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Smart Load Cells: an Industrial Application

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SUMMARY

This paper describes a data acquisition solution using a single-chip RISC type microcontroller with very few other active and passive components around, taking advantage of the ratiometric functioning of the load cells. The need for thermally stable circuits and components is minimized through the use of the same amplification chain for both signal and reference, together with software calibration. The amplification and filtering is done through switched-capacitors techniques, controlled by the microcontroller. Moreover, this option allows the choice of the proper scale according to the platform, with periodically and automatically calibration. The analog-to-digital conversion is done using the single ramp approach controlled by the microcontroller, which does all the digital processing required as well the external transmission of the data for a local network following the nine-bit protocol. The conversion time was around 13 ms. For an industrial platform of 8 smart load cells the weighing tests show errors below 100 gr. in 400 kg. The paper also describes an example of software calibration of a multi-load cell weighbridge using one processor per smart load cell.

Keywords: *load cell interfaces, industrial weighing systems, smart sensors.*

INTRODUCTION

Load cells are force sensors which are used in industrial weighing equipment. Multi-load-cell weighing systems usually use a single signal processing circuit associated with the individual load cell outputs tied together (electrical paralleling). Because this electrical paralleling, the tuning of the gain of a load cell affects the behavior of the others, calibration is difficult and tedious, specially with weighbridges for cars and trucks, requiring the motion of heavy weights around large platforms (see Fig.1) [1].

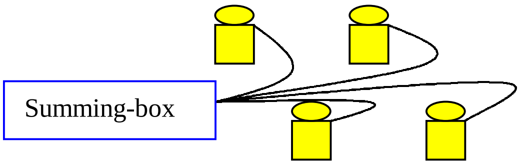

Fig. 1: Classical solution in a multi-load-cell weighing system.

The use of load cells with digital outputs, i.e., with integrated signal processing, allows the gain adjustment to be a simple multiplication of the load cell output by a coefficient, operation which does not affect the other load cell outputs (see Fig. 2). In this case, the calibration process means the calculation of the multiplying coefficients, which are given by the solution of a set of equations, operation easily performed by any general purpose microcomputer. However, this solution needs a cost effective signal processing circuit including amplification, Analog-to-Digital conversion and networking capabilities. Having in mind industrial weighing applications where 6000 divisions are needed for the equipment (external divisions) a conversion resolution of at least 60000 divisions (10 internal divisions for each external) with 50 or more readings per second, at least for static weighing applications. For dynamic weighing a faster reading rate may be required but normally with lower resolution.

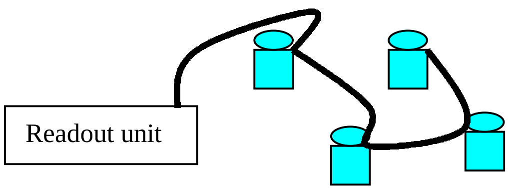

Fig. 2: Modern solution in a multi-load-cell weighing system: no summing-box, single cable, load cells with digital output, software calibration possible.

DESIGN STRATEGY

The same amplifier chain is properly switched to deal with the zero, the load cell signal and the conversion reference (see Fig. 3). In this way the thermal stability requirements for the amplifier can relaxed as a change in gain will affect all the three entities defining the A-D conversion. A simpler architecture can be used just enough to ensure that the gain remains constant during the conversion period.

The single ramp conversion was used because it requires the minimum hardware and it allows a higher rate of conversions. However, this simple conversion technique is not intrinsically compensated as dual ramp conversion for example, requiring some pos-conversion processing specially in this case where the zero, the signal and the reference are allowed to change. The counting associated

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with the single ramp A-D conversion, the control of the switches in the amplifier stage and the control of the ramping capacitor discharge are tasks to be performed by a microcontroller architecture.

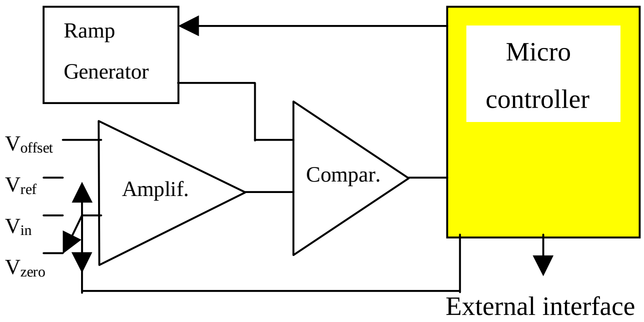

Fig. 3: Smart load cell

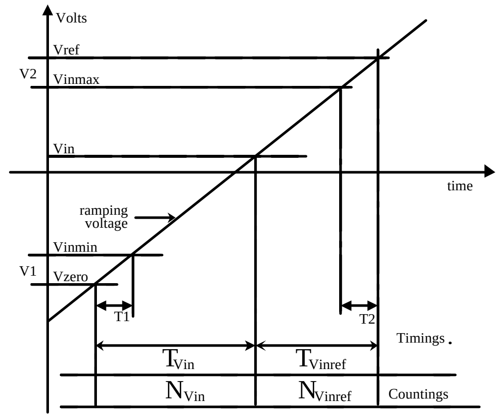

Fig. 4: The single ramp conversion scheme implemented.

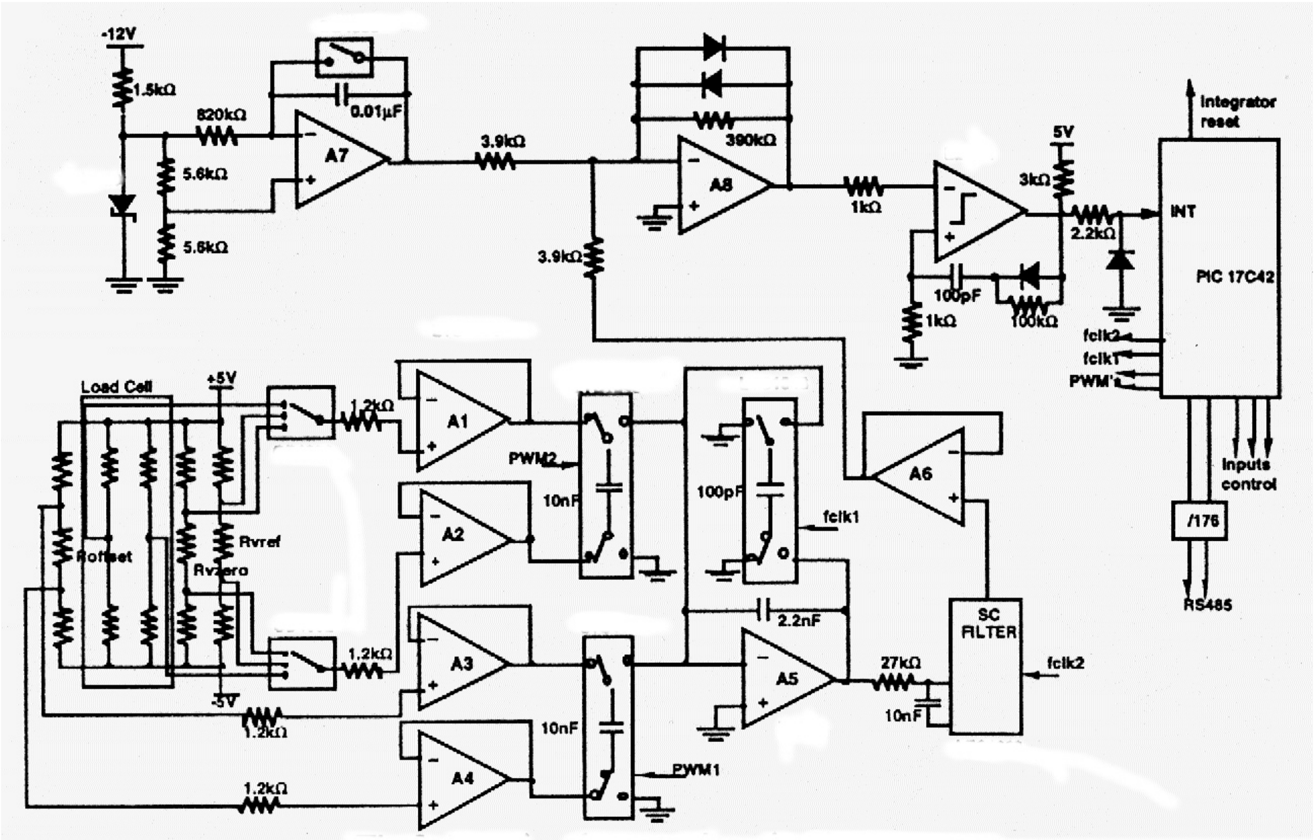

Fig. 5: The smart load cell signal processing circuit.

The counting associated with the single ramp A-D conversion, the control of the switches in the amplifier stage and the control of the ramping capacitor discharge are tasks to be performed by a microcontroller architecture. To obtain the conversion result, which may include scaling, eventually some digital filtering and the communication with the outside world, are the other tasks for the microcontroller. To minimize the hardware and to reduce the errors the same comparator is used to detect the three level crossings. Normally these comparisons are done one on each ramp, therefore requiring three ramps. In this case the three comparisons are done during the same ramp reducing the conversion time to a third. All it is needed, is to allow enough time to switch the amplifier chain from one signal to the other, until there is a stable output. This was acomplished in the conversion by restricting (Vin_{min}-Vzero) and (Vref-Vin_{max}) to be ≥ ΔV Volts to allow the transients to settle (see Fig. 4). This strategy reduces the Vin range but the precision of the conversion is improved. The controller: the circuit was developed around an 8 bit single chip Harvard architecture microcontroller with

RISC-like features (operating speed: 16 MHz clock input– 250 ns instruction cycle). The amplifier stage is composed of an instrumentation amplifier with gain programmable and was built with switched-capacitor techniques. Three blocks, controlled through PWM outputs of the microcontroller, amplify the input signals (Vzero, Vin and Vref) and the offset. On charge manipulation was used polystyrene capacitors (low drift). Filtering sfter amplification is achieved with a SC filter (low-pass 5th order) with cut-off frequecy programmable through a digital signal from the processor (see Fig. 5).

The comparator

To assure a faster and more sensitive comparison the SC filter block and the amplifiers A6 and A8 were used. The A5 output is filtered, inverted by the SC filter block and buffered by A6, so that at the A8 input summing point, the current due to the ramp is subtracted from the current proportional to the signal. When this current difference is large A8 operates at a low gain due to the diodes in the feedback loop. When the currents produced by the ramp potential and A6 very nearly balance, the potential at A8's summing junction will go low enough, so that A8 comes out of the diode bounding and operates with a gain determined by the feedback resistor (390 kΩ). The A8 makes the comparator's job much easier, it amplifies the voltage difference of the two signals to be compared by a factor of 100, reducing the comparator input uncertainties. The comparator components in the positive feedback path ensure a sharp transition.

DIGITAL FILTERING

The use of smart load cells with digital outputs needs a cost effective in digital filtering of the final converter results for each smart load cell. The presence of the microcontroller per smart load cell allows the use of a Self-Adaptive Pseudo-Moving Average Filter (SAPMAF) - software solution - to achieve a stable digital output with a fast response to weight changes. The technique was established by theoretical analysis and is justified by means of simulation and experimental results.

FABRICATION

The signal processing circuits including the controller were implemented in PCB (printed-circuit-board) using some components in SMD (surface-mounting devices) packages. The board area is 8x8 cm^2. Meanwhile, a CMOS integrated circuit including almost of all the functions described has been designed.

SOFTWARE CALIBRATION RESULTS

The calibration process means the calculation of the multiplying coefficients, which are given by the solution of a set of equations, operation easily performed by any general purpose microcomputer.

To test the software calibration method for the multi-load cell weighbridges, it was decided to use standard readout units instead of the prototypes above referred. A local weighing equipment manufacturer made available two 4 load cells platforms and 8 digital readout units with networking facilities. Load cells taking a maximum nominal weight of 100 kg, with 3000 div resolution and a sensitivity around 2 mV/V, were used. The 4-load cell platforms coupled to a single readout unit is rated to 200kg with a resolution of 100 gr. Each of the readout units were calibrated to give around 60 kg with a 20 gr resolution.

Two sets of tests were done, one for a 4 load cells platform, and another for a 8 load cells system, using two 4 load cells platforms.

The calibration method consists on doing N readings of weight on each load cell obtained by moving a mass with a known weight around the platform. The number of readings is the same as the number of load cells under the platform. The best results are given by the N readings obtained, concentrating the weight as much as possible above each one of the N load cells.

For the 4 load cells platform 4 sets of 4 readings were made, and the weights found were used to workout the multiplying coefficients. These factors affecting each one of the readings, enables the correct evaluation of the weight above the platform. A system of 4 equations and 4 unknowns was built:

$$K_1W_{11} + K_2W_{12} + K_3W_{13} + K_4W_{14} = W$$
$$K_1W_{21} + K_2W_{22} + K_3W_{23} + K_4W_{24} = W$$
$$K_1W_{31} + K_2W_{32} + K_3W_{33} + K_4W_{34} = W$$
$$K_1W_{41} + K_2W_{42} + K_3W_{43} + K_4W_{44} = W$$

The solution of this system gives the K factors required to evaluate the weight of an unknown mass (with the W_{rc} readings calculated with a calibrated mass positioned in four different places). With the following W_{rc} readings calculated with a calibrated mass of 20kg positioned in four different places:

- W_{1c} readings 3.86, 9.96, 6.82, 0.72;
- W_{2c} readings 1.74, 2.94, 10.88, 5.58;
- W_{3c} readings 4.50, 0.74, 3.54, 13.26;
- W_{4c} readings 13.30, 2.92, 1.48, 4.38;

the K_c factors evaluated:

K_1=0.90025, K_2=0.91580, K_3=0.99196, K_4 = 0.88685.

After calibration the resolution of the next equation determines the weight of the mass on the platform (with Wi’s the output’s of each smart load cell).

$$\mathbf{Mass = K_1{*}W_1 + K_2{*}W_2 + K3{*}W_3 + K4{*}W_4}$$

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Using the K's factors several (25) weighing operations were done, with different masses, located in different points of the platform, having been recorded very encouraging results, with errors below 50 gr (4000 divisions in 200 kg).

For the composite platform with 8 load cells the test was repeated and the 8 multiplying coefficients were calculated. The weighing tests done confirmed the approach followed giving errors below 100 gr, i.e. again 4000 divisions in 400 kg.

EXPERIMENTAL RESULTS

Fig. 6 shows an example for a given Vin and Vref=5.1 V, waveform Ch1 is the amplifier output, ilustrating the input signal switchings, and Ch2 waveform is the ramp.

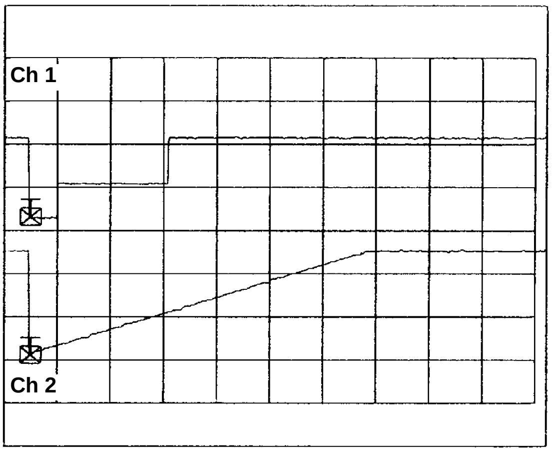

Fig. 6: Screen plot of A6 and A7 outputs respectively. Ch 1@5V/div, Ch 2@5V/div, time base@2 ms /div, for a load of 200 kg.

CONCLUSIONS

This architecture has shown to give the required performance at a very reasonable cost. The implementation of smart cells including self-calibration and networking facilities seems achievable and cost effective even for multi-load-cells applications, where considerable reduction on the commissioning time, through the software system calibration, is highly interesting.

The results achieved so far were very encouraging regarding static or quasi-static weighing applications. Now we are already working on the new filtering algorithms having in mind dynamic weighing. In dynamic weighing systems conventional filtering methods employed have limitation in improving accuracy and throughput rate. The Kalman filter may provide effective alternative to the conventional method especially when the system is non-linear and low frequency noise is incorporated in the bandwidth of the useful signal.

Moreover, silicon does not suffer from hysteresis or creep (like conventional steel load cells) and therefore, it is an ideal material for fabricating load cells [2]. To merge each load cell with the respective signal processing circuit, full process compatible [3], will create a new generation of load cells.

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