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Signal Correction of Load Cell Output Using Adaptive Method

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Abstract: This paper presents a method of dynamic compensation of load cell response using Adaptive technique. The case is illustrated by showing how the response of a load cell can be improved. The load cell is a sensor, whose output gives an oscillatory response in which the measured values contribute to the response parameter. Thus, a compensation technique is used to track the variation of the measured values to facilitate the investigation using response compensation. The first step is to make a mathematical model of a load cell. Secondly, the output is digitized by a proper sampler and suitable A/D converter. After verifying the simulated output, a model of an adaptive technique will be made to minimize the oscillation in the output and the corrected digital data again converted to analog form by proper D/A converter for using in real system. The whole system constitutes a dynamic sensor for achieving compensation response.

Keywords: Adaptive technique, Dynamic sensor, Load cell, Response compensation, Sampler, A/D converter, D/A converter.

I. INTRODUCTION

Load cells are used in various weighing applications like aerospace, medical & automation measurement, vending machine, check-weighing system etc. The settling time of this kind of transducer is long and highly damped in nature so the weight measured by load cell is distorted by a transient response. Since signal processing and control system cannot accomplish appropriately, if they pick up fallacious data, so remuneration of the inadequacy of sensor response is one of the major complication in sensor research. Redundant signals, parameter drift, non-ideal frequency response, nonlinearity and cross sensitivity are five major drawbacks in primary sensors [1, 2].

A few sensors, such as load cell and others have an oscillatory response which always demands to settle down. Dynamic computation accredit to the detection of the final value of a sensor signal, while its output is at rest in oscillation. It is therefore required to actuate the value of the measurand in the fastest time possible to accelerate the process of measurement, which is of particular importance in some application. One example of processing this one can be done on the sensor output signal is filtering to achieve response improvement [2].

The complication of the load cell responses, specially transient behavior, is studied, and it is seen that investigator has come up with a very wide literature inspection concerning response [2]. This complication has been dealt with help of few techniques. Software solutions for sensor compensation are surveyed [3].

Analog adaptive techniques have been used to minimize transient behavior of load cell [2,4]. In some cases digital adaptive algorithms have been proposed for this purpose [5]. Also application of an artificial neural network can also be appropriate for intelligent weighing systems [6,7]. Other methods, such as manipulating a Kalman filter and nonzero initial condition have been applied for dynamic weighing systems [8,9].

In this report, a new standard process is being approached by us for dynamic compensation of the load cell response using a adaptive technique. Under section II, the modeling of load cell has been accomplished. After that, in section III, load cell response rectification has been furnished through some rectification method. The cogent synthesis of the adaptive filter formation has been explained in section IV. Section V then presents the results of simulations as carried out with the help of a computer. The conclusions are revealed in section VI.

II. MATHEMATICAL MODELLING OF A LOAD CELL

There are three types of methods used to compare and investigate for calculation of weight of different types of items. These methods are “Average Method”, “Frequency Method” and “Damping Method”.

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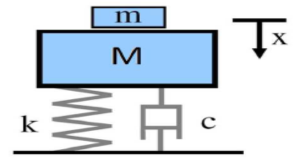

Fig.1 Mass Spring Damper system

Basically the model of the load cell (Fig.1) is represented as a "Mass Spring Damper (MSD)" system, where m is the mass of the desired item which is subjected to the load cell. Here M is the load cell equivalent mass which is attached to a mass-less spring with spring constant k. When a load is applied to the load cell, a counteracting force is generated by the spring due to an offset x from equilibrium defined by the Hook's law as $f_s = - kx$.

This suffices the modeling of the static equilibrium characteristic of load cell but in case of dynamic equilibrium characteristic, it is important to take into account the impairment of the damping factor. Viscous damping method is assumed for the dynamic characteristic, where the damping force is proportional to the velocity: $f_D = - c\frac{dx}{dt}$, where c is the damping co-efficient. Now using Newton second law of motion, the second order equation of dynamic equilibrium is obtained [3]:

$$(\mathrm{M} + \mathrm{m})\frac{d^2x}{dt^2} + \mathrm{c}\frac{dx}{dt} + \mathrm{kx} = \mathrm{R} \ldots\ldots\ldots (1)$$

The output of the load cell from the machine is either converted to system of unit or given in terms of deflection of the load cells. When the output from the machine is not in terms of any unit, a conversion factor needs to be taken into account. Therefore the new solution would be in the form of:

$$\hat{x} = \alpha\left(c1e^{-\mu t}\cos(\omega t) + c2e^{-\mu t}\sin(\omega t) + \frac{\mathrm{M} + \mathrm{m}}{\mathrm{k}}\right) \ldots . (2)$$

where α is a conversion factor,
μ is the damping factor,
and c_1,c_2 are constants, which depend on the initial conditions.

2.1. "Averaging" Method:
This type of load cell modeling method is based on the assumption that the oscillatory response has enough settling time. In the steady state the weight can be found from the value of the graph, Fig. 2.

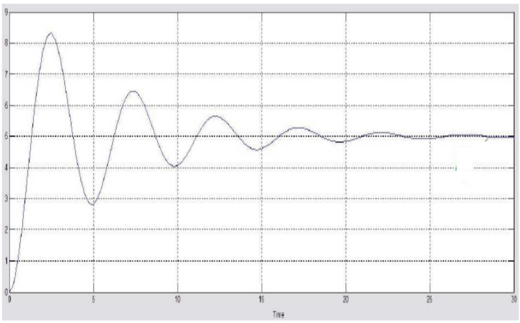

Fig. 2 Dynamic response of Averaging method.

2.2. "Frequency" Method:
The method described in this section has been named as the frequency method as the unknown mass is predicted by rearranging the frequency equation:

$$\omega = \frac{1}{2}\sqrt{\frac{4k(M + m) - c^2}{(M + m)^2}} \ldots\ldots\ldots (3)$$

Every load cell has its own unique properties. It is required to find the parameters of every load cell in terms of its mass (M), spring constant (k) and damping co-efficient (c). The parameters of a load cell M, k and c are calculated only once as they are in unique nature. Then the weight can be calculated, using these load cell parameters, by measuring the first two successive peaks in the load cell output (Fig. 2 & Fig. 3). The circular frequency (ω) can be calculated from the difference between the two peaks and final equation for solving m:

$$\mathrm{m} = \frac{k + \sqrt{k^2 - (\frac{2\pi}{t_2 - t_1})^2 c^2}}{2(\frac{2\pi}{t_2 - t_1})^2} - \mathrm{M} \ldots\ldots\ldots\ldots (4)$$

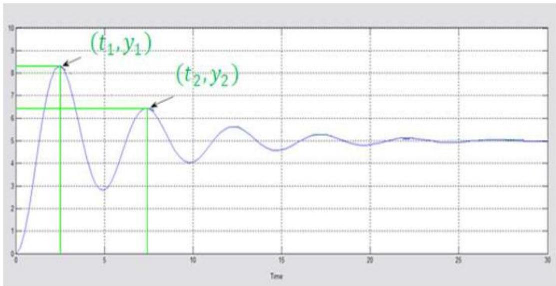

Fig. 3 Dynamic response of Frequency method.

2.3. "Damping" Method:
Considering the model of the load cell system presented (Fig.1) another method can be described. This method is damping method. It's named as such because the unknown mass is predicated by rearranging the damping factor equation:

$$\mu = \frac{c}{2(M + m)} \ldots\ldots\ldots\ldots\ldots (5)$$

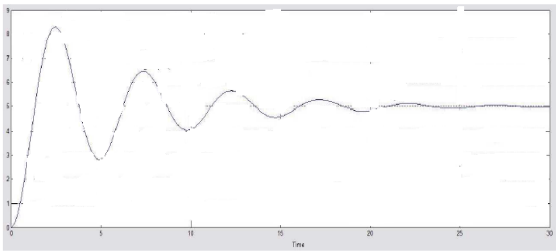

Fig.4 Dynamic response of Damping method.

III. LOAD CELL RESPONSE RECTIFICATION

Consider the transfer function of any dominant sensor as G(s). It is known that the output response of any sensor is damping in nature as already discussed in introduction part. It has obviously transient as well as steady state phase of responses. If we want to eliminate or decrease the transient

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response, that we have to use an adaptive filter having a complimentary characteristic. Before using the adaptive technique, a sampler is used to accomplish the digital adaptive technique. The response of the load cell may change for various measurands. For examples, the property of load cell changes when a load is enforced to it, because the mass of the load contributes to the internal parameter of the system. So, the transfer function of the filter should be replaced equally. Earlier work has shown that a load cell can be modeled as a second order system[3],

$$(M+m).\frac{d^2x}{dt^2}+c.\frac{dx}{dt}+k.x=R \ldots\ldots(6)$$

where M is the effective mass of the sensor,
m is the mass being weighted,
c is the damping factor, k is the spring constant,
and R(t) is the force function.
Here, the mass of the sensor has been avoided. Thus the transfer function becomes:

$$\mathrm{G(s)}=\frac{\mathrm{Y(s)}}{\mathrm{R(s)}}=\frac{1}{ms^2+\mathrm{cs}+\mathrm{k}} \ldots\ldots\ldots(7)$$

Now the transient behavior of sensor is minimized by adaptive filtering technique. For this purpose we assume an adaptive filter assigned with a weight vector P to accommodate all of the parameters of adaptive filter, i.e. components of P weight vector are used for the adaptive filter according to sensor inherent parameters.

$$P=[f_1 f_2 f_3 f_4 \ldots\ldots]^T \ldots\ldots\ldots(8)$$

The components of $P=(f_1 f_2 f_3 f_4\ etc)$ can be calculated for various values of the measurands. As it is defined that P rely upon the value of *m*, it can be written like P(*m*). When a new measurand brings about, m is unknown at that time. As the filter having the inverse characteristic, the parameters of the adaptive filter cannot be set to exact values. Thus an adaptive rule is recommended to correct the parameters of the adaptive filter according to the value of measurands. Generally, in good adaptive method, an adaptive algorithm like (LMS) least mean squares techniques can be used. The adaptive control block performs the minimization of the dynamic response of the load cell. Different performance criteria have been utilized in this work.

In this work an adaptive technique has designed with the help of the mean square criterion. The minimization of the cost function can be done adaptively by using the least men square (LMS) algorithm. The LMS algorithm updates of coefficient vector as given in following equation:

$$C_{k+1}=C_k+2\mu e_k r_k \ldots\ldots\ldots\ldots\ldots(9)$$

Where ,r_k is the input vector
,C_k is the weighted vector,
e_k is the error signal,
and μ is the step size.
The adaptation speed of the adaptive filter is controlled by the step size μ.

In order to furnish the adaptive filter, we need to develop a reference signal for the adaptive algorithm. For the primary adaptation of the filter coefficients we demand at the receiver to be able to generate the same data sequence. This known data sequence is referred to as the training sequence. During the training period the desired signal is used as a reference signal , and the error signal is defined as:

$$\mathrm{e_k}=(\mathrm{x_k}*\mathrm{D})-\mathrm{q_k} \ldots\ldots\ldots\ldots\ldots(10)$$

where x_k is the input sequence of adaptive filter
D is the filter coefficient
q_k. is quantized & delayed version of x_k.

After the training period, the rectification process can be performed in decision-directed manner. In this method it can be assumed that the decisions in the output take place most of the time, and the output decisions can be used as reference signal. In the decisions directed mode, the error signal is defined as:

$\mathrm{e_k}=\mathrm{z_k}-\mathrm{q_k} \ldots\ldots(11)$

Where z_k is the input sequence of Decision directed adaptive filter,
and q_k. is quantized & delayed version of x_k.
The mean square error (MSE) for the filter in the *n*th time instants is defined as:

$$\mathrm{MSE_k}=\mathrm{E}|\mathrm{e_k}|^2 \ldots\ldots\ldots(12)$$

According to MSE we optimize the adaptive filter coefficient and minimize the error.

IV.AN ADAPTIVE APPROACH

In this section we consider an adaptive technique to minimize the error (Fig.5).

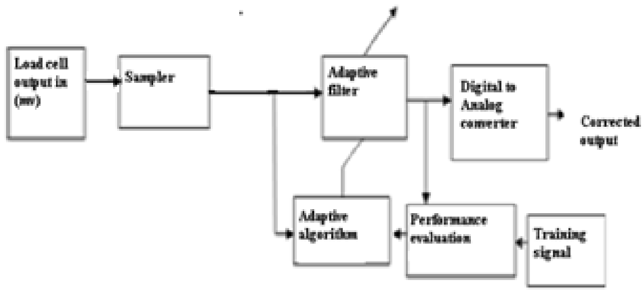

Fig.5 Adaptive correction technique of load cell output

Load cell output is sampled and the sampled output is connected to adaptive block for rectification.

$E(k)=s[k-\delta]-y[k]=s[k-\delta]-\sum_{j=0}^{n} f_j\, r[k-j]$..(13)

Where
r[k] is the sampled output from the load cell.
s[k] is the training signal for a particular load input ,
δ is the delay

$J_{LMS}=\frac{1}{2}avj\{e^2[k]\}$……………..(14)

An algorithm for minimization of J_{LMS} with respect to i_{th} filter coefficient f_i is

$f_i[k+1]=f_i[k]-\mu\frac{dJ_{LMS}}{Df_i}\Big|f_i=f_i[k]$………………(15)

μ is the step size of adaptive block.
f_i is the filter coefficient.
To create an algorithm that can be easily implemented, it is necessary to evaluate this derivative with respect to the parameter of interest. This is

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$$\frac{dJ_{LMS}}{df_i} = \frac{d}{df_i} avj\left\{\frac{1}{2}e^2[k]\right\} \approx avj\left\{\frac{\frac{1}{2de^2}}{df_i}[\mathrm{k}]\right\}$$
$$= avj\left\{e[k]\frac{de[k]}{df_i}\right\} \ldots.(16)$$

$$\frac{de[k]}{df_i} = \frac{ds[k-\delta]}{df_i} - \sum_{j=0}^{n}\frac{df_j}{df_i}r[k-j] = -r[k-i]\ldots\ldots(17)$$

Since $\frac{ds[k-\delta]}{df_i}$=0 and $\frac{df_j}{df_i}r[k-j] = 0$ or all I substituting the above equations, the update for the adaptive element is

$f_i[k+1] = f_i[k] + \mu avj\{e[k]r[k-i]\}$…………..(18)

Typically , the averaging operation is suppressed since the iteration with small step-size itself has a low pass averaging behavior. This result is commonly called the Least Mean Squares algorithm for direct linear equalizer impulse response coefficient adaptation

$f_i[k+1] = f_i[k] + \mu avj\{e[k]r[k-i]\}$……………..(19)

When all things are correct , the recursive algorithm converges to the vicinity of the block least squares answer for the particular value used in forming the delayed recovery error. As long as μ is nonzero, if the underlying composition of the received signal changes so that the error increases and the desired equalizer changes, then f_i reacts accordingly. It is this tracking ability that earns in the label is adaptive.

V. SIMULATION RESULTS

In this section load cell and Adaptive compensation filter model will be examined. Fig.6 shows load cell output for m=2kg.To illustrate the capability in tracking changes in' m'.Fig.7 shows the result when m=10kg.

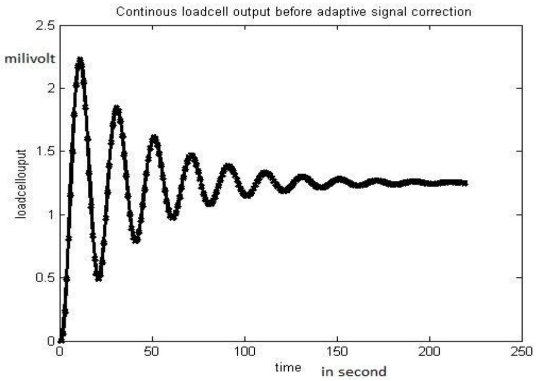

Fig.6 load cell output for m=2kg

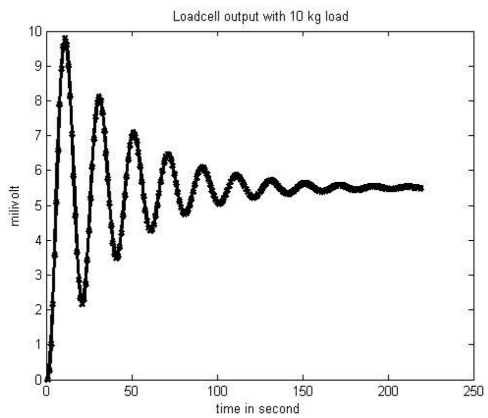

Fig.7 load cell output for m=10kg

Load cell output signal is sampled by a proper sampler. Fig.8 shows the sampled output for a 2kg weight . Fig.9 shows sampled output for 10kg weight .

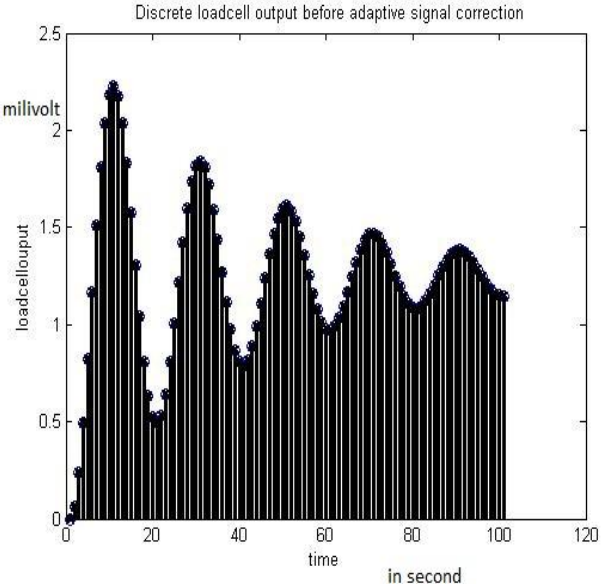

Fig.8 sampled load cell output before signal correction.

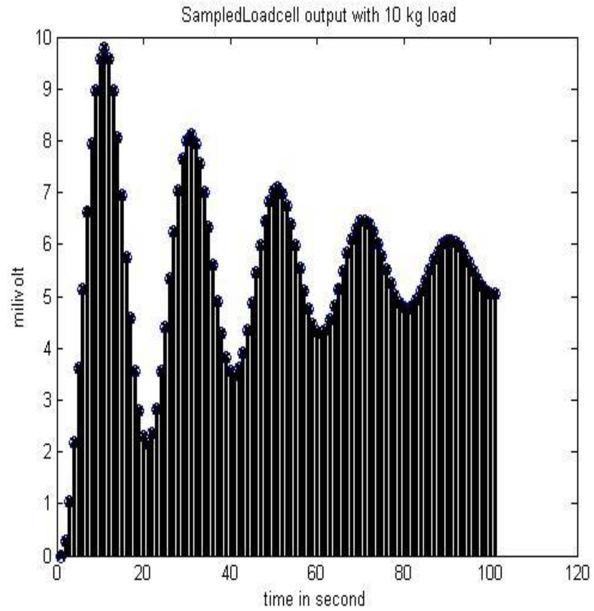

Fig .9 sampled load cell output before signal correction

Training signal :

Training signal is a signal basically generated for adaptation purpose. In this work ,we examine the output of load cell when it is subjected to a standard known weight which is a working standard as per legal metrology, Govt. of India, for a long period. Basically our target is the generation of steady state signal of the load cell output. Training signal is the step signal which is discrete in nature in this work. The amplitude of the step signal is proportional to the applied load. So we may call training signal as the delayed version of load cell output. Fig. 8

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shows the training signal for a standard weight i.e. in this case is 2kg.

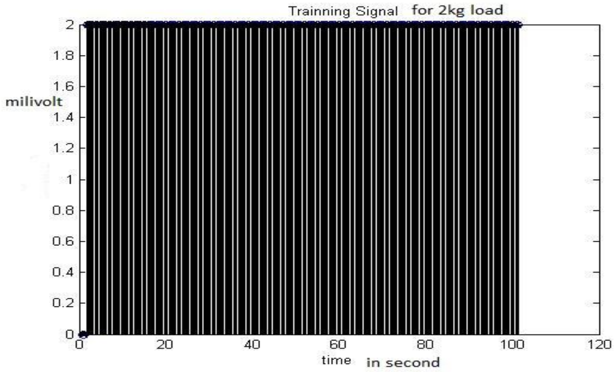

Fig. 10 shows the training signal

Adaptive filter coefficient is varied by the error signal i.e. difference between original damped load cell output and training signal.

In this work training of the adaptive filter i.e. the optimization of adaptive filter coefficient has been done during the training period. We examined the behavior of load cell with respect to various load is equal.

Here, the filter coefficient has been optimized with 2kg. load . Later, we have got the good result by the use of 10kg load. Fig9. &Fig. 10 shows that.

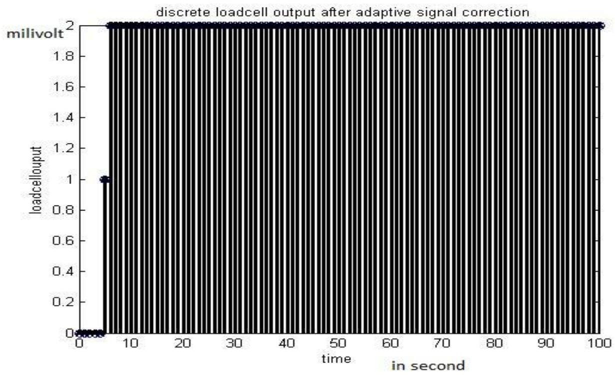

Fig.11 discrete adaptive filter output for 2kg load.

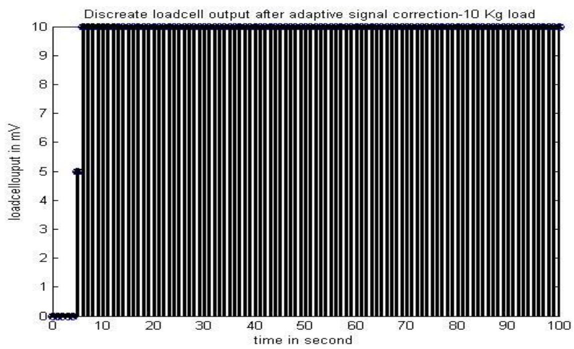

Fig.12 discrete adaptive filter output for 10kg load.

After iteration we have got the output of adaptive filter ,which shown in Fig. is discrete in nature. Now in the last step the output is converted to continuous signal with the help of a suitable converter which shown in Fig.11 & Fig.12.

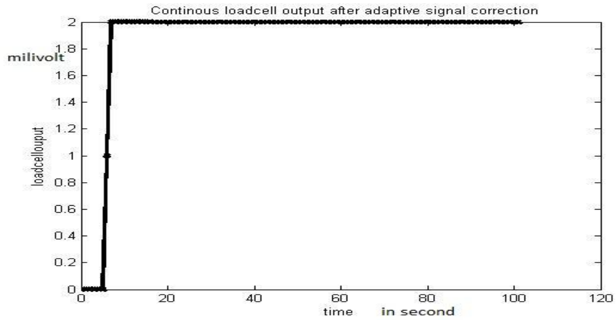

Fig.13 Final corrected output for 2kg load.

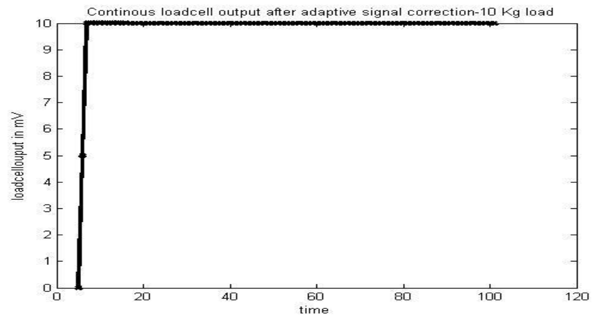

Fig.14 Final corrected output for 2kg load.

VI. CONCLUDING REMARKS

In this paper it has been shown that it is possible to perform effective response compensation of sensor output using digital adaptive technique which better may be called discrete adaptive technique. It has been demonstrated with load cell. It has been shown that how non linearity in the sensor can be compensated by adaptive technique. The feasibility of proposed technique has been shown by simulation and experimental results. The circuit development of the proposed work is in progress.

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