Oral Presentation

The 7th TSME International Conference on Mechanical Engineering
13-16 December 2016

AMM0014

Quality Assurance in Recording and Processing of Force Calibration Data with Machine Vision Technology

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Abstract

This paper presents a method for recording and processing of force calibration data using machine vision technology. The developed system is composed of a camera, a computer and software developed for the purpose. The system is used to capture the image of digital displays of load cell indicators during calibration. The images are translated to numbers using optical character recognition (OCR) to obtain calibration data. These images, together with the data, are saved to memory for further processing to issue the calibration certificate.

There were 3 categories of experiments in this study to verify the performance of the system when calibrating a load cell. First, verifying the performance of the character recognition software by reading measurement data from 4 different models of indicator devices connected to load cells. Second, testing the versatility of the system when used under various conditions such as different room illuminance or different distances, and, third, verify the performance of the system when used in full calibration experiments in accordance with ISO 376.

The experimental results reveal that the system is easy to operate and accurately reads data from the 4 models of force measuring instruments. The system was also versatile enough to be used under various conditions. The full calibration experiments on the force proving instrument gave 100% accurate results in recording and processing. This machine vision system can be efficiently used for recording and processing of force calibration data to assure the quality of the calibration process.

Keywords: Force Calibration; Quality assurance; Machine vision; OCR; ISO 376.

1. Introduction

Calibration of force-proving instruments such as load cells usually follow the guidelines of the international standard (ISO376) [1], according to which the calibrated load cell should be applied with more than 80 calibration forces for about 3 to 5 hours to complete the process, as seen in Fig.1. After each calibration force is applied, the output from the load cell's indicator will be recorded for further processing to allow the issue of the calibration certificate.

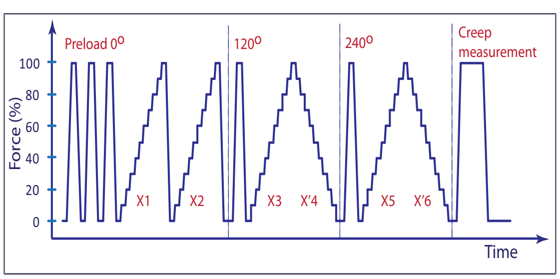

Fig.1. Example of calibration procedure according to ISO 376:2011

As illustrated in Fig.1, each calibration process is composed of 6 main series; x1 and x2 are increasing series at 0° angular position, x3 and x'4 are increasing and decreasing series at 120° angular position, x5 and x'6 are increasing and decreasing series at 240° angular position. Fig.2 shows the arrangement of the load cells during calibration at the angular positions of 0 and 120 degrees.

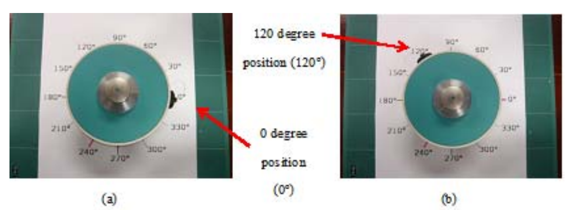

Fig.2. Example of top view images of load cell at 0 and 120 degrees angular position

In general, most calibration laboratories still use manual methods for recording calibration data. However, manual recording leads to mistakes in recording data due to human error because the output of the instruments always show some fluctuation which can be difficult to read manually.

The fluctuations more or less depend on many factors such as electrical noise, quality of instrument and type of calibration machine. Typically, there are 4 main types of force calibration machine; (1) deadweight force standard machine, (2) Lever amplification machine, (3) hydraulic amplification machine and (4) force comparator machine [2, 3].

Deadweight force standard machines (DWM) (as example in Fig.3) are a primary standard in the field of force calibration. The calibration forces of DWM are generated from the mass of the deadweights multiplied by the local gravitational acceleration, then the effect of buoyancy force from the density of the air and deadweight is further calculated [2, 4]. The calibration forces generated from the deadweight have some fluctuation because the weights are connected to a loading frame which hangs on the load cell like an oscillating pendulum (see Fig.4). However, the applied force from a typical DWM is very accurate with uncertainty of 50-100 parts per million (ppm). Fig.3 shows a deadweight force calibration machine (DWM-500N) during development at the National Institute of Metrology Thailand (NIMT).

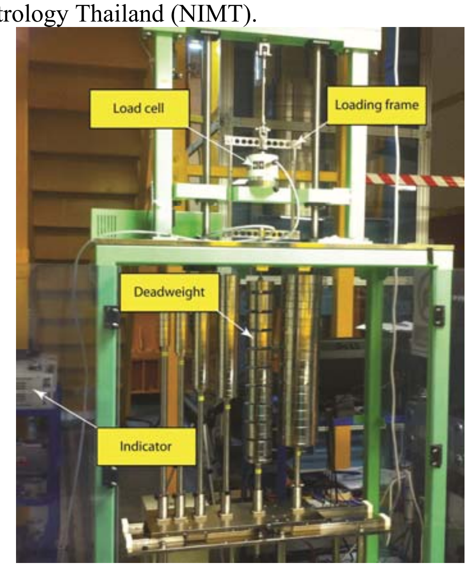

Fig.3. Deadweight force calibration machine (DWM-500N) at NIMT

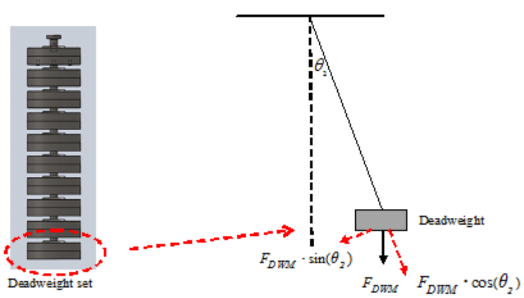

Fig.4. Oscillation of deadweight

For the lever force calibration machine (LM) [5] (Fig.5) and hydraulic amplification machine (HM), the applied forces are generated from the mass of the deadweight multiplied by the local gravitational acceleration similar to the DWM. Then, these forces are amplified using a lever mechanism in the LM and hydraulic system in the HM, which results in a larger magnitude of the oscillation force than occurs with the DWM. The uncertainty of forces generated from the LM and HM are 100-500 ppm [2]. Fig.5 shows a 100-kN LM machine at the Thailand Institute of Scientific and Technological Research (TISTR).

For the force comparator machine (FCM) in Fig. 6, calibration force, which is normally generated from hydraulic cylinder, is applied to both the standard load cell and the calibrated load cell at the same time. Then the calibration is carried out by comparing the reading of the calibrated load cell with the reading of the standard one. The uncertainty of forces from FCM were 500-5000 ppm. The force generated from FCM typically has more variation in force generation and it is more difficult to record data manually.

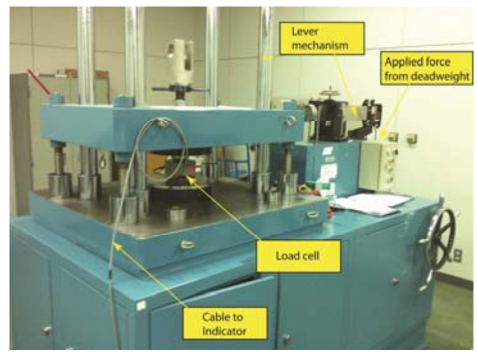

Fig.5. Lever force calibration machine (LM) at TISTR

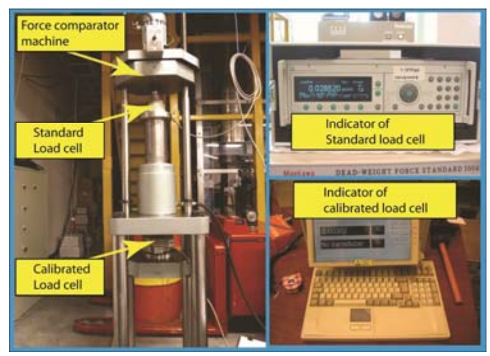

Fig.6. Force comparator machine (FCM) at NIMT

Instead of recording data manually, alternative methods are also available. Many models of load cell indicators are capable of sending measurement data to a computer via the communication port such as RS232 and GPIB. However, due to the variety in communication protocols from many different manufacturers, these require high levels of programming skill. Therefore, it is not practical for most calibration laboratories.

A better way to assure the quality of recording of calibration data, which is proposed in this study, is to use machine vision technology (MV). The MV technology is a technique that allows computers to understand the image of objects and make decisions based on the condition of that image for controlling. This technology was used in many applications. Kazemi, V and Sullivan, J used MV for face detection [6]. Wang et al. used the MV technique to inspect surgical instruments [7].

MV technology was also used in various applications in industry for quality assurance in production processes [8]. There are some studies on

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using MV for calibration of analog measuring instrument [9, 10]. The applications of MV for digital display were also been study successfully [11, 12].

In previous research, a machine vision system was developed successfully for reading a load cell indicator (model HBM-DMP40) [13]. However, the performance of other models were not investigated. Therefore, this study focuses on development of a MV system and software that is capable of reading from several of digital display types of various models of load cell indicators, assuring the correctness of data recording and processing of calibration work.

2. Materials and method

The machine vision system in this research composed of a USB-camera which is connected to a computer as seen in Fig.7. The data recording and processing software was developed using HALCON and LabVIEW programs.

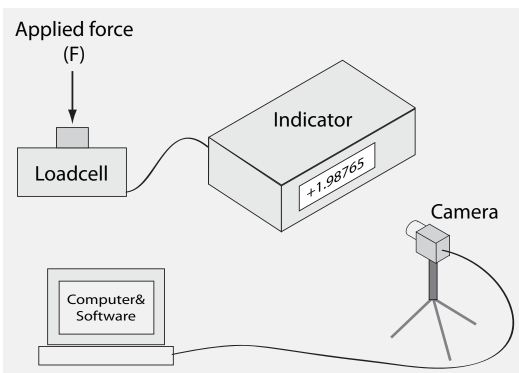

Fig.7. the developed machine vision system

After applying calibration forces on the load cell, the amplifier (or indicator) will show the measurement data on its display screen, the image of the reading from the display will be recorded with a real time camera system. Then, the numerical data of reading images will be recognized using the optical character recognition (OCR) technique. The OCR is a technique of machine vision technology that allows the machine or computer to recognize the image of the characters. The OCR is the translation of images of handwritten, typewritten or printed text into machine-editable text [14].

The details of this image analysis process to obtain numerical data in this research are according to the following steps.

Step1: Taking the raw image of the instrument after each applied calibration force. An example of the image from the indicator model (DMP40) is shown in Fig 8a. The exposure time of the camera should be set appropriately to match the refresh rate of the instrument's display to avoid the overlapping number (Fig 8b). Repeat capturing images at each calibration forces is also recommended to increase chances of having corrected calibration data [13].

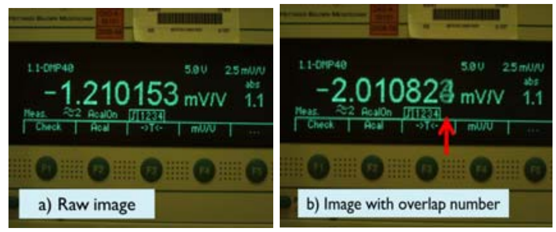

Fig.8. Example of image of DMP40

Step2: Pre-processing of image by using technique such as setup the region of interest (ROI). In this step, the operator need to specify the regions that cover image of characters to be analyzed by the software as illustrated in Fig 9a. Fig 9b shows the gray scale image which was converted from RGB image.

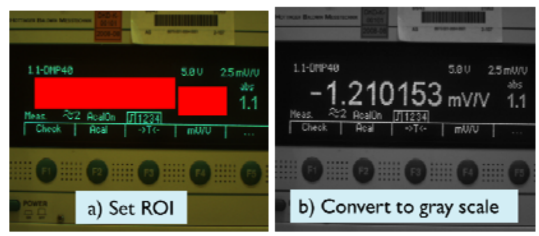

Fig.9. Pre-processing of image

Step3: The processing of the image requires the use of various techniques such as segmentation transformation and sorting techniques to separate the number image from the background (see Fig. 10) and reshape the number image for better recognition.

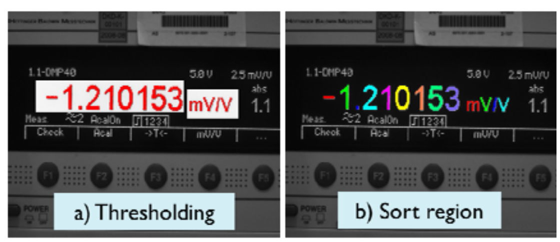

Fig.10. Processing of image

Step4: Feature analysis using the optical character recognition technique (OCR) to translate each sorting region to number [15]. Fig 11 shows the performance of the MV to translate the image into measurement data.

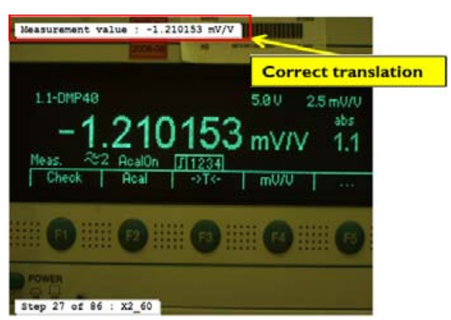

Fig.11. The translation of the image to measurement data

Step5: Post-processing step by saving the image files and input the measurement data into the calibration file as seen in Fig 12.

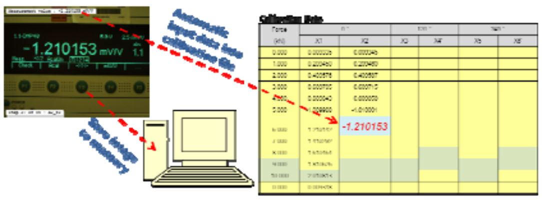

Fig.12. Post-processing step

3. Experimental setting and results

To verify the performance of the system in real calibration. There were 3 categories of experiment in this study as follows:

(1) Testing the performance of the character recognition software by reading 4 different models of load cell amplifiers. Fig 13- Fig 16 shows examples of successful translation from images to numerical data.

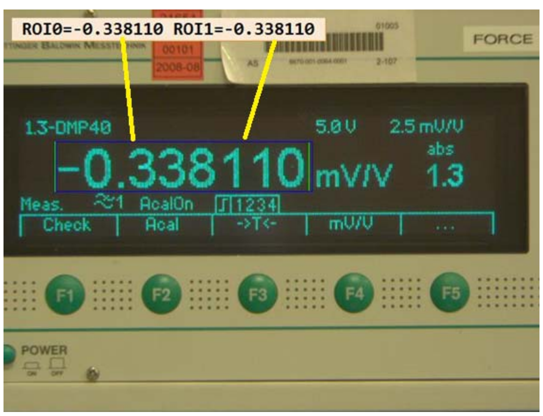

Fig.13. MV recording of indicator (HBM-DMP40)

In Fig.13, the load cell indicator of model HBM-DMP40 was used for evaluation of the MV system. The type of display of this indicator is LED-dot-matrix with bright characters and a dark background. From this figure, two regions of interest were set on approximately same area. The numerical results of MV for both areas are “-0.338110”.

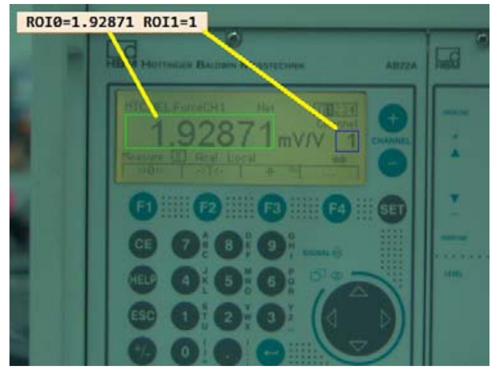

Fig.14. MV recording of indicator (HBM-MGC-plus)

In Fig.14, the load cell indicator of model HBM-MGC-plus were used for evaluation of the MV system. The type of display of this indicator is LCD-dot-matrix with dark characters and a bright background. From this figure, there were two regions of interest. The numerical results of MV for ROI0 and ROI1 were “1.92871” and “1” respectively. These results were correct translations.

Fig.15. MV recording of indicator (HBM-Scout55)

In Fig.15, the load cell’s indicator of model HBM-Scout55 were used for evaluation of MV system. The type of display of this indicator is LED-multi-segment with bright character and dark background. From this figure, two regions of interest were set on each part of the number image because the space between dot and other numbers are so close. The numerical results of MV for ROI0 and ROI1 are “-0” and “04276” respectively. These results when were combined by the developed software will be “-0.04276” which is a correct translation.

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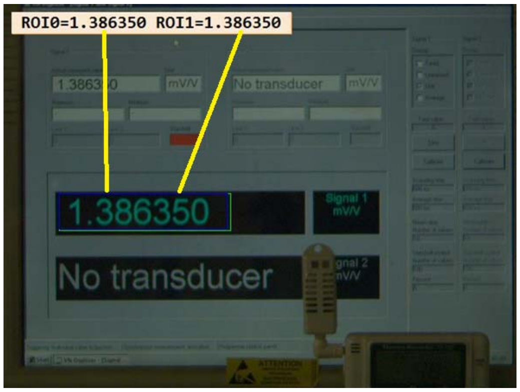

Fig.16. MV recording of indicator (GTM-VD200k)

In Fig.16, the load cell's indicator of model GTM-VD200k were used for evaluation of MV system. The type of display of this indicator is LCD-computer-screen with bright character and dark background. From this figure, two regions of interest were set on approximately same area. The numerical results of MV for both areas are "-1.386350".

(2) To test the robustness of the developed system, experiments with various conditions such as different level of light or different distances (from camera to indicator) were performed as seen in Table1.

Table 1. Testing of MV system on various environmental conditions.

Indicator	Distance (cm)	Illuminance (lux)
HBM-DMP40	65	23
	65	75
	70	80
	80	23
HBM-MGCplus	45	150
	50	-
HBM-Scout55	52	-
	56	-
	58	-
GTM-VD200k	95	15

From Table 1, the developed system can be used for recording of measurement data from all indicators accurately for all testing conditions. For DMP40, the testing distances from camera to indicator varies between 65 to 80 cm and the nearby illumination around the indicator varies between 23 to 80 lux. For MGCplus, the testing distances are 45 and 50 cm. The illumination was set at quite a high level at 150 lux, because the display screen of the indicator has low brightness with dark characters. In the case of Scout 55, the display type is LED-multi-segment with bright characters on a dark background, thus it can be used in a low illuminance environment. The testing distances on this indicator were 52, 56 and 58cm. For VD200k, the display type is a LCD-computer-screen with bright characters on a dark background. Thus, it can be used in a low illumination environment. The testing distance was set at 95 cm. In conclusion, the developed system can be used under all testing conditions, indicating that it is robust enough to be used in practical applications.

(3) To test the performance of the developed system in practical applications. The deadweight force standard machine (DWM-500N) was used to calibrate a 100-N load cell with indicator model HBM-DMP40 as seen in Fig. 17. During calibration according to ISO376, two types of recording methods (manual and MV) were used to record the measurement data simultaneously.

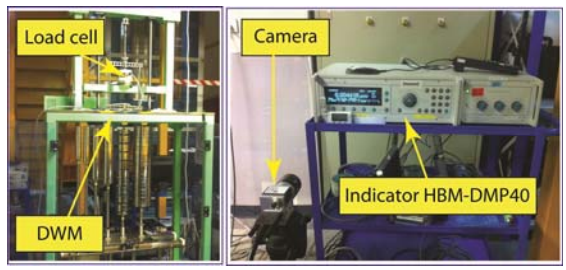

Fig.17. Calibration of load cell with indicator DMP40 using DWM

Table 2 shows the result from manually recording by the operator. The table shows 6 series of the calibration according to ISO376. The calibration forces were applied ranging from 0 N to 100 N. The result of indicator varies between 0 to 2 mV/V.

Table 2. Calibration data from manually recording of indicator DMP40

Force	0°		120°		240°	
(N)	X1	X2	X3	X'4	X5	X'6
0	0.000000	0.000000	0.000000	0.000020	0.000000	0.000046
10	0.199998	0.200280	0.200479	0.200467	0.200197	0.200530
20	0.399947	0.400114	0.400350	0.400463	0.400109	0.400138
30	0.599856	0.600004	0.600346	0.600395	0.599973	0.600082
40	0.799768	0.799921	0.800251	0.800325	0.799891	0.799982
50	0.999686	0.999852	1.000164	1.000234	0.999809	0.999907
60	1.199589	1.199781	1.200108	1.200139	1.199721	1.199856
70	1.399512	1.399641	1.400001	1.400028	1.399641	1.399710
80	1.599423	1.599531	1.599875	1.599904	1.599510	1.599553
90	1.799300	1.799392	1.799763	1.799776	1.799362	1.799418
100	1.999197	1.999287	1.999632	-	1.999263	-
0	0.000048	0.000049	-	-	-	-

Table 3 shows the result from recording by the developed MV system. From Table 2 and 3 the recording data were very close. For example the series

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x1 at the force of 40 N, the manually recorded value is 0.799768 and the MV recorded value is 0.799771. These values were not equal because the time of recording were not exactly at the same and the output of the display fluctuated, as explained in previous section. This fluctuation was because of oscillation of the deadweight set and the instability of indicator. Although the values from Table 2 and 3 were close, it is still difficult for the operator to check the correctness of the data. Therefore, graphical presentation is clearer, as illustrated in Figs 18 and 19.

Table 3. Calibration data from MV recording of indicator DMP40

Force	0º		120º		240º	
(N)	X1	X2	X3	X'4	X5	X'6
0	0.000000	0.000000	0.000000	0.000020	0.000000	0.000047
10	0.199997	0.200278	0.20048	0.200468	0.200198	0.200534
20	0.399951	0.400116	0.400351	0.400462	0.400113	0.400139
30	0.599858	0.600008	0.600343	0.600394	0.599979	0.600082
40	0.799771	0.799924	0.800253	0.800325	0.799894	0.799982
50	0.999689	0.999853	1.000166	1.000234	0.999812	0.999907
60	1.199593	1.19978	1.20011	1.20014	1.199725	1.199856
70	1.399514	1.399644	1.400004	1.400029	1.399645	1.399709
80	1.599421	1.599536	1.599879	1.599903	1.599513	1.599555
90	1.799305	1.799397	1.799766	1.799778	1.799368	1.799421
100	1.999203	1.99929	1.999637	-	1.999268	-
0	0.000047	0.000052	-	-	-	-

Fig. 18 shows linearity deviation of load cell calculated from Table 2 which the data were recorded manually by the operator. The x-axis of the figure represents applied force (N) and y-axis represents the relative deviation (in ppm) of the calibration data from the straight line between the data at zero force and the data at maximum force of each series.

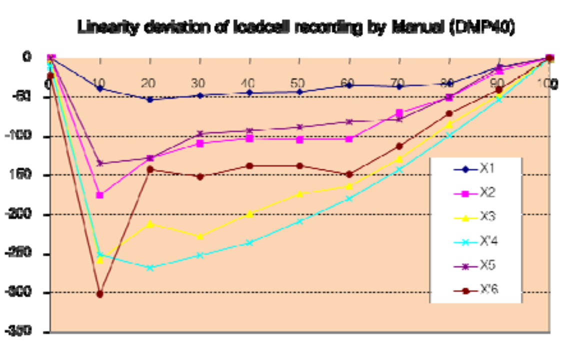

Fig.18. Linearity deviation of load cell calculated from manually recording data on DMP40

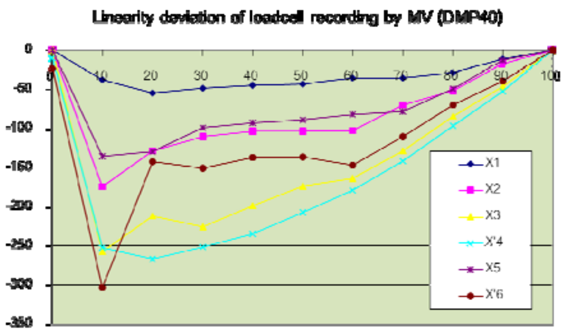

Fig.19. Linearity deviation of load cell calculated from MV recording data on DMP40

Fig. 19 shows linearity deviation of load cell calculated from Table 3 which the data were recorded by the MV system. It may be clearly seen that Figs 18 and 19 are very similar. Indicating that the MV system gave accurate recording results. However, if there are some mistakes in recording, it will obviously show as points of error on the graphs.

Fig. 20 presents another setup of the calibration of the load cell. In this case, the lever amplification force standard machine (LM) was used to calibrate a 100-kN load cell with indicator model HBM-Scout55. During calibration, two types of recording method (manual and MV) were used to record the measurement data simultaneously.

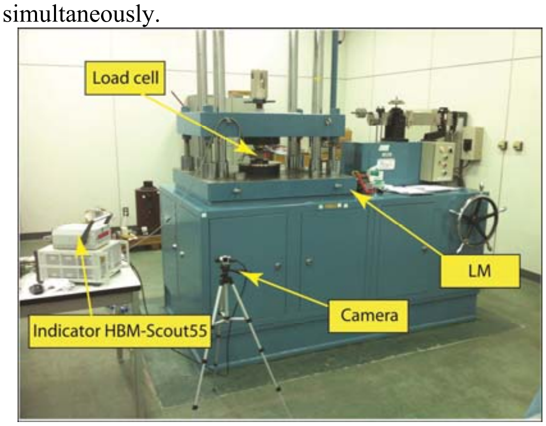

Fig.20. Calibration of load cell with indicator Scout55 using Lever machine (LM)

Table 4 and 5 show the result from manually recording by the operator and by MV system respectively. The calibration forces were applied ranging from 0 to 100 kN. The results of indicator varies between 0 to 2 mV/V.

From Table 4 and 5 the recording data were close. For example the series x1 at the force of 30 kN, the manually recording value is 0.58861 and the MV recording value is 0.58833. However, the fluctuation of this calibration system was more than the system in Fig 17. This fluctuation were because of oscillation of the deadweight set with lever mechanism and mostly on the instability of the indicator.

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Table 4. Calibration data from manually recording of indicator Scout55

Force	0º		120º		240º	
(kN)	X1	X2	X3	X'4	X5	X'6
0	*0.00000*	*0.00000*	*0.00000*	*0.00014*	*0.00000*	*-0.00014*
10	*0.19608*	*0.19601*	*0.19607*	*0.19624*	*0.19605*	*0.19637*
20	*0.39245*	*0.39207*	*0.39227*	*0.39246*	*0.39256*	*0.39243*
30	*0.58861*	*0.58851*	*0.58850*	*0.58894*	*0.58842*	*0.58872*
40	*0.78462*	*0.78483*	*0.78466*	*0.78499*	*0.78458*	*0.78482*
50	*0.98107*	*0.98100*	*0.98098*	*0.98118*	*0.98092*	*0.98135*
60	*1.17738*	*1.17727*	*1.17706*	*1.17749*	*1.17734*	*1.17738*
70	*1.37367*	*1.37356*	*1.37367*	*1.37396*	*1.37358*	*1.37386*
80	*1.57014*	*1.56965*	*1.56983*	*1.57019*	*1.57008*	*1.57010*
90	*1.76619*	*1.76605*	*1.76614*	*1.76598*	*1.76604*	*1.76613*
100	*1.96267*	*1.96240*	*1.96240*		*1.96249*	
0	*0.00020*	*0.00023*				

Table 5. Calibration data from MV recording of indicator Scout55

Force	0º		120º		240º	
(kN)	X1	X2	X3	X'4	X5	X'6
0	*0.00000*	*0.00000*	*0.00000*	*0.00014*	*0.00000*	*-0.00018*
10	*0.19640*	*0.19602*	*0.19607*	*0.19636*	*0.19625*	*0.19642*
20	*0.39240*	*0.39238*	*0.39217*	*0.39228*	*0.39210*	*0.39239*
30	*0.58833*	*0.58831*	*0.58838*	*0.58891*	*0.58850*	*0.58868*
40	*0.78464*	*0.78465*	*0.78462*	*0.78497*	*0.78467*	*0.78466*
50	*0.98085*	*0.98101*	*0.98100*	*0.98118*	*0.98118*	*0.98105*
60	*1.17729*	*1.17707*	*1.17706*	*1.17740*	*1.17701*	*1.17738*
70	*1.37404*	*1.37343*	*1.37350*	*1.37362*	*1.37333*	*1.37382*
80	*1.56986*	*1.56980*	*1.56981*	*1.56940*	*1.56984*	*1.56997*
90	*1.76621*	*1.76625*	*1.76614*	*1.76598*	*1.76590*	*1.76658*
100	*1.96279*	*1.96234*	*1.96244*		*1.96220*	
0	*0.00014*	*0.00009*				

Fig. 21 shows linearity deviation of load cell calculated from Table 4 which the data were recorded manually by the operator. The x-axis of the figure represents applied force (kN) and y-axis represents the relative deviation (in ppm) of the calibration data from the straight line between the data at zero force and the data at maximum force of each series. From Fig.21, the linearity deviation were ranging from -150 ppm to 250 ppm.

Fig. 22 shows linearity deviation of load cell calculated from Table 5 in which the data were recorded by the MV system. It is clearly seen that Fig 22 has linearity deviation ranging from -300 ppm to 300 ppm. The pattern of the graphs in Fig 21 and Fig 22 were similar, indicating that the MV system gave accurate recording results.

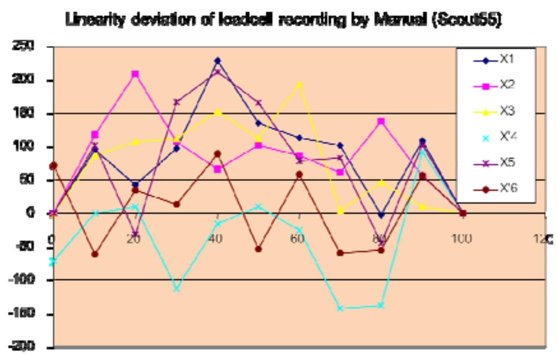

Fig.21. Linearity deviation of load cell calculated from manually recording data on Scout55

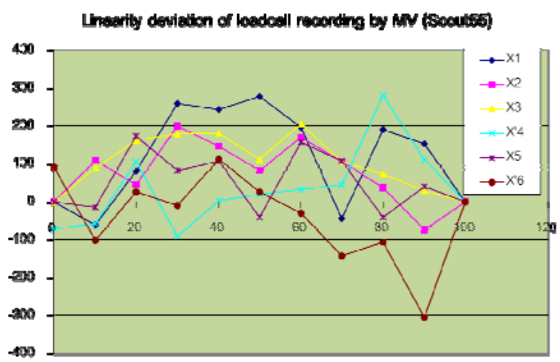

Fig.22. Linearity deviation of load cell calculated from MV recording data on Scout55

5. Conclusions

1. The developed machine vision system can be used for translation of image of indicator's screen to numerical data from various types of indicators accurately.
2. The developed system is robust enough, thus it can be used for recording at various levels of light and distances.
3. The fluctuation of the measurement data depends on many factors such as type of calibration machine, instability of the indicator and characteristics of the load cell.
4. The data obtained from the MV system were accurately recorded and saved. Therefore, this can ensure that the recording and processing of calibration data are correct. However, in case of having some uncertainty about the data, it is possible for the operator to trace back to the raw image and check the data for accuracy.
5. From the experiments, overlapping measurement number images is a major source of problems with this technique. However, it is recommend to have repeat capturing images for each calibration step to increase chances of having correct calibration data.

6. From the experiments, all images without overlapping problems were translated to numerical data with 100% accuracy. Therefore, this machine vision technique is appropriate to be used in force calibration. However, the accuracy of the machine vision system depends on many setting parameters. In the case of using inappropriate program parameters, it may result in lower accuracy. Therefore, the user should check the accuracy of the system before each calibration. Moreover, the operator should also recheck the correctness of the recording results with the raw images of the calibration data.

6. Acknowledgement

This study was supported by the Coordinating Center for Thai Government Science and Technology Scholarship Students (CSTS), National Science and Technology Development Agency – NSTDA

Thank you to the National Institute of Metrology (Thailand), and Industrial Metrology and Testing Service Centre, Thailand Institute of Scientific and Technological Research (TISTR) for their invaluable assistance during the experiments.

The authors would also like to thank Dr. Jirapong Kasivitamnuay, Mr. Somsak Charkkian, Mr. Tawat Changpan, Ms. Pusadee Lim-O-Pasmanee and Mr. Sumrerng Kerdchiy for their valuable suggestions.

Many thanks also to Mr. Roy Morien and Kevin Roebl of the Naresuan University Language Centre for their editing assistance and advice on English expression in this document

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