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A Study of the Feasibility of Obtaining a Systems Calibration of a Load Cell and Indicator from Independent Calibrations of the Components

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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

A STUDY OF THE FEASIBILITY OF OBTAINING A SYSTEMS CALIBRATION OF A LOAD CELL AND INDICATOR FROM INDEPENDENT CALIBRATIONS OF THE COMPONENTS

1. INTRODUCTION

Load cells and indicators are customarily calibrated as complete systems by applying accurately known loads to the cell and noting the corresponding readings on the indicator. Normally the indicator is supplied with an internal electrical calibration check consisting of a passive resistance circuit that can be substituted for the load cell bridge to present a single-point bridge unbalance simulating the output of a loaded load cell. The use of the calibration check in service gives reasonable assurance that the indicator is showing the same electrical response as it did during the initial calibration of the system. The calibration check does not verify the response of the load cell output to load.

Since frequently an indicator is used with a number of load cells, it would be advantageous to be able to calibrate a load cell independently and match the resulting data to the indicator to obtain a systems calibration. Such a technique would minimize the out-of-service time for the indicator during the period needed to transmit the equipment to the standardizing laboratory.

2. APPROACH TO THE PROBLEM

One possible method of accomplishing the independent calibration goal would be to calibrate the load cell by measuring the ratio of the bridge output voltage to the bridge input voltage under a series of precisely known loads. This technique, generally referred to as a millivolt per volt calibration, is a well-established method and can be performed with adequate accuracy. The load cell indicator would have been originally calibrated in terms of its response to millivolt per volt ratios. This technique is less well established, although there are available several types of resistance networks which simulate load cell bridges and afford specified ranges of voltage ratio steps. From such a calibration, indicator readings could be computed corresponding to the voltage ratios obtained in the load cell calibration to provide a systems calibration.

In this study, the technique was applied to a series of load cell and indicator systems and the results compared to a direct systems calibration at the same test loads. The load cell systems were largely those being calibrated for DoD standards laboratories together with some NBS systems. Each load cell and indicator combination was subjected to the following operations.

A. A systems calibration by deadweights was performed on the load cell and indicator at 15 or more different loads. A second degree calibration equation was fitted to the data to obtain a smooth curve of indicator readings.

B. Immediately following step A, a voltage ratio calibration at the same deadweight loads was performed on the load cell. A second degree calibration curve was fitted to these data in the same manner as outlined in step A. The voltage ratio measurements were made with a direct current millivolt per volt indicator reading to 0.01 microvolt per volt. This least count is equivalent to 1 part in 200,000 of the voltage ratio of a 2 mV/V load cell at capacity load. The reference indicator was in turn calibrated against a four-terminal resistance network, voltage ratio standard which had been calibrated by the Resistance Section of the National Bureau of Standards. The precision of the calibrated values for the standard was given as not exceeding 0.05 microvolt per volt. This four-terminal network was used as the reference standard for all measurements reported in this study.

C. The load cell indicator was then connected to the four-terminal voltage ratio standard which had been adjusted to have the same input and output resistance as the load cell. Indicator readings were obtained for a series of voltage ratios matching the load cell ratios as closely as practicable. A second degree curve was fitted to these data to permit the calculation of indicator readings corresponding to any applied voltage ratio.

D. The voltage ratios obtained in step B were converted to indicator readings by means of the relationship established

in Step C and the resulting values compared to the data from step A.

3. RESULTS

Six 100,000-lbf force calibration kits were tested according to the plan. Each kit consisted of a single 100,000-lbf compression load cell, 120 ohms input and 2 millivolts per volt output at capacity. The indicator was a manually balanced, alternating current bridge graduated into 100,000 units. The following results were obtained in the comparison of step D.

Table 1 - Direct vs. Independent Calibration for Six 100,000-lbf Load Cell Systems

Load	Nominal indication	Difference[1] between direct and independent component calibrations.					
		1	2	3	4	5	6
kips	units	units					
5	5,000	22	5	11	20	11	29
10	10,000	12	-9	2	7	-11	21
15	15,000	2	-22	-6	-7	-32	11
20	20,000	-9	-37	-16	-21	-53	0
25	25,000	-21	-51	-25	-36	-73	-11
30	30 000	-33	-67	-35	-51	-92	-24
35	35,000	-46	-82	-45	-67	-111	-37
40	40,000	-59	-99	-55	-83	-130	-52
45	45,000	-74	-115	-66	-100	-148	-67
50	50,000	-89	-133	-77	-117	-165	-83
60	60,000	-120	-169	-99	-153	-199	-119
70	70,000	-155	-207	-123	-191	-231	-159
80	80,000	-193	-247	-149	-232	-261	-202
90	90,000	-233	-290	-175	-274	-289	-250
100	100,000	-277	-335	-204	-319	-316	-301

[1]The difference is obtained by subtracting the direct systems calibration values from the values calculated from the independent component calibrations.

A similar result was obtained for a 60,000-lbf load cell having an input resistance of 350 ohms and a 3 millivolt per volt output at capacity. The cell was made by a different manufacturer than those above and the indicator was of different design. The indicator was manually balanced with an alternating current carrier.

Table 2 - Direct vs. Independent Calibration for a 60,000-lbf Load Cell System

Load	Nominal indication	Difference
kips	units	units
3	2,700	-7
6	5,400	-11
9	8,100	-16
15	13,500	-24
18	16,200	-28
24	21,600	-37
27	24,300	-41
30	27,000	-45
36	32,300	-53
45	40,400	-65
48	43,100	-69
54	48,500	-77
60	53,900	-85

The results in tables 1 and 2 suggest a strong bias between the condition of the indicator coupled to a load cell and the same indicator coupled to the four-terminal ratio standard. The suggestion was made that there were reactive components in the impedance of the four-terminal ratio standard that do not appear in its primary calibration by direct current methods. Further investigation of this hypothesis was beyond the limited scope of the project.

As a test of the possibility that the differences arise from some factor connected with the use of alternating current, the technique was applied on a direct current indicator loaned by the office of the Naval Plant Representative at Pomona, Calif. This indicator was provided with a 12-step, multiple range, internal voltage ratio standard. The unit read in percent of capacity load and was adjustable over a wide range of voltage ratios. The scale was graduated to 0.001 percent of capacity load.

Four load cells were calibrated with this unit, following the plan outlined above. In step C where the unit was compared to the four-terminal voltage ratio standard it was found that a linear slope correction was all that was needed to provide satisfactory conversion from voltage ratio values to indicator readings. The following results were obtained in the comparison of step D.

Table 3 - Direct vs Independent Calibration for Four Load Cells and a Direct Current Indicator

Approximate indication in percent of capacity load	Differences in percent of capacity load			
	1,000 lbf load cell	2,000 lbf load cell	5,000 lbf load cell	10,000 lbf load cell
5	- ---	-0.003	0.002	-0.002
10	-0.012	-0.003	0.003	0.000
15	-0.012	-0.002	0.004	0.001
20	-0.012	-0.001	0.004	0.003
25	-0.012	-0.001	0.005	0.004
30	-0.012	0.000	0.005	0.005
35	-0.012	0.001	0.005	0.006
40	-0.011	0.001	0.005	0.007
45	-0.010	0.002	0.005	0.008
50	-0.009	0.003	0.005	0.009
55	-0.008	- ---	0.005	0.009
60	-0.007	0.004	0.004	0.009
65	-0.006	0.005	0.004	0.010
70	-0.004	0.005	0.003	0.010
75	-0.003	0.006	0.002	0.009
80	-0.001	0.007	0.001	0.009
85	0.001	0.007	0.001	0.009
90	0.004	0.008	-0.001	0.008
95	0.006	0.009	-0.002	0.008
100	0.008	0.009	-0.003	0.007

The differences shown in Table 3 are somewhat greater than could be accounted for from the precisions obtained in the calibrations of the NBS reference millivolt per volt indicator and the Navy indicator against the four-terminal millivolt per volt standard. Characteristic standard deviations observed in the linear slope fits for these two indicators were approximately 0.11 microvolts per volt (0.0055 percent of 2000 microvolts per volt) for the NBS reference indicator and 0.012 microvolts per volt (0.0006 percent of 2000 microvolts per volt) for the Navy indicator. The differences of Table 3 range up to 0.012 percent of capacity load, but the slight increase may very well have been due to other factors such as variability in the load cell outputs. It should be noted, however, that direct current indicators are not frequently used for load cell measurements in the field, most of the applications being the combination of a load cell and some form of alternating current indicator.

As a part of the examination of the indicator furnished by the Navy, a series of measurements was made of the internal voltage ratio standardizer of the instrument set to the 2 millivolt per volt range. The measurements were made with the Navy indicator, each run being made with a different span adjustment and the instrument calibrated against the four-terminal voltage ratio standard. The five runs were spaced over a period of slightly more than two weeks. Table 4 shows the voltage ratio values obtained for the internal standardizer and the deviations of the individual runs from the average.

Table 4 - Voltage Ratio Measurements of the Internal Standardizer, S/N 26279, of a Direct Current Indicator

Standardizer step, as percent of 2 millivolts/volt	Average value of step	Deviations from average				
		Run 1	Run 2	Run 3	Run 4	Run 5
	microvolts per volt					
10	200.18	0.00	0.00	0.00	0.00	0.01
20	400.08	-0.01	0.00	-0.01	0.01	0.00
30	600.08	0.00	0.00	0.00	0.00	0.01
40	800.09	0.01	0.00	0.00	0.00	0.01
50	1000.10	-0.01	0.00	0.01	0.00	0.01
60	1200.12	-0.02	0.00	0.00	0.00	0.01
70	1400.16	-0.01	0.00	0.00	0.00	0.00
80	1600.20	0.01	0.00	0.00	-0.01	0.00
90	1800.25	0.00	0.00	0.00	-0.02	0.00
100	2000.25	0.00	0.00	0.00	-0.01	0.00
110	2200.31	-0.01	0.02	- --	-0.02	0.00
120	2400.28	-0.02	- --	- --	0.00	0.03

4. SUMMARY

From the results shown in Tables 1 and 2 of this report, it is concluded that independent calibration of load cells and alternating current type indicators may result in errors on the order of 0.3 or 0.4 percent of load and that, consequently, the method is not feasible without further investigation. It was suspected, but not proven, that the source of the error lies in undetected reactive (inductance) components in the millivolt per volt ratio standard. Only one such unit was employed in the investigation and it is possible that the fault was peculiar to this unit. However, it is recognized that in the design of a resistance standard where a stability and precision on the order of 20 to 30 parts per million is required, it is exceedingly difficult to insure absolute freedom from inductance in the windings. Alternating current indicators commonly operate at frequencies of 1000 to 1200 Hz and only a very small amount of inductance in the standard is required to produce a significant error.

When an indicator operating on direct current was tested, the method of independent calibration of load cells and indicators worked acceptably well. As noted earlier in the report, direct current indicators are not commonly used in load cell systems, alternating current indicators being generally lighter and more compact as well as being somewhat faster in operation. Direct current indicators also require special attention to assure that observed data are not biased by thermal electromotive forces.

A direct current indicator furnished for the investigation by the office of the Naval Plant Representative in Pomona, California, displayed outstandingly good performance during all tests made with it. This indicator normally reads in percent of capacity load, but the indications may be easily transformed into voltage ratio values by means of a linear factor.