

A LOW COST LOAD CELL APPROACH

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Abstract. Load cell are important transducers for the development of biomechanical applied research, but even low capacity load cells have typically high prices. Also there is the necessity of A/D converters, with signal conditioners with huge amplifications. As a low cost alternative to traditional high prices load cell and its data acquisition systems, this work proposes the utilization of a modified potentiometric displacement transducer with an usual digital multimeter to perform static load measurements for biomechanical applications.

Keywords: load cell, instrumentation, transducer

1. INTRODUCTION

Commercial load cells are accurate and reliable, with a minimum of four strain gages connected in a Wheatstone bridge arrangement, but they are relatively expensive and its signal has to be amplified before going to A/D converter Tokheim (1990). The high cost and the need of a signal conditioner induced the proposition of a low cost load cell to biomechanical applications. There are several utilizations of load transducers to measure indirectly specific body muscle forces. A good reference for numerous types of orofacial load transducers can be found in Furlan et al. (2012) and also in Furlan et al. (2010).

In the same line of Kenedi et al. (2005) and Souza et al. (2004) that have proposed reconditioning of an existent testing machine and an especial electronic circuit for instrumentation, in this work the authors proposes an adaptation of an existing displacement transducer, through the utilization of a spring, to convert it to a homemade load transducer. Figure 1.a shows the low cost load cell, for now on called LCLC, schematically drawn, with all components. The system comprises a commercial mobile phone power plug (a DC power plug) to provide the electrical excitation; a voltage divider circuit to adjust the DC power voltage (V_{pow}) to voltage excitation (first to V_{exc}^* , and after an initial adjustment to V_{exc}); an adapted displacement transducer (with the addition of a spring) and a common 3 ½ digit multimeter to read the resultant transducer signal.

To simplify the system operation the V_{sig} , the voltage signal output, shown at the 3 ½ digit multimeter display has an one per one relationship to load measured by the LCLC transducer. In other words not requires signal conditioning and could display the load directly in kgf, with gram resolution, from 0 up to 1.999 gram (almost 2.0 kgf).

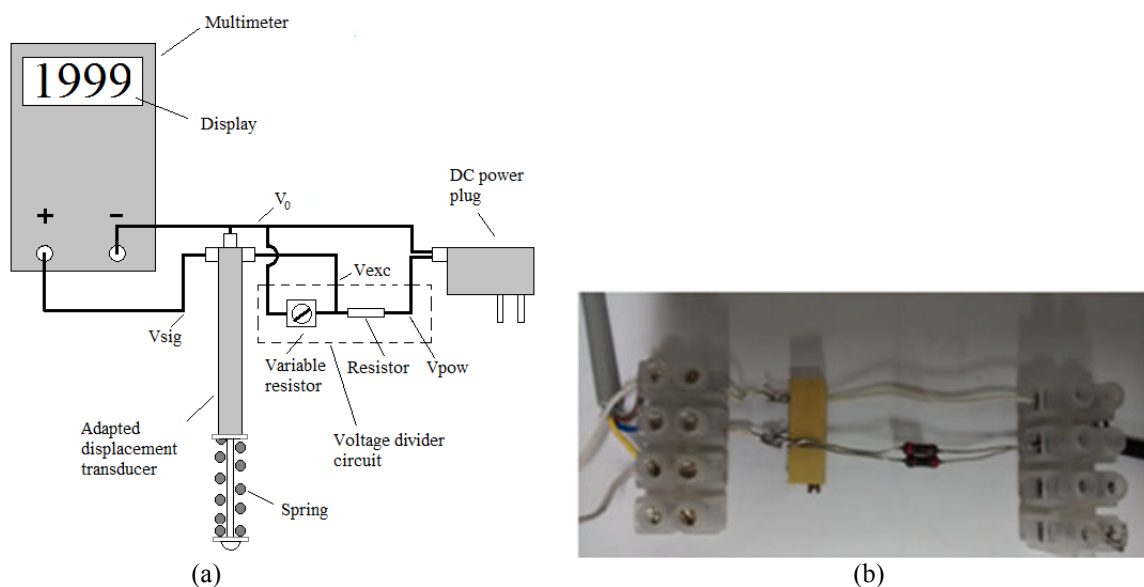


Figure 1. (a) The LCLC schematic drawn and (b) the Voltage divider circuit.

The LCLC has three electrical connections: V_{exc} is the excitation voltage, V_{sig} is the voltage signal output and V_0 is the electrical ground, ideally at zero volt. The set shown at Fig. 1.a is one of various possible combinations and at Fig. 1.b a photo of the Voltage divider circuit is shown. In this work a commercial mobile phone power plug is used, only because it is quite available nowadays. Alternatively it is possible the utilization of another sources of DC power, for instance, a $9V_{DC}$ battery. If the multimeter has an interface RS-232, or similar, it is possible to save the measurements at a notebook HD. Another far more sophisticated interesting variation is to use of a microcontroller, like Arduino, to do the A/D conversions and communication functions with a notebook.

2. THEORETICAL APPROACH

In this section it will be show the theoretical basis used to do the transducer adaptation. Figure 2 shows the electrical circuit, which is composed of the Voltage divider circuit and the Potentiometric circuit. The first adapts the V_{pow} , generated by DC power source, to the desired voltage level (first to V_{exc}^* , and after an initial adjustment to V_{exc}). The second one is the electric circuit of the displacement transducer utilized, which generates a voltage signal V_{sig} linearly proportional to imposed displacement. The components of the Voltage divider circuit are chosen to accomplish the main objective of provide a good range of V_{exc}^* adjustment, as well limiting the current that flows from the Voltage divider circuit to the Potentiometric circuit.

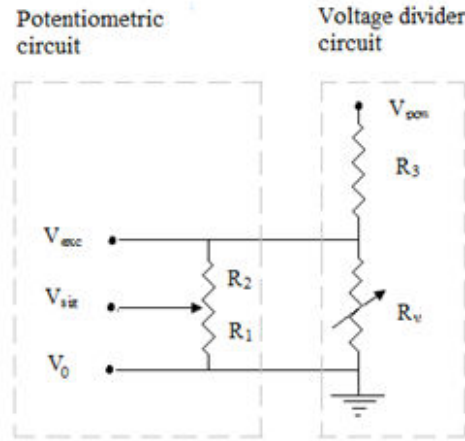


Figure 2. LCLC electrical circuit.

Equations (1) and (3) represent, respectively, the Voltage divider circuit and the Potentiometric circuit, which are schematically drawn at Fig. 2. The Equation (2) shows the necessary adjustment to adapt V_{exc}^* to V_{exc} through the utilization of the variables initial end of scale $F_{es_initial}$ and the final end of scale F_{es_final} , which are explained latter in this work.

$$V_{exc}^* = \left[1 + R_3 \cdot \left(\frac{R_T + R_v}{R_T \cdot R_v} \right) \right]^{-1} \cdot V_{pow} \quad \text{where,} \quad R_T = R_1 + R_2 \quad (1)$$

$$V_{exc} = \frac{V_{es_final}}{V_{es_initial}} V_{exc}^* \quad (2)$$

$$V_{sig} = \frac{R_1}{R_T} \cdot V_{exc} \quad (3)$$

Although the Eq. (1) explicitly relates V_{exc}^* and V_{pow} there is no need to apply it, because only the actuation on the variable resistor R_v experimentally conducts V_{pow} to V_{exc}^* . Note that R_T is the total resistance of the displacement transducer, represented at Fig. 2 by the potentiometric circuit, V_{pow} is an intrinsic characteristic of DC power source, R_3 and V_{exc}^* are selected by the user. The R_v value can be estimated by:

$$R_v = \left[\frac{\left(\frac{V_{pow}}{V_{exc}^*} - 1 \right)}{R_3} - \frac{1}{R_T} \right]^{-1} \quad (4)$$

Figure 3 shows the initial adjustment of V_{exc}^* to generate V_{exc} using $V_{es_initial}$ and V_{es_final} . Note that is an electrical adjustment, the spring constant k is maintained constant. To do this a reliable reference must be used. This reference can be provided by a mechanical material test machine, as used in this work, an A/D conversion system with a load cell or even a digital balance.

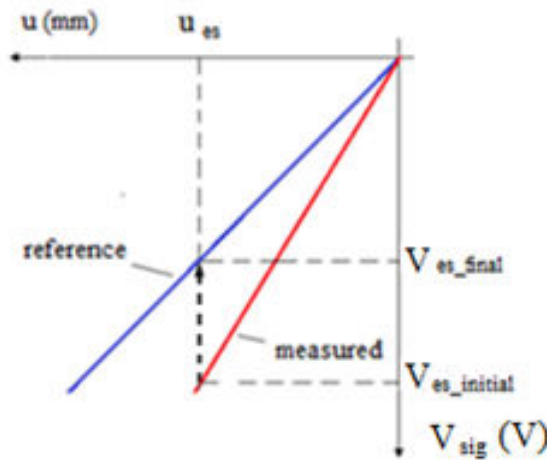


Figure 3. Schematically representation of an initial adjustment of end of scales for voltage.

Note that the adjustment of end of scale from measured with LCLC, labeled as $V_{es_initial}$, to the reference end of scale supplied, in this work by a mechanical material test machine, labeled as V_{es_final} , is a fundamental to LCLC do reliable measurements.

The Eq. (5) shows the relationship between forces and displacements of a spring like used in this work:

$$F = ku \tag{5}$$

Although it is not necessary to know the exact value of the used spring constant, it is important to know the range of values of k that are reasonable to the spring displacement not be excessive. So, it was established that a range from 1 to 10 mm of spring displacement was acceptable. For some end of scale F kgf, the range of k was calculated using (5):

$$k = F/u \quad \text{for } F = 0.5, 1.0, 1.5 \text{ or } 2.0 \text{ kgf} \tag{6}$$

Figure 4 shows the graphical representation of Eq. (6).

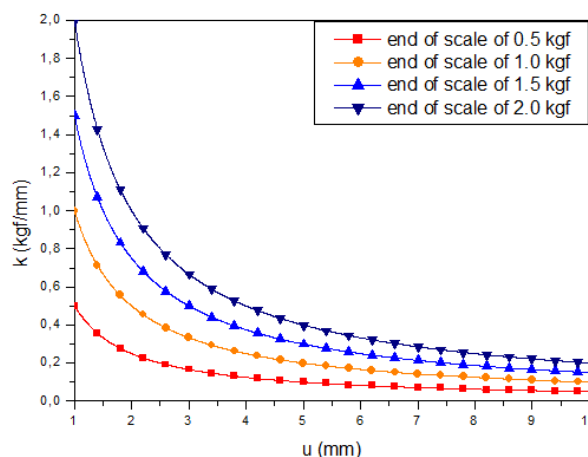


Figure 4. Graphical representation of Eq.(6).

For example, for a force end of scale of 1.0 kgf the k will range from 0.1 to 1 kgf/mm. To LCLC works the spring has to create a mechanical resistance to the applied force and it is fundamental that the spring has a linear response. Also it is supposed that at force end of scale the spring coils do not touch each other. The force end of scale can be changed, within a reasonable range, with a simple change of pre-calibrated springs.

The LCLC has to be calibrated before the first use. At the next section it will explained how to do and an example of adjustment to adapt V_{exc}^* to V_{exc} will be shown.

3. EXPERIMENTAL RESULTS

An experimental apparatus was mounted to calibrate of the LCLC transducer. Figure 5 shows the experimental apparatus used, which consists of an INSTRON material testing machine, a HBM Spider 8 Data Acquisition System with a notebook, a Gefran displacement transducer and the voltage divider circuit.

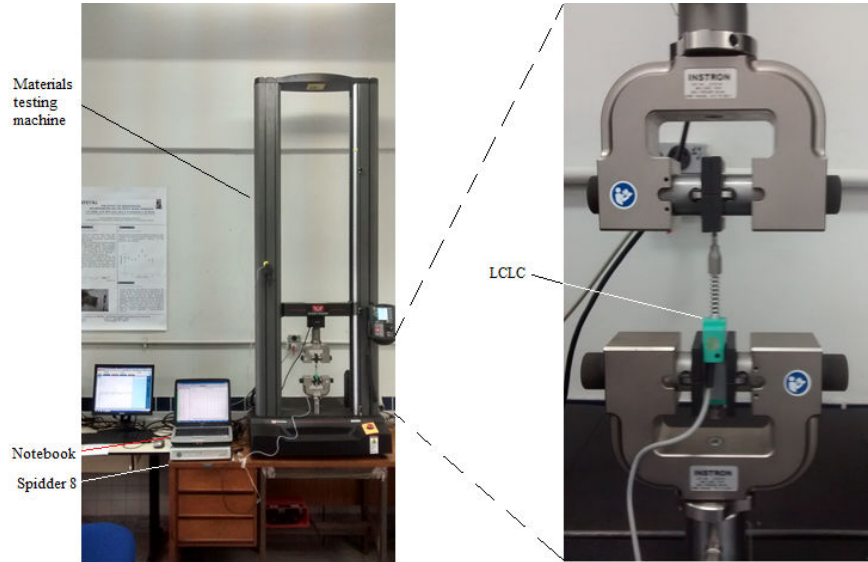


Figure 5. Experimental apparatus to calibrate the LCLC.

Fig. 6.a shows the result of experimental calibration of LCLC and fig.6.b shows the adjustment of end of scales.

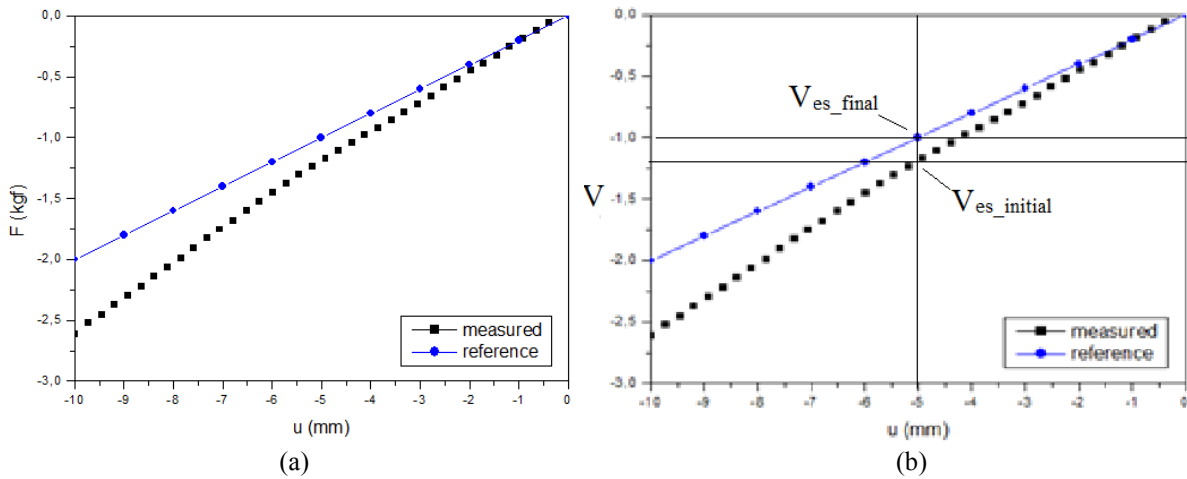


Figure 6. LCLC (a) Experimental results and (b) End scale adjustment.

Note that the calibration was done with compression loading and the initial point is at up right graphic side and the load increases at negative direction. To generate the experimental data show at both Figs. 6.a and 6.b, the following variables values were utilized: $V_{pow} = 7.2 \text{ V}$, $V_{exc}^* = 6.0 \text{ V}$, $R_3 = 60 \text{ } \Omega$, $R_T = 10 \text{ k}\Omega$, $R_v = 309 \text{ } \Omega$, which was estimated by Eq. (4).

Comparing the reference blue line with the measured black points it is possible to verify experimentally that the spring has at least two slopes, or in other words, two different spring constants in the proposed range of 2.0 kgf. This behavior does not follow the main hypothesis of linearity of previous section. This unexpected behaviour could commit the LCLC performance. To solve this problem, one possible solution is to reduce the initial proposed range to a value that maintain the linearity through the entire new range. Analysing Fig. 6.a is easy to see that reducing the transducer range from 2.0 kgf to 1.0 kgf can maintain the linear behavior required to the utilization of LCLC transducer.

Using Fig.6.b, the end scale adaptation can be done, where the points $V_{es_initial}$ and V_{es_final} can be obtained as 1.2 V and 1.0 V, respectively, which result from Eq. (2) of $V_{exc} = 5.0$ V. Therefore, adjusting at variable resistor, or trimpot, from $V_{exc}^* = 6.0$ V to $V_{exc} = 5.0$ V, it adjusts the LCLC experimental line to the reference line; generating a load cell transducer with end of scale or range of 1.0 V and 1 mV of resolution. As had already said at Introduction Section the LCLC has an one per one relationship between voltage and mechanical load, so is possible to say that the LCLC has an end of scale or range of 1.0 kgf and 1 gf of resolution. For this example, at the beginning of scale, the LCLC indicates 0 kgf that correspond to 0 V or 0 mm; and at the end of scale the LCLC indicates 1.0 kgf that correspond to 5.0 V or 5 mm.

4. CONCLUSIONS

A low cost load cell was proposed through a simple adaptation of an inexpensive spring to an existent displacement transducer. Its utilization was focused to phonoaudiology and physiotherapy researches. The theoretical background was fully explained. A prototype was mounted and tested. The result was not a high precision system, but it is an affordable one that can be composed with ordinary instrumentation devices, it is mechanically robust, no signal amplification is required at all and its end of scale can be changed, within a reasonable range, with a simple change of calibrated springs. The principal drawback is the criticality of the spring linearity, as it has to maintain the same k throughout the entire measurement range. This basic idea can be readily improved with utilization of nowadays well known microcontroller technology.

5. REFERENCES

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6. RESPONSIBILITY NOTICE

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