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Weighing Heavy Loads to an Accuracy of 0.001%

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Weighing Heavy Loads to an Accuracy of 0.001%

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This study was performed to determine the accuracy attainable using a load cell and a readout technique developed by the writer. The data were obtained on a 200 pound Toledo Precision Load Cell. Equally reliable data are to be expected for 50,000 pounds on larger models of the same type of transducer.

Operating the system for one week in a constant ambient temperature and with regulated line voltage, a total deviation of 0.001% was noted for like operating procedure. For percentages over 18% of full load the total variation of readings amounted to 0.004% of full load in an ambient temperature that was uncontrolled.

Summary

A technique was developed for obtaining the voltage ratio across a load cell to a six decimal place accuracy. Since this is a measured ratio, moderate changes in excitation voltage will not noticeably affect the reading. Therefore the requirements, which must be placed upon the excitation power supply, are reduced. A second, and separate, stable power supply must be used to correct for the no load voltage from the load cell if the weight is to be read directly in pounds (or grams).

The output of the load cell is amplified by means of a d.-c. amplifier. This amplifier must have no electrical connection between the input and output. The input voltage to the load cell is also fed to the input of

a voltage divider accurate to 0.0001%, such as the Julie Research VDR307. The output from this voltage divider is "bucked" against the output from the amplifier and the difference was indicated on a Keithley Model 153 microvoltmeter. A schematic of this circuit is shown as Figure 1.

It is apparent from this schematic that the limiting factor determining the accuracy is the d.-c. amplifier. The Beckman Fitgo, Model C-24 Amplifier was chosen because of its gain stability, high input impedance, the electrical isolation between input and output, and the necessary controls to change the gain by large amounts (coarse gain) and by small amounts (fine gain). Acceptance tests were conducted on the two amplifiers purchased and one of them was returned to the vendor.

Figure 1.—Weighing system schematic.

The accepted amplifier was satisfactory but a smaller d.c. output level change would be a help in this work.

The reading of the output of the load cell is the reading as obtained from the accurate voltage divider. This voltage divider is accurate to one part per million and is readable to one part in ten million. By proper calibration the accuracy can be increased to one part in ten million.

There was an appreciable d.-c. drift in the output of the amplifier. When the excitation is removed from the load cell, the amplifier d.-c. output is the only voltage appearing at the microvoltmeter. Therefore, true null was determined by adjusting the voltage divider until the same reading was obtained with switch SW1 (Figure 1) opened and then closed. As near as possible these readings were made the same within one microvolt.

To read the voltage divider directly in pounds, a second, separate, stable power supply was required. This was accomplished by a resistance of approximately 200 ohms being inserted between "A" and "a" (Figure 1) and a voltage of the proper polarity placed across it to give a zero output for zero load. Most of the work was done without this refinement because the basic stability was the desired goal and this addition would add a measure of unknown variability.

The Toledo Precision Load Cell was found to be very satisfactory. The 200 pound load cell used in this work more than met the manufacturer's specifications. This work indicates that with proper calibration standards, a load can be weighed to an accuracy of 0.001%. When the ambient temperature was held constant and the line voltage regulated, there was a total variation of 0.001% in one week for uniform operating standards. Exercising the load cell made a difference of 0.004% for ten flexings. For high accuracy the load cell must be exercised at least eight times. In addition, for these accuracies, the manufacturers recommended excitation of 15 volts must be reduced to about 2.7 volts because of internal heating.

Introduction

There is a potential need at Rocky Flats for weighing heavy loads to an accuracy of $\pm 0.001\%$ because of the value of the material. A potential load would be between 10,000 and 15,000 pounds. Load cells are rugged and if sufficient accuracy could be obtained they would provide an excellent means for weighing heavy loads. This study was performed to determine the accuracy of this system.

Experimental Work.—It was realized that this study would end in failure if an amplifier having the required stability and high input impedance could not be found. From the various manufacturers specifications it seemed that the Beckman Fitgo Model C24 d.-c. amplifier was the best. Two of these amplifiers were ordered.

Acceptance tests were made on them with the result that one was accepted and one was rejected. The main tests conducted on them were for gain stability and input impedance determinations. The rejected amplifier was returned to Rocky Flats by the vendor and has been retested. The stability test results are shown in Figures 2 and 3.

Figure 4 shows the method used to determine gain stability on the retested amplifier, Serial #00111, returned by the Beckman Company. This setup is slightly different from that used to check the accepted amplifier, Serial #00105, in that the zero level was determined and corrections were made for drift. Because a voltage is apparent on the input terminal of the amplifiers, the input impedance checks out to be a "negative resistance." In any event, the amplifier Serial #00111 is now satisfactory and the amplifier Serial #00105 was satisfactory from the start.

It was intended that this study would cover differential transformer type transducers as well as strain gage type of transducers such as the Toledo load cell. Attempts have been made to obtain a differential transformer with a range of ± 1.000 inch or more, but manufacturers indicate that they can not make one with a linearity of $\pm 0.001\%$. If a satisfactory differential transformer is found, both amplifiers will be needed. In any event, the accurate weighing system using a strain gage type of transducer was pursued and good results have been attained.

Although other systems were considered, the schematic system, as shown in Figure 1, was used for all work on weighing. The earliest work used a LeBow 200 pound load cell, model 3108-2005, serial number 134, which was available. It was apparent that this load cell was not accurate and that the readings continually changed in one direction. This was most noticeable when the load exceeded 150 pounds.

Based upon the manufacturers specifications, the Toledo Precision Load cell was the most accurate best available and one such load cell of 200 pounds capacity was ordered. This load cell is hermetically sealed so that atmospheric pressure changes should not affect the operation.

Again, referring to Figure 1, the output of the load cell is fed to the input of the Beckman Amplifier. There is essentially no load on the load cell because the amplifier input impedance is 1000 megohms. The output of the amplifier is connected to the output of the Julie Research Voltage Divider in series opposing and the difference determined by a Keithley Model 153 Microvoltmeter.

All equipment must be thoroughly shielded, all wires must be shielded, and shields must be tied in at one point and only one point. The common grounding point is connected to the black lead of the Keithley instrument.

It was found that the amplifier d.-c. output varied

Figure 2.—Amplifier No. 00105 stability test.

Figure 3.—Amplifier No. 00111 stability test.

SW1-CLOCK MOTOR OPERATED-3.6 MIN. OPEN, 41.4 MIN. CLOSED

Figure 4.-Amplifier stability test schematic.

even with the amplifier input shorted. This was not too great a problem with switch SW1 in the circuit. (Figure 1). When the switch is off, the amplifier is shorted (240 ohms). Therefore, the true null is obtained by opening and closing switch SW1. The voltage divider is adjusted so that both readings are the same within approximately 1 microvolt. The setting on the microvoltmeter must be at a high enough sensitivity to determine this.

Most of the readings were obtained with the tray and seven lead bricks considered full load. The actual load was 192.860 pounds. Except for some earlier runs the gain of the amplifier was set so that the difference in readings between no load and 192.860 pounds was a ratio difference of 0.192860. The ratio at no load was 0.000380. This means that the normal reading with 192.860 pounds load would be 0.193240. The figure of 0.000380 can be subtracted electrically so that the reading actually was 0.192860. Some readings were obtained with this correction built into the circuit, but most of the work was done without the correction in order to avoid any variation in the mercury cell supplying the correction voltage. See Figure 5.

To have some uniformity in load application, the loads were applied to the load cell by using the load cell to pick up the load. Two pieces of $\frac{1}{8}$ inch cable, each about 3 inches long above and below the load cell, minimized any side forces. Care was used to see that the cable was not vibrating while a reading

was taken.

It was necessary that the effect of exercising the load cell was known as well as the effect of excitation voltage. Figure 6 is the result of this investigation. The load was picked up and then weighed. The load was lowered and picked up again and weighed. This was repeated ten times. Readings were taken after this with 2.7 volts excitation on the load cell until the readings were stable. The excitation was then increased to 7.5 volts which is one half the manufacturers recommended value. It appeared that there was too much heating involved for the accuracy desired. Therefore, the voltage was standardized at 2.7 volts.

For a period from August 23 to August 30, 1966, various weights were picked up to see if the readings were consistent and also how near they were to the known weight. Instead of subtracting the no load voltage electrically, it was subtracted arithmetically. In all cases, the desired load was placed on the tray and the tray and load were then raised. During this week, twelve weighings were made on each load. The plots of these weighings are shown on Figure 7. The data shown on Figure 7 were replotted in Figure 8 to show the linearity of this load cell. For perfect linearity, the percent deviation should be zero. The greatest error based on percent of full scale was 0.022% at 58% full load. The percent of error based on reading increases as percent of full load decreases.

The stability of the amplifier and the load cell will

REMOVE CONNECTION "A-a" OF FIG. 1 AND INSERT

Figure 5.—Zero correction system.

Figure 6.—Effect of exercising and excitation upon load cell.

Figure 7.—Stability at various load levels.

be improved if the ambient temperature is held constant. The various pieces of equipment were taken to the Standards Laboratory in Building 25 to see how stable the equipment would be under constant temperature conditions. Three readings were taken daily for a period of one week. At approximately 8:30 each morning, before the excitation was applied, the load cell was exercised by raising and lowering the load four times. The excitation was applied and the reading was obtained. Immediately after this, the load cell was exercised four more times and another reading was obtained. The load was left on the load cell with 2.7 volts excitation. At 1 p.m. another reading was taken without further exercising the load cell. After the afternoon reading, the load was removed and the excitation shut off until the next day. These readings were taken each working day and are plotted in Figure 9.

Discussion.—All the satisfactory work done towards accurate weighing of loads was done on a Toledo Precision Load Cell of 200 pounds capacity. Other capacities of the same make and type of load cell range up to 50,000 pounds. It is believed that the similarity in design criteria, between the small and large units, would yield similar percentages of accuracy. The writer did not desire to work with multi-ton loads although it would not be difficult to expand the work to include them. An additional cost would be for a larger load cell and for a known heavier weight.

This technique could be applied to any strain gage

type transducer whether the measured variable is pressure, strain, or other functions. It may not be apparent, but this system is ideal for looking at minute changes of a variable. For instance, if the strain level of the test object averages 2000 microinches per inch and it varies from 1999 to 2001 microinches per inch, the actual variation could be plotted on a strip chart recorder. In this example, the width of the chart would represent ± 1 microinch. In some research projects this would be an excellent tool to have. Unfortunately, pressure transducer have not been designed to utilize the accuracy available in this readout system. The use of this system might result in design changes which will increase the accuracy of pressure transducers.

It is expected that two standard known weights would be used as references. One of these standard weights would be slightly below the range of unknown weights and one standard weight would be slightly above the range of unknown weights. This would allow a very accurate determination of the unknown weight. Of course if the range of unknown weights is great, more than two standards may be required.

The effect of the excitation voltage on the accuracy of readout was considered as a possible problem in trying to attain extreme accuracy. Figure 6 indicates the magnitude of this problem. Thirty minutes is required to obtain the 0.03% change in reading when an excitation voltage of one half the recommended value of 15 volts is used. But, an excitation voltage of 2.7 volts

Figure 8.—Load cell linearity.

appears to change the reading by 0.0015% in 15 minutes. No change was noted after 15 minutes. Therefore, it seems that an excitation voltage of 2.7 volts should be used.

An attempt was made to determine the hysteresis of this load cell. The technique was to start with a 4.4 pound additional load over each desired load level and to remove the additional 4.4 pound load in an identical manner each time. The deviations from the corresponding values of increasing load were 0.003% to 0.007% of full scale and 0.007% to 0.06% of the reading. Perhaps there are better methods of determining this property of the load cell, but the writer did not have the need of expending additional time on this determination. Perhaps the removal of a load larger than 4.4 pounds would give a larger hysteresis figure. These figures are considerably less than the manufacturer quotes.

The equipment used in this work is shown in Figure 10. The stable d-c. amplifier is shown on the right. The voltage divider is shown in the center (the readings were obtained from the seven dials on this unit). The last digit was not used. The microvoltmeter is shown on the left and its purpose is to indicate the null. The minibox in the left front position contains the excitation and all equipment connects to it. A switch to turn the excitation off and on is located in this box. Figure 11 shows the load cell and the standard weights.

If a high degree of accuracy is required, it appears that the room temperature in which this system is operated must be carefully controlled. For loads above 20% of full load on the load cell, variation in readings amounted to $\pm 0.002\%$ deviation but in a constant temperature environment the deviation was only $\pm 0.0005\%$.

Conclusions.—1. It is possible to obtain an accuracy of 0.001% by using the Toledo Precision Load Cell provided that comparison standards of suitable accuracy are available.

2. Over a period of one week, the readings obtained under constant temperature conditions varied only $\pm 0.0005\%$.

3. Over a period of one week, the readings obtained under normal temperature variations amounted to $\pm 0.002\%$. As the temperature range increases, the reading variations will increase.

4. For the highest accuracy, the load cell must be exercised at least eight times. Additional exercising will do no harm but is not likely to change the reading.

5. No added precaution is needed to pick up the load except that the pickup should be smooth. Also, there should be no vibration

of the load support member while the reading is being obtained.

6. The excitation voltage should be kept low (2.7 volts) to avoid internal heating.

7. With the proper amplifier gain and with a stable zero reference voltage, a direct readout in pounds can be obtained.

8. The Beckman Fitgo C24 amplifier is satisfactory for this work, but less shift in the d-c output level would be helpful and the reading could be obtained faster.

9. This type of readout system can be used with any transducer using strain gages.

Recommendations.—1. It is recommended that this system be used when highly accurate data are required.

2. It is recommended that this system be used for

Figure 9.—Full load stability at constant ambient temperature.

Figure 10.—Readout equipment.

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Figure 11.—Load cell.

any high accuracy weighing systems required in the 100 to 50,000 pound range.

3. It is recommended that efforts be continued to find a way to utilize this system as applied to a long range transducer.

4. It is recommended that this system be modified to include a print-out of the weight to avoid human error. This should be easy to include. An encoder on each knob of the voltage divider and a standard printer would accomplish this.