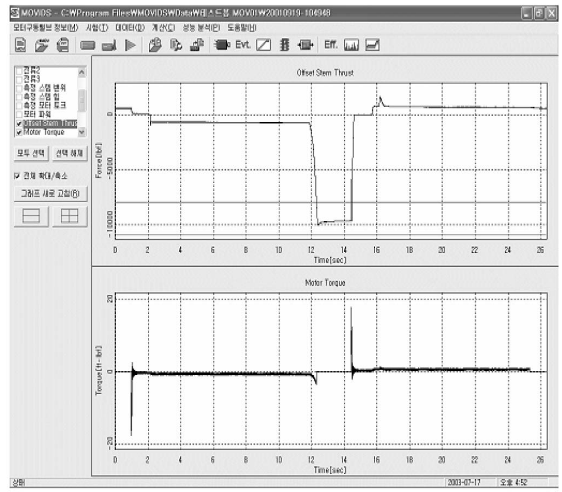


Fig. 2. Typical Signatures: Estimated Motor Torque (lower graph) and Measured Stem Thrust of One Full Stroke

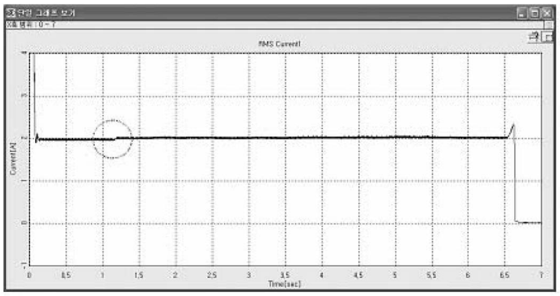
Normally, there are two different switches that control the MOV: a geared limit switch and a torque switch. Usually, the geared limit switch is used to stop the valve stroke at a previously determined position, and the torque switch is used to secure the required stem thrust. After the motor turns off, it continues to rotate due to the inertia of moving parts that further increase the stem thrust. Typical estimated motor torque signature and measured stem thrust signature of one full stroke are shown in Figure 2.

1.2 Monitoring Parameters of an Mov

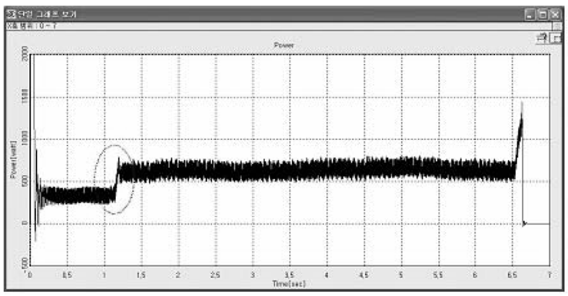
For monitoring the condition of MOV, the stem thrust is the essential parameter, since the stem packing thrust and the seating thrust indicate the condition of the packing and the seating, respectively. For the actuator, the motor torque and the stem thrust provide information regarding the overall efficiency. Therefore, the two most important parameters ensuring the operability of an MOV are the motor torque and the stem thrust (or torque), as recommended by US NRC.

Currently, for an at-the-valve test, only the stem thrust is measured, using a strain gage type sensor attached on the stem. However, to carry out an MCC-based test, it will be necessary to estimate the stem thrust as well as the motor torque. Methods for motor torque estimation and stem thrust estimation will be discussed in subsequent sections. Here, a brief explanation on the advantages of using the torque signature over the current or power signatures will be discussed.

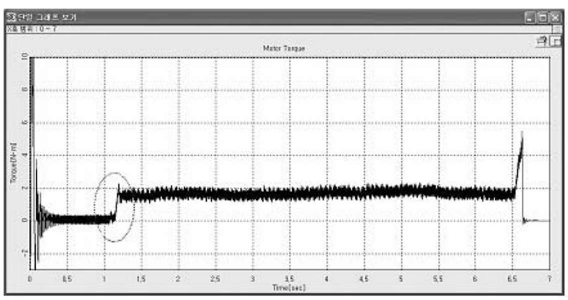
Figure 3 shows a current signature (root-mean-square of the stator current), a power signature, and a torque signature, respectively, which demonstrate the typical patterns in a closing stroke. Around 1 second after the motor starts, a hammer blow occurs, a phenomenon which indicates



(a) Current Signature

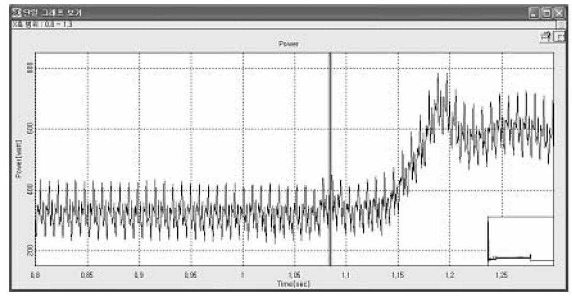


(b) Power Signature

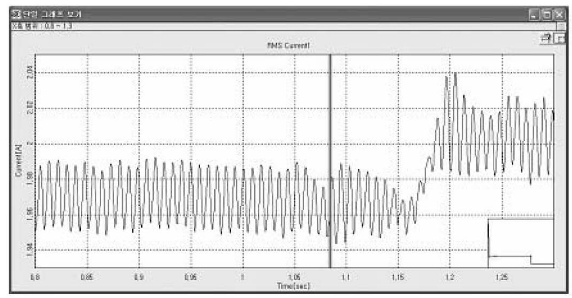


(c) Torque Signature

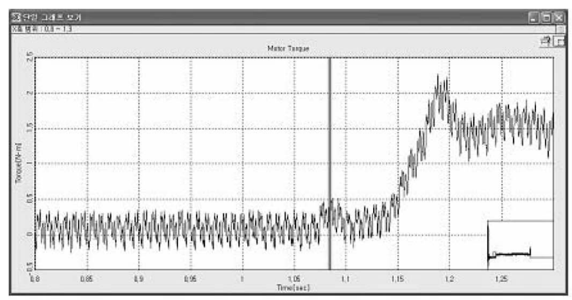
Fig. 3. Electrical Signatures in the Closing Stroke



(a) Current signature



(b) Power Signature



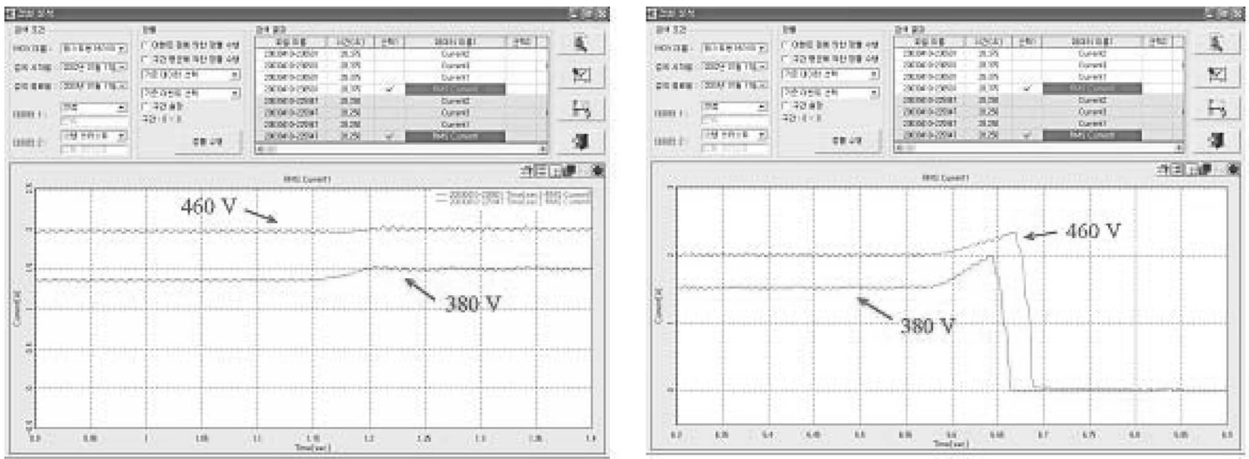
(c) Torque Signature

Fig. 4. Fluctuations of Electrical Signatures Due to Hammer Blow

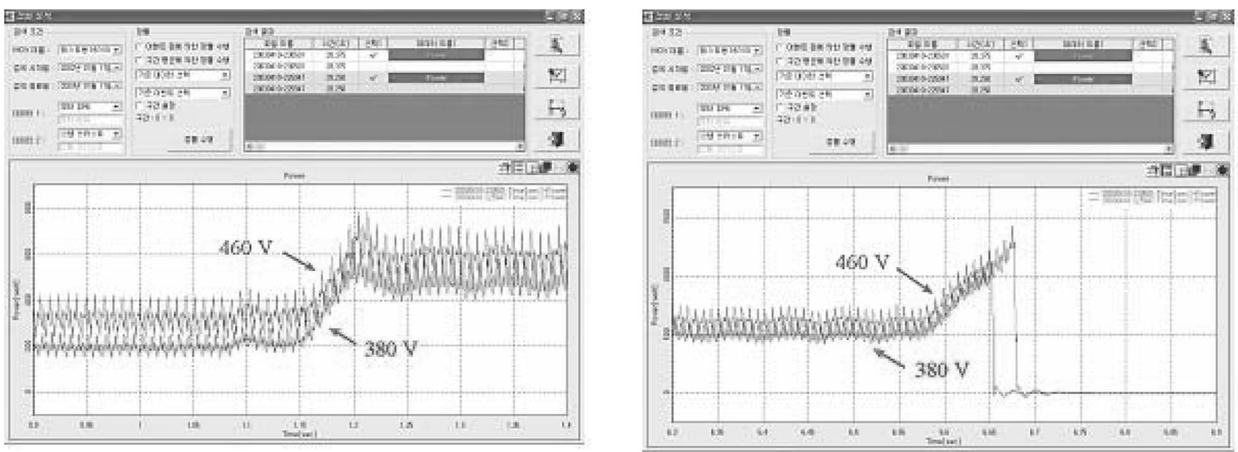
when the worm gear engages with the drive sleeve of the actuator. This is indicated by the small peak inside the circle in Figure 3 . Then, the stem nut rotates without engaging with the stem, since there is clearance between the stem nut and the stem. Notice the slow increasing load after the hammer blow . Once the stem nut engages with the stem, the stem starts to move to close the valve, and the load on the motor increases due to the stem packing. Therefore, the increase of the magnitude in every signature indicates the packing load. The stem keeps on moving until it reaches the valve seat. After seating, it is difficult to move the valce disk further , and this condition causes the current, the power, and the torque to increase until the control switch de-energizes the motor.

Figure 4 shows the fluctuation of the signatures due to the hammer blow. It is difficult to recognize the hammer blow effect in the current signature. Furthermore, the current signature is not sensitive to load change when the hammer blow causes the slight increase of the load, which means that the current signature is not always proportional to the load but is sometimes opposite to the load. Therefore the current signature is not a good parameter for monitoring the load on MOVs. The power and the torque signatures have distinct peaks at the hammer blow, and both of them show similar trends. The torque signature seems to have less noise and better sensitivity. The most important difference, however, is that the torque signature is linear to the load, while the power signature is not, since the efficiency of the motor changes according to the load on the motor. This difference is critical when we want to trend the packing condition of the MOVs.

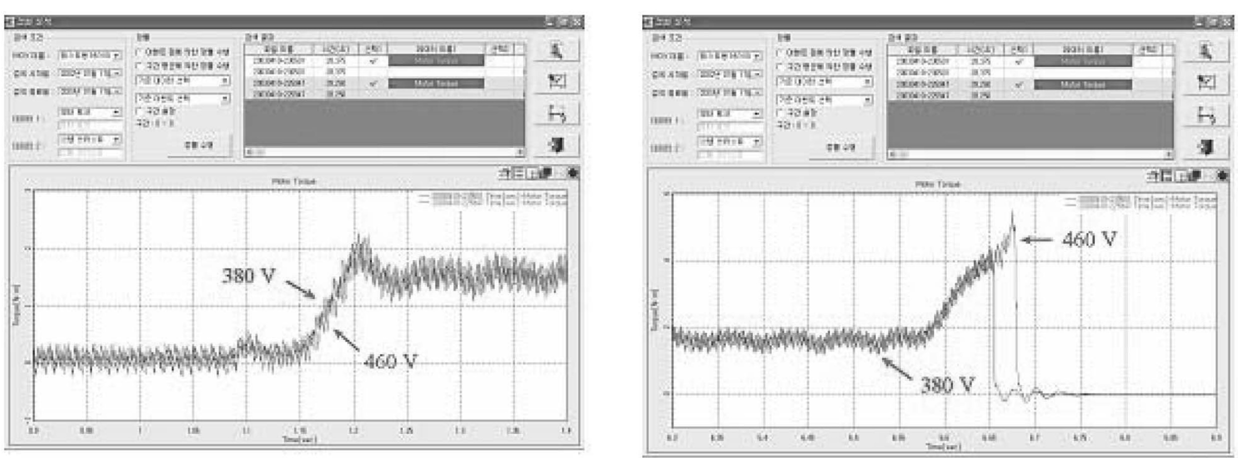
Another important advantage of the torque signature over all other signatures is that the torque signature is robust with respect to the conditions of input voltages. Figure 5



(a) Current signature



(b) Power signature



(c) Torque signature

Fig. 5. Electrical Signatures Around the Stem Nut Engaging and the Seating Region Under Different Voltage Conditions of 308V and 460V

shows the electrical signatures under different voltage conditions (380 V and 460 V) when the same load is applied. Only the torque signature provides consistent and correct information regardless of the input voltage. Since the accuracies of other signatures are highly deteriorated by variations of the input voltage level, special care must be taken to use the current signature and the power signature in detecting the level of the load.

2. THE NEET METHOD

2.1 Method Description

The Non-invasive Evaluation of Electric Torque (NEET) method calculates the electric output torque of the three phase induction motors. The NEET method was developed on the basis of several assumptions. First, the stator windings are assumed to be sinusoidally wound to couple only to the fundamental-space-harmonic component of the air-gap flux. Second, the self-inductances of the rotor are assumed not to vary with rotor angular position. Finally, linear magnetics are assumed.

Under these assumptions, the air-gap torque produced by a two-phase induction motor that can be transformed from a three-phase induction motor is given by

$$T_E = P\left(\lambda_{s\alpha} i_{s\beta} - \lambda_{s\beta} i_{s\alpha}\right) \tag{1}$$

Where $\lambda_{s\alpha}$ and $\lambda_{s\beta}$ are the flux linkages of the two stator phases, $i_{s\alpha}$ and $i_{s\beta}$ are the currents of the two stator phases, and P is number of pole pairs. [2,3,4] The currents $i_{s\alpha}$ and $i_{s\beta}$ can be directly measured at the stator terminals. The flux linkages can also be determined from terminal measurements. For a two-phase machine,

$$\begin{bmatrix} v_{s\alpha} \\ v_{s\beta} \end{bmatrix} = R_s \begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \lambda_{s\alpha} \\ \lambda_{s\beta} \end{bmatrix} \tag{2}$$

Where $v_{s\alpha}$ and $v_{s\alpha}$ are the two stator voltages, and $R_{s\alpha}$ is the stator phase resistance. Thus, the motor torque is expressed only in terms of stator variables that can be measured in the MCC.

2.2 Verification of NEET Method

The experimental verification of the motor torque estimator was performed using a dynamometer setup, as illustrated in Figure 6. The dynamometer setup consisted of a motor, a torque cell, and a load simulator. The torque cell was placed between the motor and the load simulator to measure the torque transferred from the motor to the simulator. Torque was estimated by the NEET algorithm loaded in the Motor Operated Valve Intelligent Diagnostic System (MOVIDS)[1)].

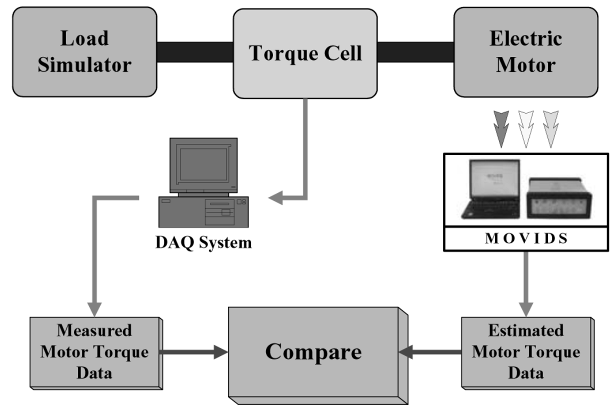


Fig. 6. Dynamometer Setup

The load to the motor was controlled with the load simulator. Experiments were carried out under 4 different voltage levels: 380V, 435V, 460V, and 475V. The accuracy of the NEET method was verified by comparing the estimated torque and the directly measured torque for the Limitorque and Rotork actuator according to the procedure recommended by National Institute of Standards and Technology (NIST). The results are presented in Table 1.

Table 1. Accuracy of NEET Method

Verification section	Accuracy
Less than 20 % start torque	± 1.91 % Full Scale(FS)
20 % ~ 100 % start torque	± 3.94 % Reading(rd)

3. THE NEST METHOD

3.1 Method Description

The NEST method calculates the stem thrust based on the motor torque and the stem displacement. The motor torque can be estimated by the NEET method, as described in the previous section, and the stem displacement can be obtained using the motor speed and the dimensions of the moving components.

1) MOVIDS (Motor Operated Valve Intelligent Diagnostic System) is the diagnostic system for MOV developed by Ajou University & KEPRI (Korea Electric Power Research Institute)

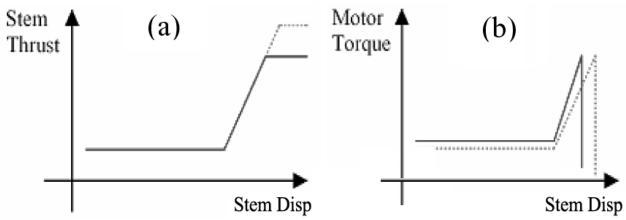


Fig. 7. Increase of Slope in Motor Torque Signature Due to Degradation of Efficiency

The NEST method was developed on the basis of a major assumption: the rigidity of an MOV does not change with time. This means that the increasing rate of torque with respect to the stem displacement during the valve seating dose not change. This relation is shown in Figure 7(a), where the dotted line represents a baseline stem thrust signature and the solid line represents the stem thrust signature after a certain time. Since we assume that the rigidity does not change, the slope of the solid line and that of the dotted line coincide with each other. However, it is worthwhile to recognize that the rate of change in the stem thrust with respect to time does change even though the rigidity does not change, because the motor speed that is related to the stem displacement may change due to degradation of the motor.

Based on the above assumption, the efficiency of the transmission mechanism can be estimated. Figure 7(b) shows the motor torque vs. the stem displacement graph corresponding to Figure 7(a). As mentioned earlier, the dotted line represents the baseline signature. As the efficiency of the transmission mechanism degrades, more motor torque is needed in the stroke. Therefore, the slope of the motor torque signature increases as a solid line in Figure 7(b), which gives us a good indication of the change of efficiency. Once the efficiency is obtained based on that of baseline condition, the stem thrust can be calculated using the motor torque and the efficiency, as follows.

$$Th_{stem} = T_{motor} \times Ratio_{gear} \times \eta \tag{3}$$

Where Th_{stem} : stem thrust

Th_{motor} : motor torque

$Ratio_{gear}$: gear ratio

η : efficiency

Additionally, the NEST method considers the inertia effect of moving parts after the motor is de-energized. Therefore, it estimates the stem thrust for the entire opening and closing stroke, including the thrust increase due to the inertia.

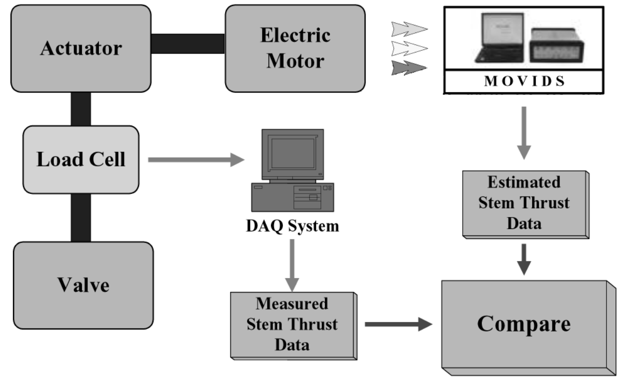


Fig. 8. Experimental Setup

3.2 Verification of NEST Method

The experimental verification of the NEST method was made by comparing the directly measured stem thrust with the estimated stem thrust, as was done for the NEET method.

MOVIDS was also used for acquiring data and calculating the stem thrust by NEST. Figure 8 shows a schematic diagram of the experimental setup. The load cell was inserted into the stem to measure the stem thrust transferred from the actuator to the valve. The accuracy of the NEST method was obtained and is presented in Table 2.

Table 2. Accuracy of the NEST Method

Verification section	Accuracy
Entire opening and closing stroke	±(5.03% RD + 2.6% FS)

4. EXAMPLE OF FIELD TEST

The NEET and NEST methods were tested for their applicability in nuclear power plants. MOVIDS was also used to acquire data at the valve and in the MCC simultaneously. The stem thrust was measured with a strain gage type sensor at the valve. Additionally, the voltages and the currents were measured non-invasively in the MCC. To characterize the MOV of the test, baseline data were used. To confirm the validity of the characterization, the measured stem thrust and the estimated stem thrust of the

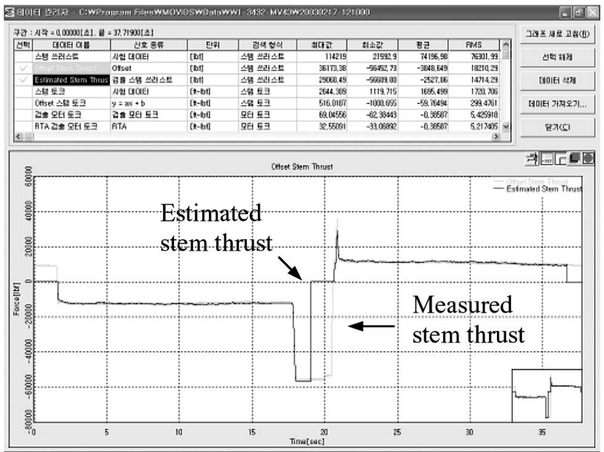


Fig. 9. Characterization of the MOV in Test

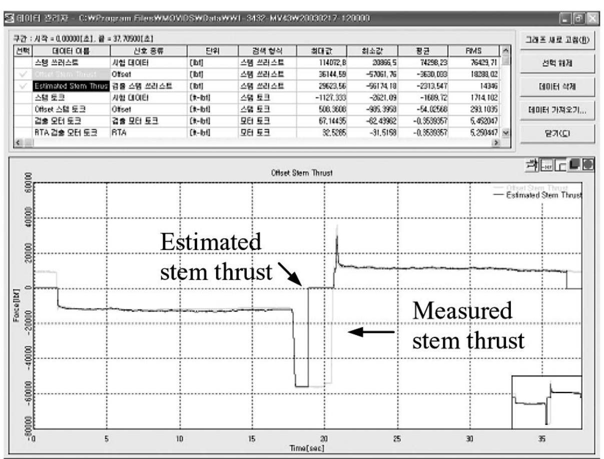


Fig. 10. Comparison Between the Estimated Stem Thrust in the MCC and the Measured Stem Thrust at the Valve

baseline data were compared, as shown in Figure 9. There was good agreement between the measured and estimated values, which means that the characterization was successful. Figure 10 shows the estimated stem thrust with the voltages and the currents measured in the MCC, utilizing the rigidity and the inertia characterized from the baseline data. The stem thrust measured at the valve is depicted in the same graph. It can be seen that the NEET and NEST methods provide very accurate estimation through the entire stroke range, including the range of the inertia effect after the motor was turned off.

5. MOV DIAGNOSTIC EQUIPMENT

The developed method was implemented in MOVIDS, as shown in Figure 11. This system integrates state of the art technologies for diagnosis and analysis to enable easy assessment of the mechanical and electrical operational condition of MOVs. Thus, MOVIDS helps plant personnel prepare reliable and effective MOV preventive maintenance programs. The major features of MOVIDS as a maintenance tool are as follows:

- Design Verification
- Trouble Shooting
- Setup (torque and thrust, limit switch, packing adjustments)
- Trending

MOVIDS is composed of 3 parts: sensors (voltage probes and current probes), a data acquisition system, and a notebook computer loaded with MOVIDS software to analyze the data with various signal processing methods and to build databases. Additional channels are available for other sensors. The signals can be obtained remotely and without disassembly of valves by using non-invasive sensors. Furthermore, MOVIDS was developed focusing on the user interface, so that beginners can operate it easily.

Fig. 11. MOVIDS Equipment

6. CONCLUSIONS

It has been shown that the NEET method and the NEST method can remotely and accurately estimate MOV motor torque and stem thrust, respectively. The accuracies of both methods were calculated according to the procedure recommended by NIST by comparing the measured and the estimated data gathered from repeated experiments under various conditions. Two 3-phase induction motors and two actuators of different sizes and manufacturers were used in the process. The load simulator or valves determined the experimental conditions. The accuracy of the NEET method was found to be $\pm$ 1.91 % FS with a 20 % starting torque and $\pm$ 3.94 % rd with a 20 % starting torque. The accuracy of NEST method was found to be $\pm$ (5.03 % rd + 2.6 % FS) for the entire opening and closing stroke. Additionally, the NEST method was tested in a nuclear plant, and its accuracy was confirmed.

Since these proposed methods provide accuracy and applicability superior to any present methods, it is expected that these new methods will increase safety and reduce outage costs when applied in nuclear power plants.

REFERENCES

[1] "Guidance on the Use of MCC-Based Technologies for Static MOV Performance Testing and Condition Monitoring", MOV USERS GROUP, (2000)

[2] H.H. Woodson, J.R. Melcher, *Electromechanical Dynamics* (R.E. Krieger Pub. Co., 1985)

[3] A.E. Fitzgerald, C. Kingsley, Jr., S.D. Umans, *Electric Machinery* (McGraw-Hill, New York, 1991)

[4] J. Chai, R.H. Lyon, J.H. Lang, "Non-Invasive Diagnostics of Motor-Operated Valve", American Automatic Control Conference, Vol. 2 (1994)