Analysis of the Sensitivity to the Environmental Temperature of High Accuracy Load Cells

[1]Maria Velasco, [2]Roberto Salas, [1]Heinz Luchsinger

[1]CENAM (Centro Nacional de Metrología), Queretaro, Mexico.
[2]Free Lance, Queretaro, Mexico.

Email: mvelasco@cenam.mx

Abstract. *In an ordinary process of measurement it's possible that the environmental changes of temperature induce errors of measurement which exceeds the accuracy specifications of load cells. The paper describes the effects of the environmental temperature on one type of high accuracy load cells, it indicates the degree of correlation between the variations of temperature and the mass readings of the cells, and furthermore it figures out the mathematical model of its behavior.*

1. Introduction

A simple matter of sensitivity is, that all sensors we use, respond to every kind of input. We know that the design of an ideal load cell would be the one which wouldn't be affected by temperature, moist, electromagnetic interferences, vibrations and other possible characteristics of the environment that cause errors in the measurement.

In theory, the autocompensation of temperature in the load cells, should provide a constant output signal over a wide range of temperature. However, the practice had shown, that even small variations of temperature can affect significantly the load cell output signal.

The majority of previous reports mentioned this effect only in a very superficial form, like the OIML R 60 [1] that only mention the importance of the stabilization of the load cell to the working temperature. So most of the authors had avoided to explain further effects of temperature. Usually it is not possible to find information about the time required for environment stabilization , neither the maximum temperature variation, which doesn't affect the load cell accuracy. That is why the International Standard (ISO 376) [2] specifies the use of the force-proving instrument must be used only at the temperature in which it was calibrated. If the temperature is different, a correction must be made.

This present paper realizes an analysis of the response of load cells to changes in the temperatures. So its main purpose is to characterize the changes of mass measurement caused by variations of temperature and to obtain a mathematical model to correct this effect.

The tests have been performed at CENAM, using high accuracy load cells, which have been analyzed without load, with minimum and maximum load. The creep time was considered according to OIML R 60.

The tests where realized in an environmental chamber with a stability of 0,01 °C, in a range from 10 °C to 30 °C.

The analysis is divided in two matters. In the first one it is characterized the response to temperature changes, and the second one a mathematical model is obtained in order to regulate its behavior.

2. Response of the load cell to temperature changes

Three types of tests about the sensibility of the cells to the effects of temperature were realized. The first one is about monitoring the response of the reading of the mass of the cell in the presence of environmental changes in temperature, the second and the third are to obtain the response of the reading of the mass of the cell in presence of controlled variations in temperature.

2.1 Response of the unloaded cells to environmental conditions

The test was performed in a laboratory with environmental conditions and with unloaded cells. Once the cells are compensated to the environment, it is proceeded to acquire the readings of mass from the cell and the environmental temperature.

Fig. 1a shows the response of the readings of a load cell with a range of 2000 kg in different environmental conditions. The horizontal axis indicates the time of sampling in minutes (400 min) and the vertical axis the mass variations in kilograms. Fig. 1b shows the variation of temperature respect to time. The series 1 proves, that an increment of temperature of 4,32 °C in 400 minutes causes a variation in the reading of 0,30 kg and a correlation factor of – 0,97. Series 2 points out a variation of mass reading of 0,15 kg correlation of –0,92 at an increment of temperature of 1,47 °C in 400 minutes.

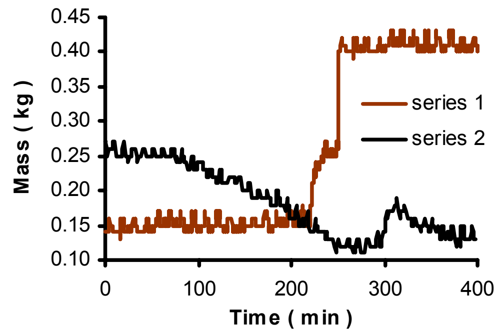

Fig. 1a. Response of the load cell to environment conditions

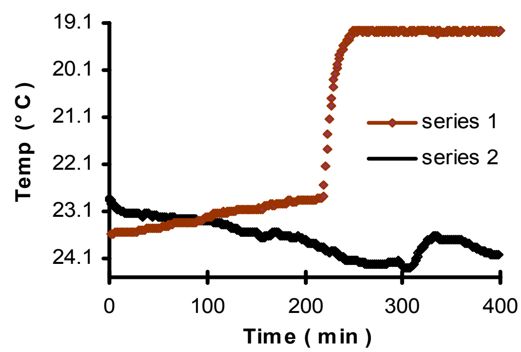

Fig. 1b. Indication of environment temperature

2.2 Response of the unloaded cells to controlled temperature

The experiment was performed with an unloaded cell enclosed inside an environmental chamber. Once the reading of the mass of the cell is stabilized, at least with the resolution indicated by the manufacturer, the tests star. An increase of temperature in the environmental chamber is done and the response of the cell is observed.

Fig. 2a presents the load cell's response to ascending temperatures. Its abscissa indicates the sampling time in minutes and the ordinate the mass variations in kilograms. The temperature curves are plotted in Fig. 2b over a period of 250 min.

The series 1 and 2 demonstrate the behavior of load cells with a range of 2000 kg resp 5000 kg. In series 1 was notified an increment of temperature of 10,29 °C in 29 minutes, which lead to an increment of mass reading of –1,26 kg with a correlation of -1,0. Series 2 showed a temperature increment of 10,28 °C at the 5000 kg load cell. There the readings presented a change of mass of –7,03 kg and a correlation of 0,99. Both series stabilized in 130 min.

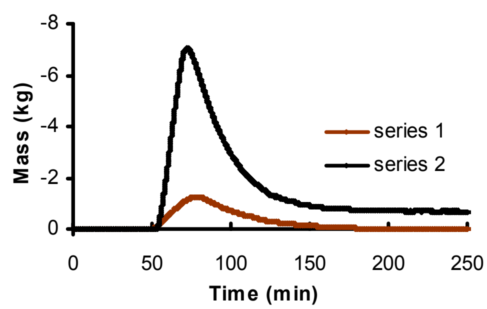

Fig. 2a. Response of the unload cell to controlled temperature

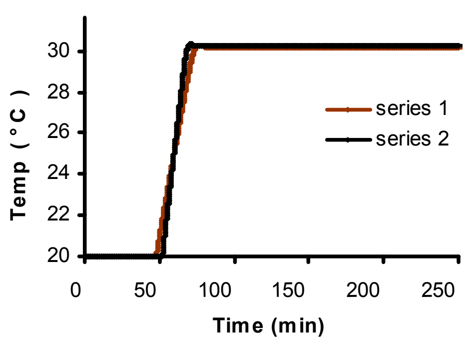

Fig. 2b. Indication of the controlled temperature

2.3 Response of loaded cells to controlled temperature

The test characterizes the response of the load cell to temperature changes.
With the only difference of a force of minimum mass loaded into the cells of 2000 kg, the experiments were proceeded like the previous test in an interval of 150 min with a load cell enclosed within the environmental chamber and in consideration of the creep time [1].

Fig. 3a represents the load cell's response, corresponding to the changes of temperature. Fig. 3b follows the changes of adjustment of the temperature. In series 1, the cell loaded with 244,81 kg responded to a descending temperature change of 5,17 °C with a variation of mass of 6,50 kg. The correlation factor is 0,99. Series 2, with an initial mass reading of 245,26 kg, shows as respond to an increasing temperature change of 5,27 °C a variation of 6,60 kg with a correlation of –0,94. The stabilization time was 120 min.

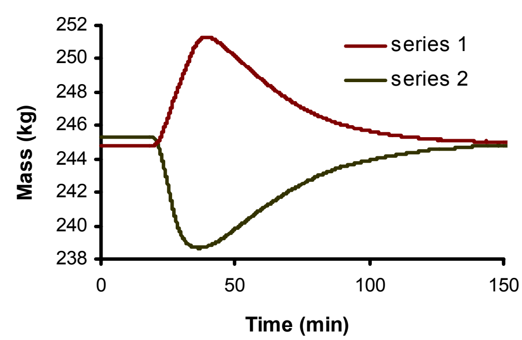

Fig. 3a. Response of the load cell to controlled temperature

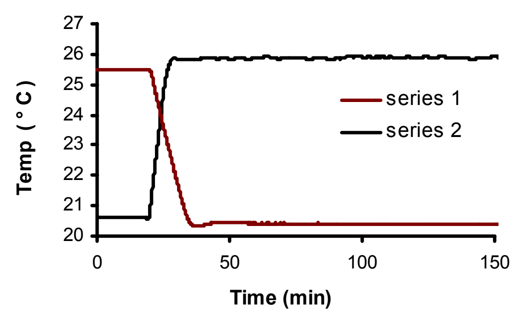

Fig.3b. Indication of the controlled temperature

3. Analysis of the cell's respond to changes in temperature

The response of the load cells to changes in temperature was analyzed by strategies of stochastic optimal control of ARMAX [3] model. It was developed with the help of the Software of Matlab.

This discrete model is described in equation 1.

$$M_k = -a_1 M_{k-1} - a_2 M_{k-2} + b_0 T_n + b_0 T_n + b_1 T_{n-1} + C_o \xi_k + C_1 \xi_{k-1} \quad (1)$$

Where is:

M_k = Lecture of mass in the instant (kT_s)
T_s = Temperature
ξ = Perturbations
$fs = 1/T_s = 14/60$ Hz

4. Results

With the test realized in the load cells, it was found that in different ranges of measurement, the high accuracy load cell will respond in the same way to variations of temperature. In order to obtain the accuracy specifications of load cell's manufacture, it requires, at least, a stabilization of temperature of 0,01 °C, in a stabilization time not less than 3 hours.
Even with an applied force to the minimum range of the cell, a variation of only one degree Celsius is enough to exceed the load cell's limits of accuracy.

5. Conclusions

The temperature changes affect significantly the uncertainty of measurement of mass of the load cells. The errors due to temperature variations could be attributed to the load cell's creep and drift. The model developed in equation 1, realize a correction in the load cell indicators when they are used in non stabilized temperatures. The model proposed is based in an ARMAX model, which shows is to be appropriated to introduce the correction in the measurement system. The correlation factor greater of 0,9 shows, that there is a dependency between the mass reading and the temperature.

5. References

[1] OIML R 60, Organization Internationale de Métrologie Légale R 60, Metrological Regulation for Load Cells, Bureau International de Métrologie Légale (1991).

[2] ISO 376, Metallic materials – Calibration of force-proving instruments used for the verification of uniaxial testing machines (1999)

[3] AutoRegressive Moving Average with eXternal input.

[4] Strain Gage Users´ Handbook, Society for Experimental Mechanics, Inc. (1992).

[5] James G. Pierson, 1999, The Art of Practical and Precise Strain Based Measurement (1999).

[6] Thomas W. Bartel and Simone L. Yaniv, Creep and Creep Recovery Response of Load Cells Tested According to U.S and International Evaluation Procedures, J. Res. Natl. Inst. Stand. Technol. 102, 349 (1997).

[7] Peter. E. Caines, Linear Stochastic Systemas, McGill University Montreal (1998)