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IMPROVEMENT OF THE RELIZATION OF 500 KN FORCE BY DEADWEIGHT FORCE MACHINE AT NIMT

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Abstract – A 500 kN Deadweight force standard machine (DWM) was originally installed at Rama IV, Bangkok. In 2005, the DWM was moved to the new location at the Technopolist, Pathumthani. Due to some factors that could affect the force generation of the system, many parts of the machine needed to be modified and recalibrated.

This paper presents the comparison results of the DWM between before and after modification, using two loadcells as the artefacts to compare in term of repeatability, reproducibility and linearity of the system.

Keywords: deadweight force machine, DWM, Uncertainty

1. INTRODUCTION

In 2005, NIMT's Force laboratory moved from Rama IV, Bangkok (old location) to the Technopolist, Pathumthani (new location). At that time, the 500 kN DWM was moved and reinstalled in the force laboratory at the ground floor of the second block of the Pha-dung-mart building in the Technopolist. All of weights were recalibrated by NIMT's Mass laboratory. The gravitational acceleration at the new location was measured as 9.783124 m/s^2 by the National Institute of Metrology (NIM).

Some structures of the machine were modified to have better alignment and to reduce the first weight step (loading frame weight). The initial loading frame weight was about 3400 kgf, after modification, the frame weight reduced to about 1600 kgf.

After these modifications, the measurement uncertainty of the machine was evaluated and compared to the previous value. The comparison results were reported in this paper.

2. OUTLINE OF THE MACHINE COMPONENTS

The 500 kN deadweight machine (DWM) has major components as follows.

1. A 5000 kgf weight set which combines of 10 pieces of 500 kgf weight as seen in figure 1.
2. A 45000 kgf weight set which combines of 9 pieces of 5000 kgf weight as shown in figure 1.

3. Loading frame, which the original weight was 3400 kgf. After modification, the loading frame weight is approximately 1600 kgf. The upper platen of the loading frame is shown in figure 2.
4. Compression and tension platens, which were mounted to force proving instrument as seen in figure 2.
5. Main hydraulic cylinder. (for lifting the compression and tension platens).
6. Small hydraulic cylinders. (for controlling the number of loading weights of the small weight set).
7. Hydraulic cylinders for adjusting compression platen. (these were removed during modification).
8. Hydraulic cylinders for adjusting tension platen. (these were removed during modification).
9. Controller (PLC)



Figure 1. A 500 kN Deadweight force machine (large and small weight sets)

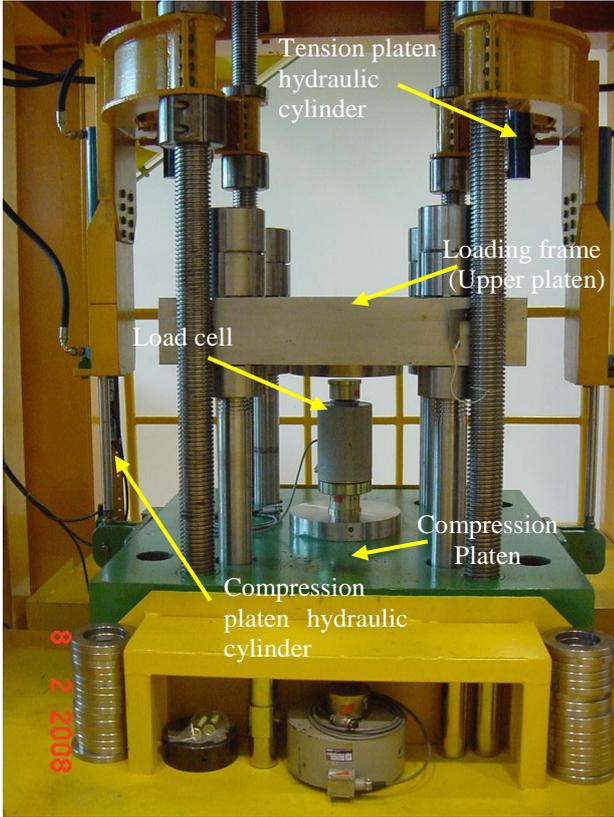


Figure 2. 500 kN Deadweight force machine

The working principle of the machine, for example in compression mode, a force proving instrument such as load cell was placed on the center of the compression platen and under the center of loading frame as seen in figure 2. The main hydraulic was used to lift the compression and tension platen. As a result, the load cell will move up and then lift up the loading frame. The lower part of the loading frame linked to the large weight set which the number of applied weights depend on the lifting distance of the main hydraulic. The number of small weights, which applied on the lower plate of the loading frame, was controlled separately by using the small hydraulic cylinders.

3. THE MASS AND UNCERTAINTY MODEL

All the weights were recalibrated by NIMT’s mass laboratory. The force realization of the deadweight force machine can be represented as follows [1, 2].

$$F = mg_{loc} \left(1 - \frac{\rho_a}{\rho_w} \right) \prod_{i=1}^n (1 - \Delta_i) \quad (1)$$

Where

- m is the mass of deadweight.
- g_{loc} is the local gravitational acceleration.
- ρ_a is the density of air.
- ρ_w is the density of deadweight.

$\Delta_i (i = 1, \dots, n)$ is the relative error component caused by the structure of force standard machine, such as the error caused by an inclined compression table of machine or by oscillations of the deadweight.

From the mathematical model of force, Eq. (1), the relative combined uncertainty of the deadweight force machine can be represented as follows:

$$w_c = \left\{ \sum \left(\frac{1}{F} \frac{\partial F}{\partial x_i} u_{xi} \right)^2 \right\}^{\frac{1}{2}} \quad (2)$$

where F is force generated by the deadweight machine, and u_{xi} implies an absolute standard uncertainty component due to variation of x_i which is one of the independent variables in Eq.(1), such as m, g_{loc} , etc. By substituting Eq. (1) in to Eq. (2), the relative combined uncertainty can be represented as follows:

$$w_c = \sqrt{\left(\frac{u_m}{m} \right)^2 + \left(\frac{u_g}{g} \right)^2 + \left[\left(\frac{u_{\rho_a}}{\rho_a} \right)^2 + \left(\frac{u_{\rho_w}}{\rho_w} \right)^2 \right] + \left(\frac{\rho_a}{\rho_w - \rho_a} \right)^2 + \sum_{i=1}^n w_{\Delta_i}^2}$$

$$= \sqrt{w_m^2 + w_g^2 + [w_{\rho_a}^2 + w_{\rho_w}^2] + \left(\frac{\rho_a}{\rho_w - \rho_a} \right)^2 + w_p^2 + w_{osc}^2} \quad (3)$$

From calculation, the overall uncertainty of the 500 kN deadweight machine was 0.008% at the confidence level of approximately 95%.

4. MODIFICATION OF THE MACHINE

The major modifications of the 500 kN deadweight machine are the modification to reduce the weight of the loading frame and the modification to improve alignment of the machine. Unnecessary parts such as hydraulic cylinders for compression and tension platens were also removed to improve rigidity of the system.

4.1. Reduce the weight of the loading system.

The loading frame was modified to reduce the weight from 3400 kgf to 1600 kgf. As shown in Figure 3, the upper platen of the loading frame was reduced in size and holes were made to reduce weight. The distances between loading columns were also reduced.

The modification of lower platen of the loading frame was shown in figure 4. Holes were made on the lower platen to reduce weight. The loading frame supports were mounted to the loading columns under the lower platen.

After modification, the weight of the loading frame reduced to approximately 1600 kgf. This improved the machine capability to be used for calibration of a smaller load cell (50 kN rated capacity) according to ISO 376 [3] which requires at least 8 force steps. The new loading diagrams were presents as follows.

For calibration of 50 kN rated capacity, the force steps are 0 kN, 16 kN, 21 kN, 26 kN, 31 kN, 36 kN, 41 kN, 46 kN and 51 kN respectively.

For calibration of 500 kN rated capacity, the force steps are 0 kN, 16 kN, 66 kN, 116 kN, 166 kN, 216 kN, 266 kN, 316 kN, 366 kN, 416 kN, 466 kN and 516 kN respectively.

4.2. Modification of system alignment.

To improve the system alignment, compression adapter with spherical metal ball was used to lift the loading frame as seen in figure 3d.

The flat lifting plate of the main hydraulic cylinder was also modified by replacing with semi-spherical joint as presented in figure 5.

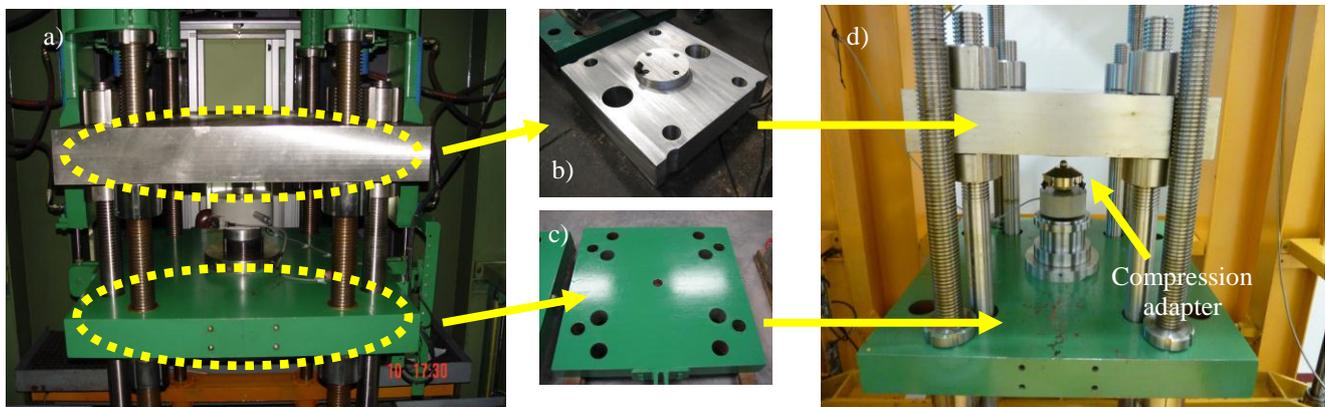


Figure 3. Modification of the loading frame (upper platen), a) before modification, b) modified upper platen, c) modified compression platen and d) after modification

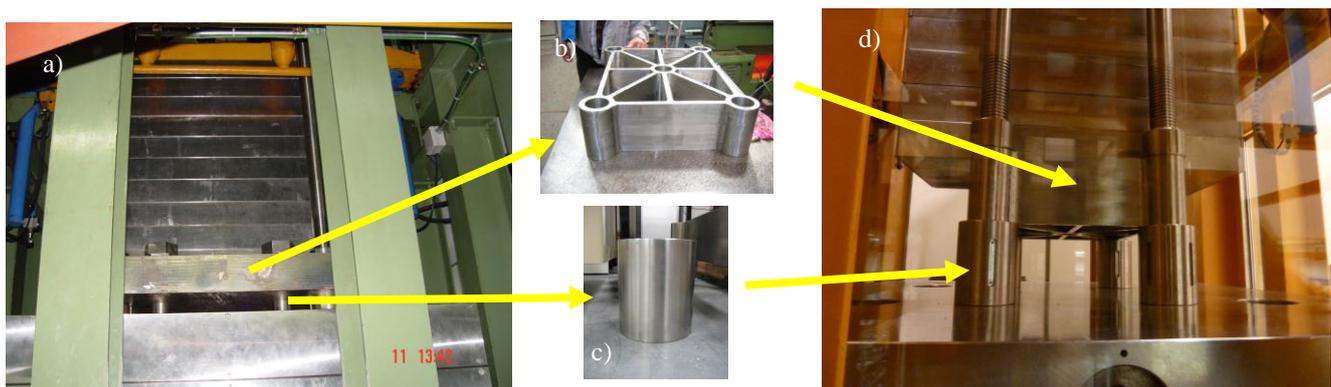


Figure 4. Modification of the loading frame (lower platen), a) before modification, b) modified lower platen, c) loading frame support, d) after modification

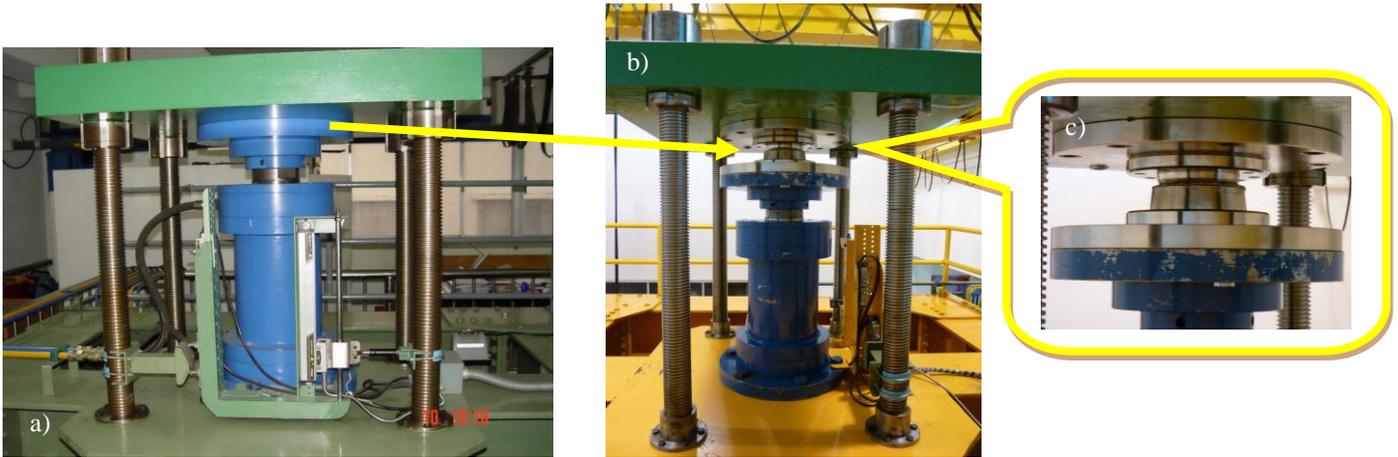


Figure 5. Modification of system alignment, a) before modification, b) after modification, c) zoom view of semi-spherical joint

5. EVALUATION PROCEDURE

In order to evaluate the effect of the modification, two force transducers with a DMP-40 as an amplifier were calibrated using the DWM before and after modification. Calibration results were compared in terms of repeatability, reproducibility and linearity. The two force transducers, called transducers 1 and 2, both had rated capacities of 500 kN. The calibration procedure was in accordance with ISO 376 [3], and its loading pattern is shown in Figure 6.

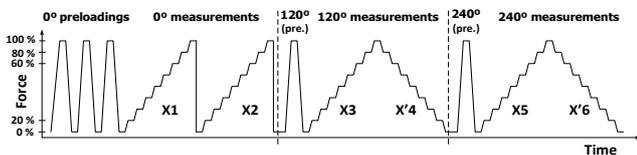


Figure 6. Loading pattern.

6. RESULT AND DISCUSSION

6.1 Repeatability

Figure 7 and 8 show the comparison of the repeatability error (calculated from loop X1 and X2 in figure 6) before and after modification from the transducer 1 and 2 respectively. The x-axis indicates the force applied and the y-axis indicates the relative repeatability error in ppm. The dashed and solid line represents the results from before and after modification respectively. From figure 7 and 8, the repeatability error after modification is less than before modification. Indicating that, the repeatability of the DWM was improved after modification.

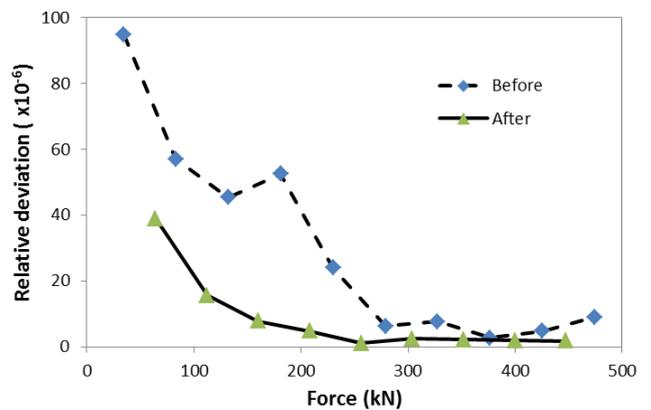


Figure 7. Repeatability of the transducer #1

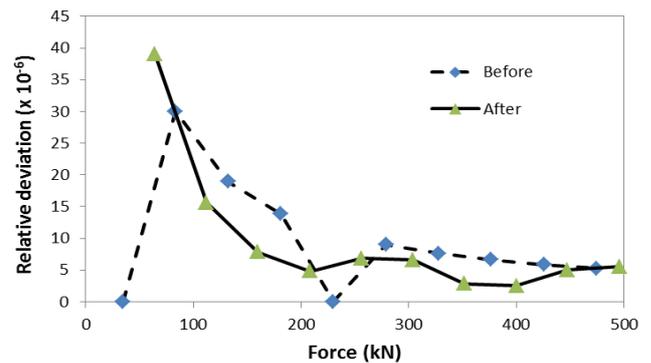


Figure 8. Repeatability of the transducer #2

6.2. Reproducibility

Figure 9 and 10 express the comparison of the reproducibility error (calculated from loop X1, X3 and X5 in figure 6) before and after modification from the transducer 1 and 2 respectively. Dashed and solid lines correspond to the results recorded before and after modification respectively. For the reproducibility results, it was not clearly seen that the results were better after

modification. But the trends of the graph were smoother for the results after modification.

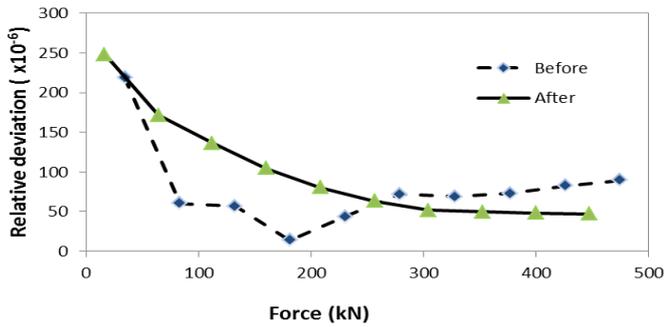


Figure 9. Reproducibility of the transducer 1

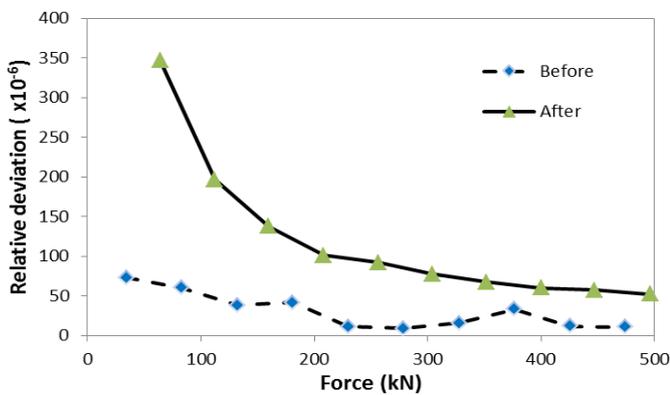


Figure 10. Reproducibility of the transducer 2

6.3. Linearity

Figure 11 to 14 show the linearity of the force transducer outputs. The horizontal and the vertical axes indicate calibration force steps and nonlinearity of readings, respectively. The curves with different symbols indicate different rotational positions of the force transducers and calibration cycles as shown in figure 6. Solid and dashed lines correspond to increasing and decreasing forces, respectively.

For the transducer 1 (Figure 11 and 12), the range of non-linearity was about 130 ppm before modification and 120 after modification.

For the transducer 2 (Figure 13 and 14), the range of non-linearity was about 180 ppm before modification and 80 ppm after modification.

The results from Figure 11 to 14 indicate that, after modification, the machine had better alignment system and more reliable because the trends of the graphs were smoother.

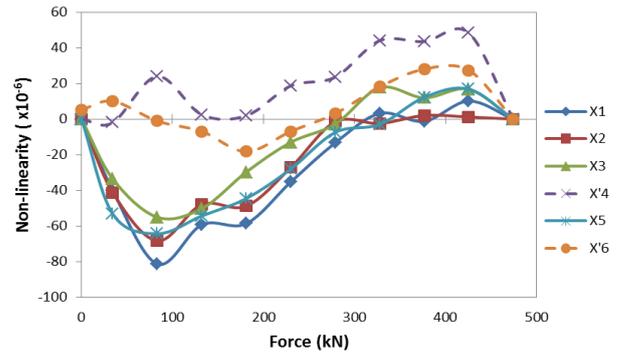


Figure 11. Linearity of transducer 1 before modification

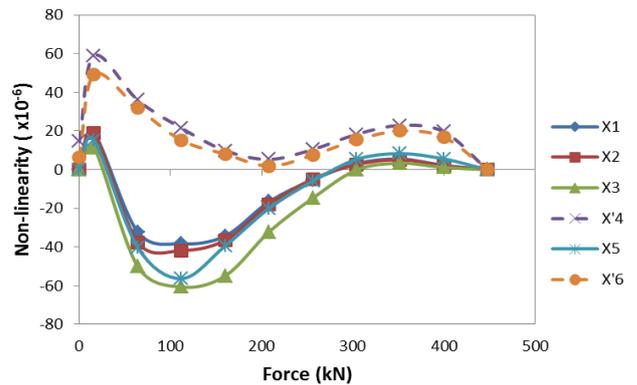


Figure 12. Linearity of transducer 1 after modification

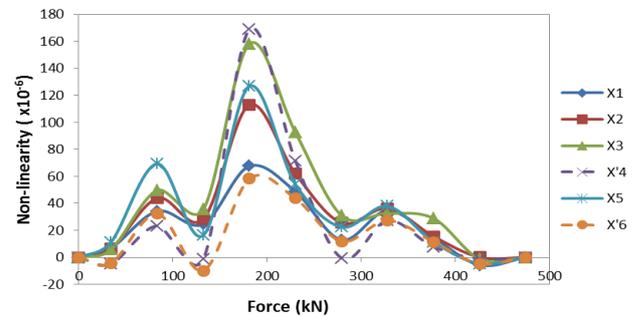


Figure 13. Linearity of transducer 2 before modification

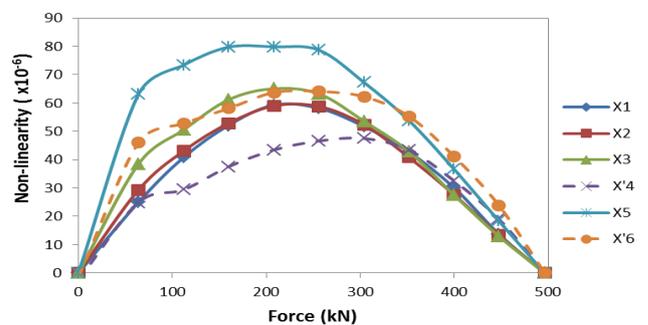


Figure 14. Linearity of transducer 2 after modification

7. CONCLUSIONS

The 500 kN deadweight force standard machine was original used in calibration of the force proving instrument at rated capacity of 500 kN. After modification, the loading frame weight was reduced to 1600 kgf. Therefore, the DWM can also be used to calibrate smaller rated capacity (50 kN).

After modification, the reliability of the machine was improved. For example, the repeatability error reduced about 50% for the transducer 1. The trends of the graphs for the reproducibility and linearity results were smoother after modification. Indicating that, the machine had better alignment.

There were some important factors that were not controlled in this experiment such as the drift of the transducer itself and the effect of the person skill. Further experiments and interlaboratory comparison are necessary in order to understand the actual system performance.

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