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GENERAL PURPOSE PIEZOELECTRIC LOAD CELL

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Abstract: *Quite often, the need for measuring dynamic forces occurs in laboratory and in industrial works. Ideally, such measurements should be done without disturbing the mass, the strength and the stiffness of the structure where the measurements are being carried out. Even though piezoelectric load cells are not suitable for static load measurements, they perform fairly well during dynamic loadings measurements, with the advantage of being compact, rigid and precise, with a good dynamic range. This paper describes a piezoelectric load cell, designed and developed by the author, and presents its performance throughout a calibration procedure, which employs an inertial load subjected to a controlled sinusoidal acceleration, within a broad frequency range.*

Key words: load cell, piezoelectric, dynamic force.

1. INTRODUCTION

Dynamic forces occur in many working devices, both in laboratory and in industry. The measurement of these forces is very important, not only for safety reasons, but also for the design and development of new products, such as cars, airplanes, buildings, and so on. Ideally, a load cell for measuring forces should not interfere with the behaviour of a structure, introducing undesired mass, flexibility and bulk. Therefore, an ideal load cell should be light, stiff and small. Piezoelectric load cells constitute a good approach for these characteristics, even at the cost of not measuring static loads. However, their compactness and easy installation and operation, providing clear as stable signals over a broad range of frequencies with a large dynamic range, recommend their use even in hash environments. This paper presents a piezoelectric load cell, designed and developed by the author, and explains two calibration procedures used for defining its sensitivity. A charge amplifier for conditioning the signal produced by the load cell is also presented in detail. In fact, it is expected that the information conveyed in this paper will facilitate not only the understanding of the working principles of piezoelectric load cells in general, but also they may lead to the plain manufacture of similar devices.

2. WORKING PRINCIPLE

A piezoelectric load cell converts an applied force into an electric charge by a piezoelectric ceramic or crystal. For the load cell described in this investigation, a ring of piezoelectric ceramic, polarized for compression on the axial direction, was employed. Figure 1 shows the final appearance of the load cell, while in Fig. 2, its drawings, with the

Figure 1. Load Cell: top side at left and bottom side at right.

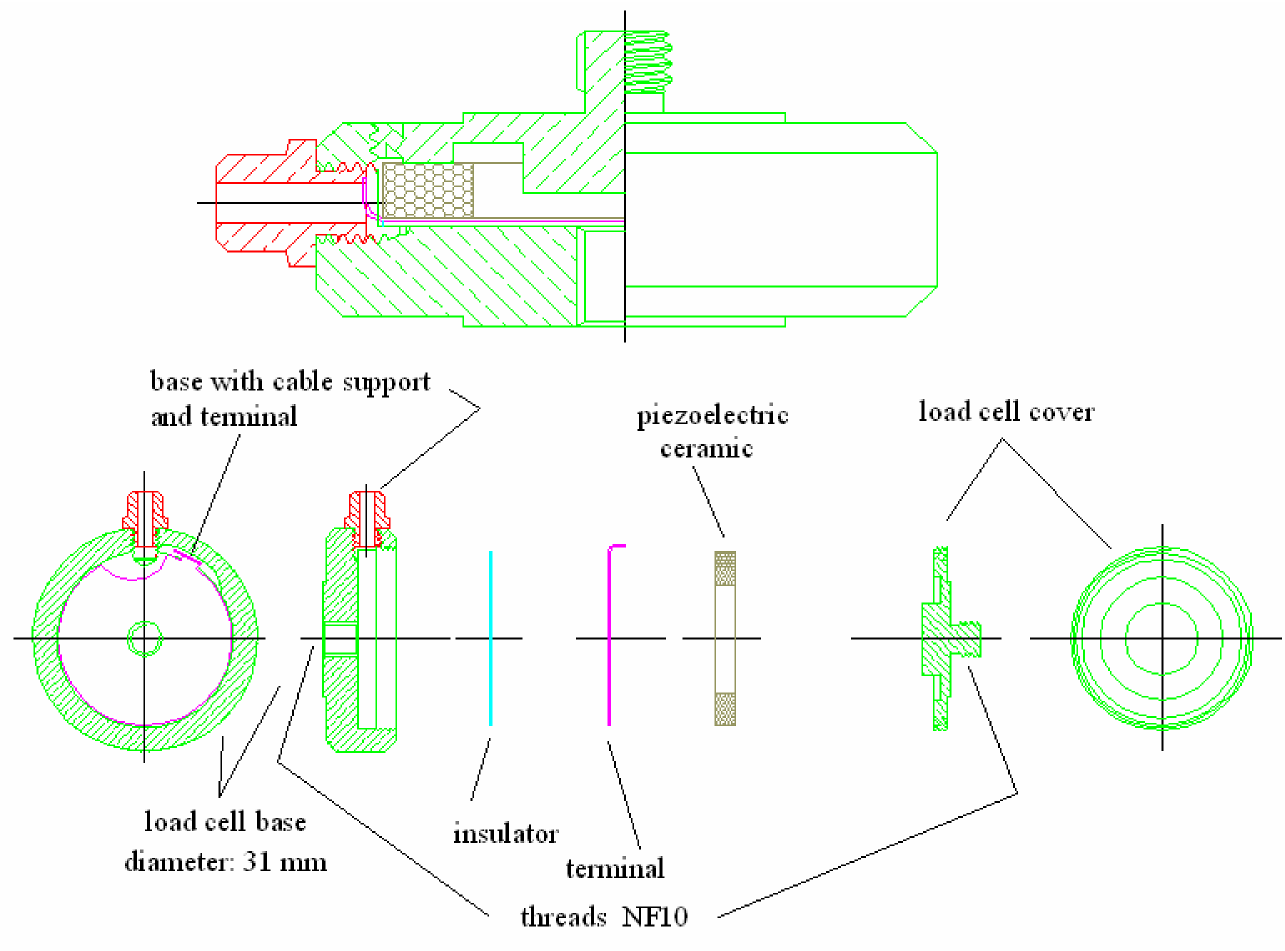

Figure 2. Load Cell Architecture.

most important features, are shown.

After the dissipation of initial charges, generated by the assemblage forces applied to the load cell, any subsequent variable load $F=F(t)$, where t is the time, applied to it, produces a charge $q = q(t) = k_{11} F(t)$, where k_{11} is the ceramic piezoelectric constant, as described by Harris and Crede (1976) and by Dally et al. (1993), where complete accounts of the electronics behind the charge generation process are given, and the later explains the electronic conditioning of the generated signal $q = q(t)$.

3. CALIBRATION

In order to establish the sensitivity of the load cell, the following procedure was employed: a) the load cell was fixed to a vibration exciter, from one side, and to a known auxiliary mass, from the opposite side; b) an accelerometer was mounted on this auxiliary mass, so that the acceleration of the assemblage could me measured; c) the set composed by the load cell, the auxiliary mass and the accelerometer was subjected to sinusoidal vibrations, of various frequencies and amplitudes; d) knowing the vibrating mass supported by the load cell and the acceleration imposed upon it, the evaluation of the dynamic load on the load cell was straightforward. Figure 3 illustrates the experimental apparatus used for these measurements: a vibration exciter, a power amplifier, a signal generator for supplying the power amplifier with a sinusoidal signal, two charge amplifiers, an oscilloscope, an auxiliary mass and an accelerometer. The charge amplifier of the load cell was adjusted so as to produce either 1.0 V/N or 0.10 V/N. Table 1 lists the most important features of the load cell, while in Fig. 4, a drawing illustrates the mounting details of the load cell for this experiment. For both calibration procedures described below, the seismic mass acting upon the piezoelectric load cell, was composed of the auxiliary mass, the accelerometer mass and the mass of the load cell cover, equalling 1.02 kg, so that an acceleration of 9.8 m/s² would produce a force of 10 N on this load cell.

The first calibration procedure involved two series of tests. In one of them, the load cell was tested under a 60 Hz sinusoidal acceleration of several amplitudes, so that, with the seismic mass of 1.02 kg, the load cell was subjected to several sinusoidal forces, covering the range 0.10 N to 60.0 N, as listed in Tab. 2, where the respective force readings are presented. For applying the loads of 20 N to 60 N, listed in this table, the vibration exciter and the power amplifier were more powerful than the ones shown in Fig. 3. In the other series of tests, the sinusoidal load imposed upon the load cell was kept at the constant peak of 10 N, while its frequency was varied from 15 Hz to 2000 Hz, as listed in Tab. 3, where the respective force readings are presented.

Table 1. Load Cell Characteristics.

Useful force range	±0.1 N to ±60 N
Useful frequency range	15 Hz – 2000 Hz
Total Mass, without cable	48 grams
Mass of the cover	7.9 grams
Dimensions: diameter x height	31mm x 11 mm
Sensitivities	1 N/V and 10 N/V
Capacitance	1.23nF

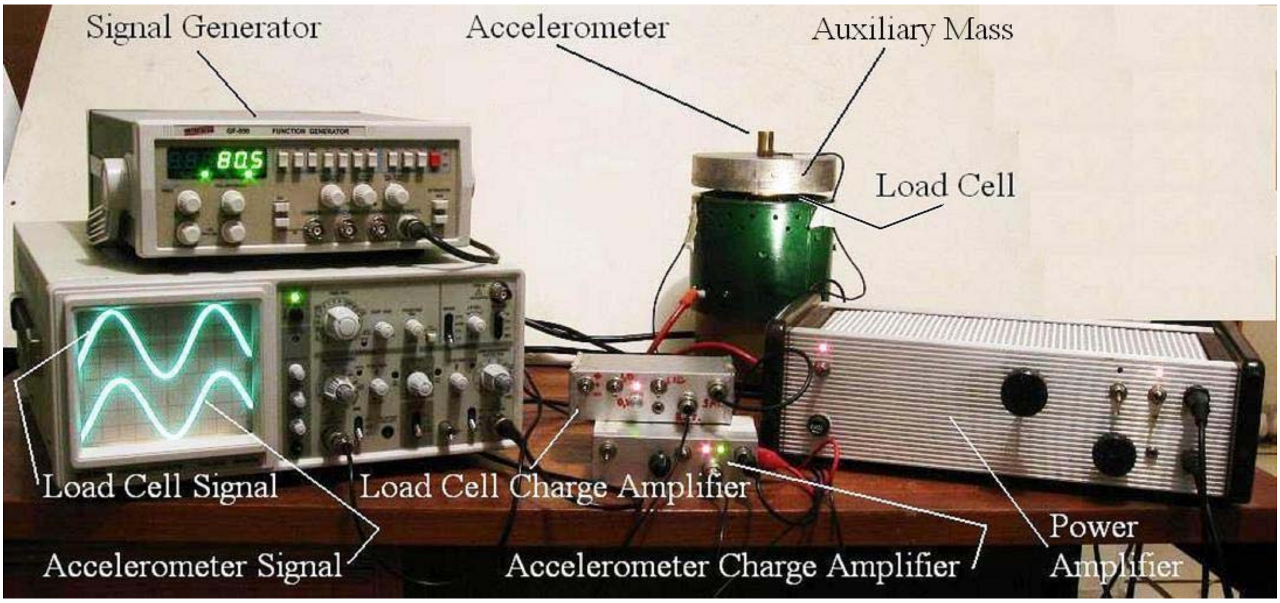

Figure 3. Calibration Arrangement with Accelerometer.

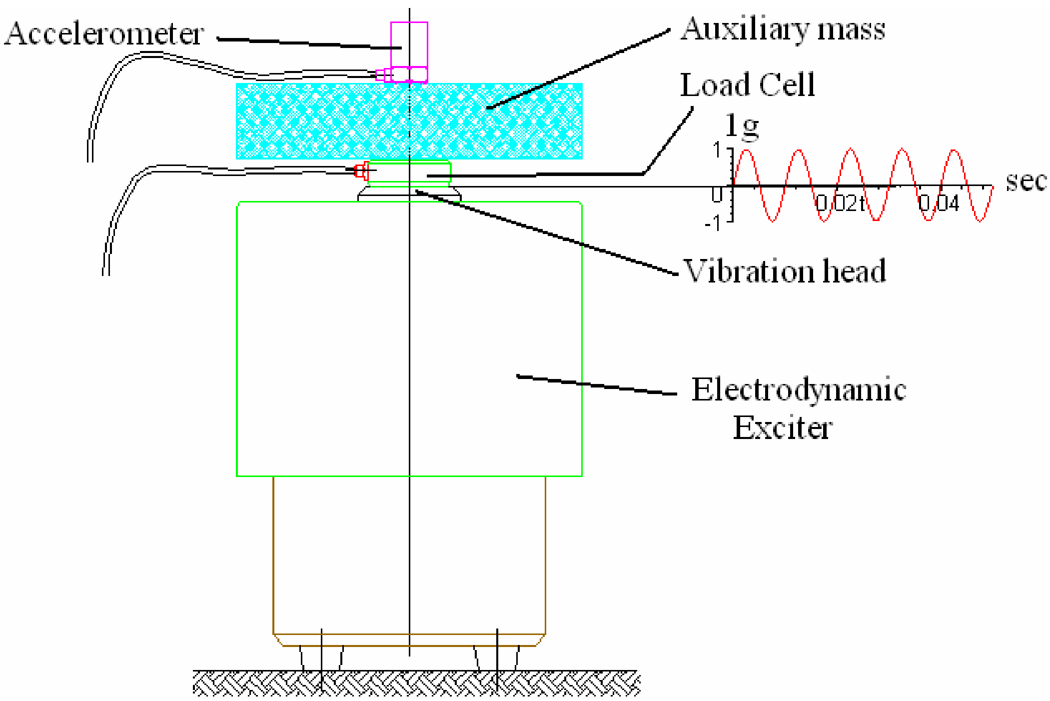

Figure 4. Load Cell Testing Assemblage.

Table 2. First Calibration Procedure Results, with a Constant Frequency of 60 Hz.

Applied Force (N)	Measured Force (N)
0.10	0.10
0.20	0.20
0.50	0.50
1.00	1.0
5.00	5.0
10.0	10
20.0	20
40.0	39
60.0	57

Table 3. First Calibration Procedure Results, with a Sinusoidal Peak Loading of 10 N.

Frequency (Hz)	Measured Force (N)
15	10.2
30	10.0
60	10.0
100	10.0
200	9.6
500	9.6
1000	10.0
2000	10.8

The second calibration procedure is illustrated in Fig. 5, in which the piezoelectric load cell performance was compared with the results from a load cell with strain gages. For this comparison to be valid it was necessary to take into account two additional parameters: a) the seismic mass acting upon the strain gages load cell should include, not only the auxiliary mass and the accelerometer mass, but also the whole piezoelectric load cell mass and the mass of the upper half of the strain gages load cell, as illustrated in the detail of Fig. 5, resulting in 1.093 kg for this seismic mass, and b) a low resonance frequency of the system, caused by the fact that the strain gages load cell is much less rigid than the piezoelectric load cell. However, this resonance frequency of 471 Hz, allowed for measurements to be made from 15 Hz to 240 Hz. Table 4 shows the readings of these tests, for which the frequency was varied from 15 Hz

Table 4. Second Calibration Procedure Results, with a Sinusoidal Loading of 10 N Peak.

Frequency (Hz)	Piezoelectric Load Cell Readings (N)
15	10.0
30	10.0
60	10.0
100	10.0
240	9.6

Table 5. Second Calibration Procedure Results, with a Constant Frequency of 60 Hz.

Applied Force (N)	Piezoelectric Load Cell Readings (N)
1.0	1.0
5.0	5.0
10.0	10
20	20
50	47

to 240 Hz, while the data of Tab. 5 were obtained with the frequency fixed at 60 Hz while the applied loadings were varied from 1 N to 50 N. In these tables, the readings of the strain gages load cell were taken as references, for the comparison purpose with the readings of the piezoelectric load cell.

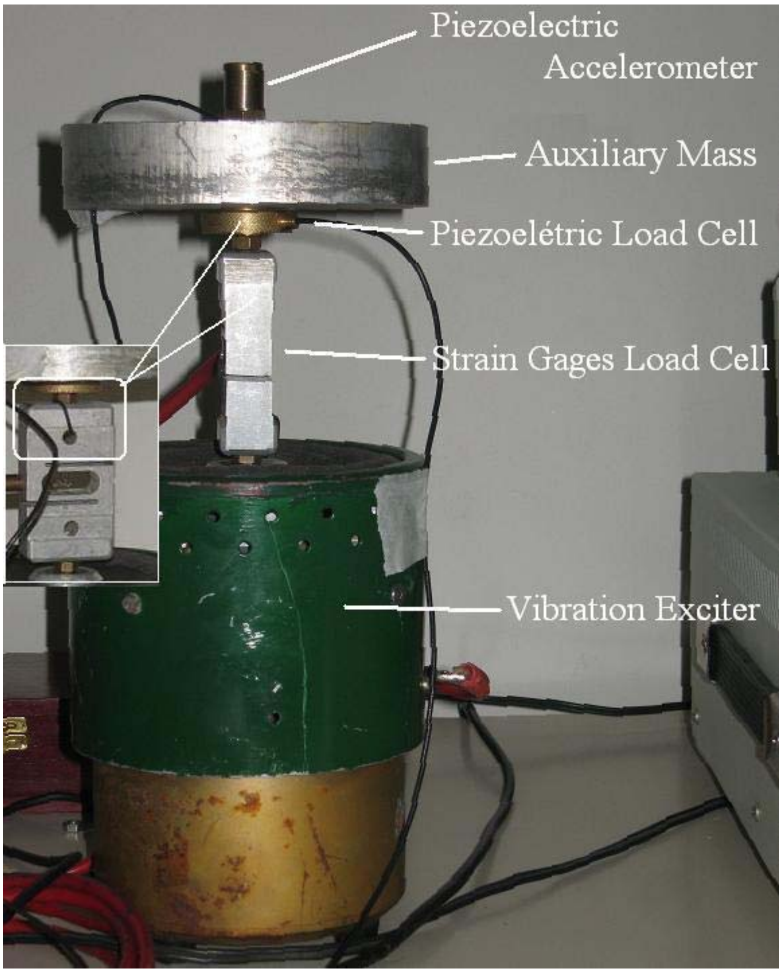

Figure 5. Comparison with a Strain Gages Load Cell.

4. CHARGE AMPLIFIER

Under operation, the load cell generates an electric charge q(t), which has a very high impedance and is fed into a charge amplifier, where this very high impedance is accommodated, and a calibrated voltage signal is output. Dally et al. (1993) describe the electronics behind a typical charge amplifier, and the one used in this paper is presented in Fig. 6, where the load cell signal is input trough terminal 2 of the operational amplifier TL072. The first stage of this operational amplifier handles the high impedance input signal. The output 1 of this stage is fedback to input 2 through resistance R_f = 30 MOhm, in parallel with either C_f = 1.11 pF or C_f = 11.11 pF, according to the position of switch S1. Thus, this switch adjusts the final gain of the charge amplifier in a ratio of very nearly ten to one. Notice that the product R_f C_f equals the time constant **τ,** which defines the response of the load cell when it is subjected to a low frequency signal, as described by Dally et al. (1993) and by Harris and Crede (1976).

The second stage of the operational amplifier is used for adjusting precisely the sensitivities of the load cell. This is achieved by adjusting the 4,7 kOhm variable resistance. Notice a 15 nF capacitor which can be connected in parallel with the 27 kOhm resistance by the switch S2. This procedure works as a low pass filter, which can be useful when the signal generated by the load cell is too noisy. Another feature of this charge amplifier is the offset adjustment, made by the 5 kOhm potentiometer, whose cursor is connected to the positive input of the first stage of the operational amplifier and whose extremes are fed with two small voltages of opposite sign. To work properly, this charge amplifier requires that the difference between the batteries voltages should not be more than a couple of Volts, while the modulus of each voltage should not be more than 18 Volts.

Figure 7 illustrates constructive details of this charge amplifier. At the upper left of this figure, an idea of the layout of the charge amplifier components is given; at the upper right of the figure, the supporting rail is ready to be fitted into the enclosure and, at the bottom of the figure, the assembled charge amplifier can be appreciated. Notice the P2 female plug, which is used for connecting the charge amplifier to an external symmetrical source from ±5 to ±18 Volts.

It is very important to protect the whole procedure, from the load cell to the charge amplifier output, with a good electromagnetic shielding.

5. CONCLUDING REMARKS

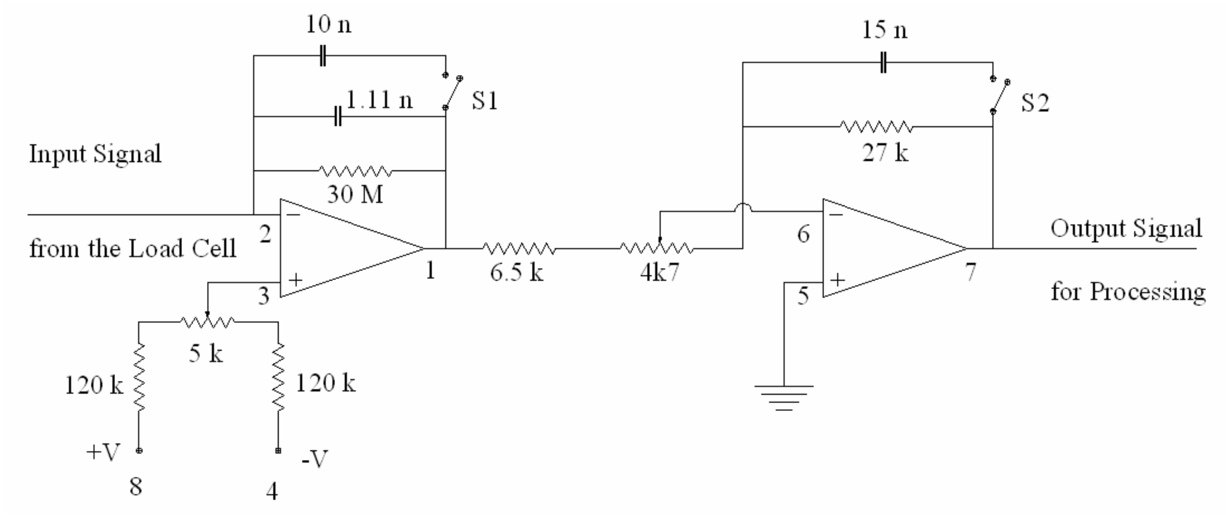

Figure 6. Charge Amplifier.

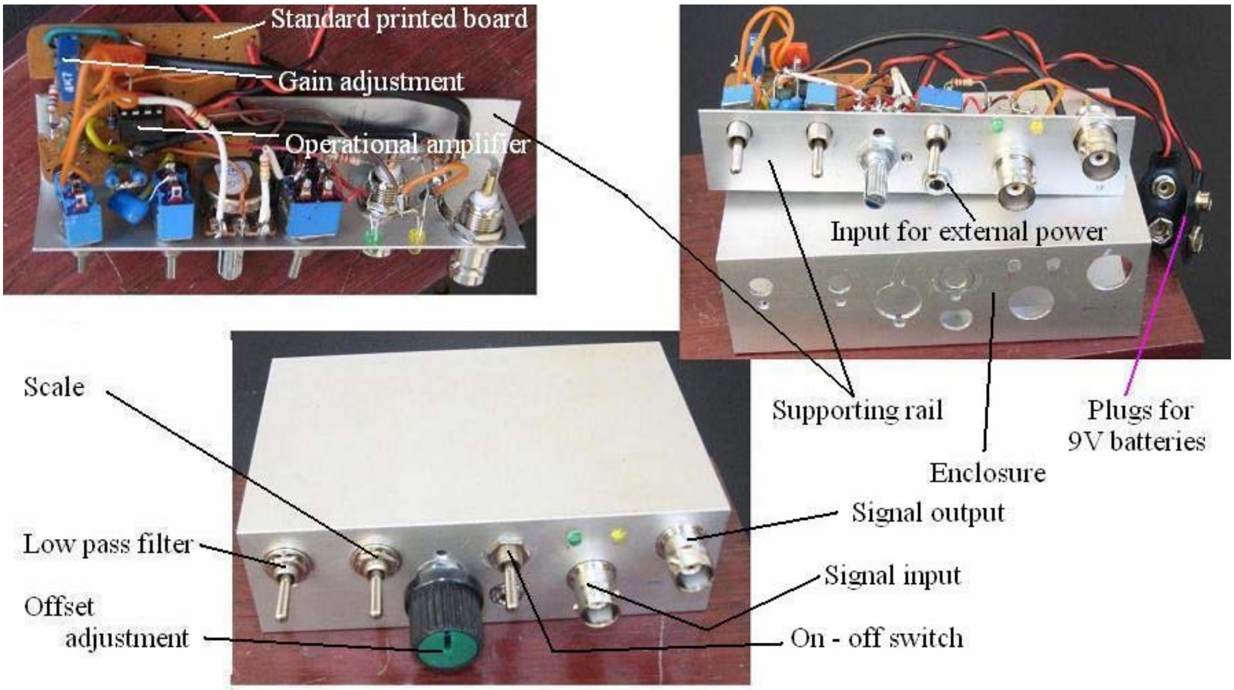

Figure 7. Charge Amplifier Constructive Details.

From what was said above, it is possible to arrive to the following conclusions: a) a general purpose piezoelectric load cell can be built using ordinary manufacturing procedures; b) the dynamic calibration of the load cell can be made with a seismic mass, which is pushed by the load cell with a known sinusoidal acceleration and c) the charge amplifier, for conditioning the signal produced by the load cell, is practical and versatile.

As for suggestions the following would apply: a) the methods presented above can be used for the design and development of impact hammers of several sizes and b) the presented design of the load cell can be adapted for other models, larger or smaller, covering customized frequencies and load amplitude ranges.

6. REFERENCES

The references below are just a sample of a good source of information, not only for the subject of this paper, but for related matters as well. Many sources of information on the subject can be found at the internet and at the documentation of manufacturers of load cells.

Harris, C. M. and Crede, C. E., "Shock and Vibration Handbook", 1976, 2 nd edition, McGraw-Hill.
Dally, J. W., Riley, W. F. and McConnell, K. G., "Instrumentation for Engineering Measurements", 1993, 2 nd edition, Wiley.

7. RESPONSIBILITY NOTICE

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