Dynamic weighing and dosing with Fast Intelligent Transducers FIT$^{®}$

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Abstract

We present new, weighing sensors with integrated electronics, specially optimized for dynamic weighing and dosing. There is already extensive signal processing in the transducer, with all the necessary functions for fast weight value acquisition and for full, local dosing control.

1.   Requirements

Nowadays, there are a great variety of electromechanical load cells available for static weighing. As well as electrodynamic force compensation systems, it is preferable to use load cells based on strain gage technology to convert the weight force to an electric signal. These are also suitable for high nominal (rated) loads, are extremely accurate (< 0.03%) and are economical to make. Often already equipped with integrated electronics, they deliver a digital output signal that can be quickly and easily processed in a master automation system.

Weighing processes in automation systems should not only be looked at statically. Time is critical, as there is not much time available in the overall process for weighing. The weighing process must therefore run dynamically. But the movements of the product to be weighed, the settling behavior of the scale and the vibrations from conveyors, valves or drives still cause measurement errors and reduce the level of accuracy that can be achieved.

It is only possible to achieve satisfactory accuracy and an acceptable process time for dynamic weighing if the weighing system is optimized to the dynamic conditions both mechanically and with regard to signal processing.

What is needed is extremely fast digital signal processing, which sets exacting requirements for the transmission speed between the sensor electronics and the automation system, especially when there are several weighing stations and dosing processes that have to be controlled at the same time in the filling machines. In installations of this kind, it is an advantage if the sensor electronics can locally execute both the signal processing and the control functions independently and relieve the burden on data transmission to the control computer.

2.   The dynamic behavior of a weighing system

An electromechanical load cell is loaded by weight force M·g of mass to be weighed M, the load introduction point is displaced by a distance x. The dynamic behavior of this weighing

system corresponds to a spring-mass system and a good approximation of this is described by the motion equation

$$(M + m) \cdot a(t) \; + \; b \cdot \frac{dx}{dt} \; + \; c \cdot x \; = \; (M + m) \cdot g \qquad\qquad (1)$$

a(t) is the acceleration of the mass to be weighed M, m is the tare mass of the scale, b is a material-dependent damping constant, c is the spring constant of the load cell. The electrical output signal of the load cell is proportional to displacement x.

Equation (1) is a differential equation of the second degree and describes a system capable of oscillation at the resonance frequency

$$fo \; = \; \frac{1}{2 \cdot \pi} \; \sqrt{\frac{c}{(M + m)}} \qquad\qquad (2)$$

This means that every external stimulus results in a settling action at resonance frequency fo, which dies down more or less quickly, depending on the system damping.

The resonance frequency decreases as the mass (M+m) increases, at a loading with nominal (rated) load, a scale with strain gage load cells has a resonance frequency of about 50Hz. As suppression is better for higher frequencies, it is better not to load the load cell up to the nominal (rated) load.

Equation (1) shows that it is only in the static case (a(t) = 0, dx/dt = 0) that the output signal is proportional to the applied weight M.

3. Interference effects

Under dynamic conditions, the expression (M+m) · a(t) leads primarily to measurement errors.

Dynamic conditions occur when

1. mass M on the weigher platform changes temporarily,
    i.e. when the product to be weighed is put on the weigher.

2. jolting or vibrations cause the weigher to move (a(t) ≠0).

Depositing mass M or jolting cause settling action at the resonance frequency according to equation (2), that interferes with the static measurement signal and unless additional measures are taken, causes measurement errors during formation of the weight value .

Vibrations caused by the drives or the conveyors generate oscillations (M+m) · a(t) that also interfere with the static measurement signal. Because damping is usually weak, vibrations close to the resonance frequency are particularly disturbing.

As well as mechanical interference effects, electrical faults can also interfere with the measurement signal, although these are usually at higher frequencies and suppression is therefore better.

4. Reducing dynamic interference effects

Dynamic oscillations are stimulated primarily by jolting. It is therefore advisable to do everything possible to prevent the possibility of jolting around the weighing system or at least to reduce this risk to a minimum.

Balance errors in the drives, joins in the conveyor belts or valves opening and closing should be regarded as exciters and either eliminated or isolated by a vibration-related design. It may also be necessary to look for the resonance frequencies of the entire mechanical installation. If the construction is too flexible, under certain circumstances, the entire weighing system may vibrate. Resonance frequencies of < 10Hz can then occur, the effects of which can only be eliminated if you accept long weighing times.

According to equation (1), large tare masses result in great sensitivity to vibration and should therefore be avoided.

Interference effects that cannot be avoided can be reduced by filtering if the cutoff frequency of the low-pass filter being used is lower than the disturbing frequency. With conventional low-pass filters, an adequate filtering effect is always connected with long settling times, that usually lengthen the process times by an unacceptable amount.

Far better results are achieved with digital, fast-settling FIR filters. With a suitable layout, they have a good filtering effect and at the same time, have a comparatively short settling time.

5. Fast Intelligent Transducer FIT®

5.1 Overview

With the Fast Intelligent Transducer FIT® program, platform load cells were developed specifically for use in dynamic weighing processes. Both in their mechanical construction and in the integrated electronics, they take into account the requirements for dynamic weighing, dosing and filling systems. They include fast digital signal processing with fast settling digital filters and are also able to weigh under dynamic conditions with great accuracy and short measuring times.

For use in checkweighers, there is a very effective trigger function available for event-driven weight value formation.

In addition, FIT® load cells can take over the local control functions in automation systems. With each individual FIT® load cell, it is possible to implement full dosing control, including driving coarse and fine flow valves and independent optimization of the dosing parameters.

5.2 Mechanical construction

The measuring element of FIT$^{®}$ load cells is a platform load cell specifically designed for dynamic weighing processes. It is marked by extreme stiffness, a low minimum load cell verification intervall and high overload stability. The ratio of the minimum load cell verification intervall v_{min} (OIML R60) to the nominal (rated) load is 10,000. This means that according to equation (2), it is possible to achieve high weighing system resonance frequencies, because even at a resolution of 3000 parts, the load cells only have to be loaded with a part of the nominal (rated) load ($\geq$ 30%).

FIT$^{®}$ load cells are fully enclosed in a laser-welded stainless steel enclosure (IP 66) and can also be used in aggressive environments (e.g. use of cleaning agents in the food industry).

Figure 1 shows the mechanical construction:

Figure 1: FIT$^{®}$ load cell

Figure 2 shows variant PW 18i with connectors (IP 67), that is not enclosed in stainless steel. It includes all the FIT functions, but is more economical to buy and takes up less space and is an alternative, if a high level of corrosion resistance is not required.

Figure 2:   PW 18i load cell

All FIT® load cells are designed as platform load cells with an adjusted eccentric loading error according to OIML R76 and are available at nominal (rated) loads 5kg, 10kg, 20kg, 50kg and 75kg. The permissible size of the weighing platform is 400mm x 400mm or 600mm x 500mm at nominal (rated) loads $\geq$ 50kg.

5.3   Signal processing

Figure 3 shows the block diagram for the integrated electronics:
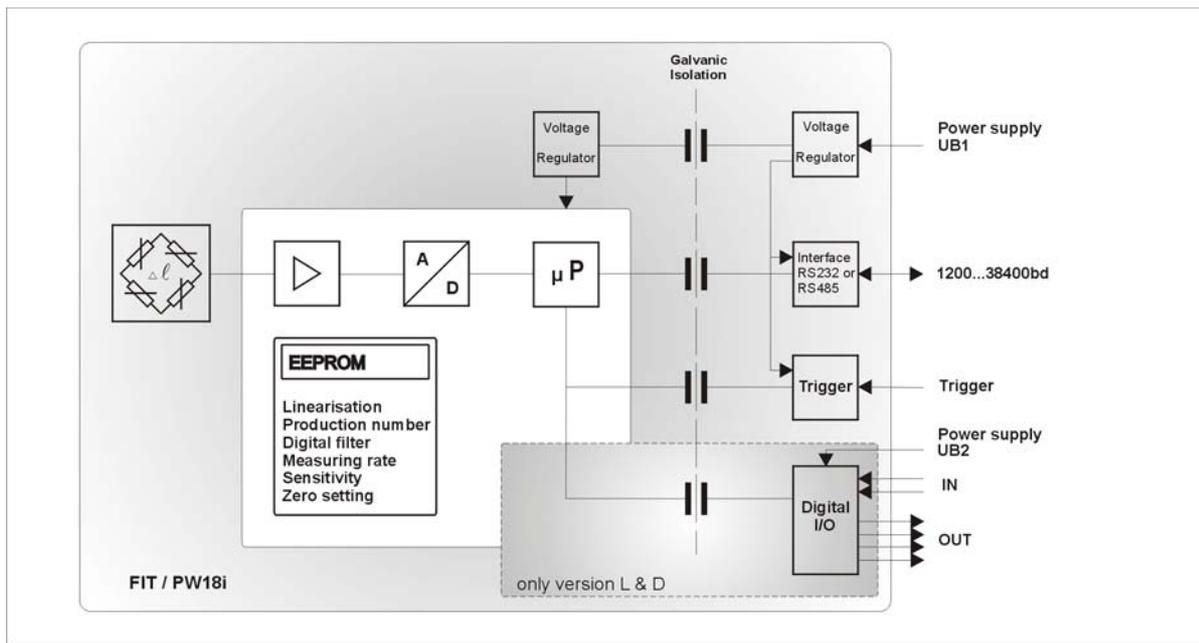

Figure 3:   Block diagram of the FIT® load cell

The analog measurement signal of the strain gage bridge circuit is first amplified and then converted to a digital value in the analog-to-digital converter. All further signal processing is performed by a microprocessor that outputs the filtered and scaled measurement signal via a serial interface at a high measuring rate of up to 600 measurements per second.

Configurable inputs and outputs are available to implement the control functions. To largely exclude electrical interference effects during use in industrial automation systems, both the digital outputs and the power supply, serial interface and trigger input assemblies are galvanically isolated from the measurement electronics.

All the parameters are set via the serial interface and stored power fail safe in an EEPROM.

The important components for dynamic weighing are the adjustable digital filters, the measuring rate setting and the trigger function.

The digital filters are configurable both as IIR filters and as FIR filters, the cutoff frequencies are adjustable via parameters. FIR filters have short settling times and high suppression in the stop band and can be optimally adjusted for fast weighing.

The trigger function can be used to trigger event-driven weight value formation. The event can be an external signal (photoelectric barrier) or an internal level overflow. Integrated measured value formation is always only started after an adjustable off period and this allows the settling action to be effectively blanked out. As this function is integrated in the signal processing, it is no longer necessary in checkweigher applications for example, to have the weight determination monitored by an external computer at a high measuring speed.

Additional signal processing components are factory calibration of the characteristics, the linearization function and scaling of user-defined characteristics.

For the serial interface, the option is between the RS232 or RS485 4-wire interfaces, available with transmission speeds of up to 38,400 baud. With the RS485 interface, bus operation is possible with up to 90 bus nodes.

With the supplied PC software, the user is not only able to set the parameters, he can also run economical analyses of the mechanical system. He can also use the graphics function to display the time characteristic of the dynamic weighing signal and optimize the dosing characteristic. The integrated Fourier analysis allows resonance frequencies to be looked for in the mechanical construction and assessments to be made of the effectiveness of the various filters.

6. Applications in filling and dosing systems

Filling and dosing controls usually set exacting requirements for the transmission speed of the communication paths between the control computer and the sensor electronics, especially if a number of filling stations have to monitored and controlled at the same time.

With the integrated dosing control function of the FIT® load cell, filling or dosing stations can be operated locally and independently of a central control computer, there is no longer any need to invest in fast, expensive data communication.

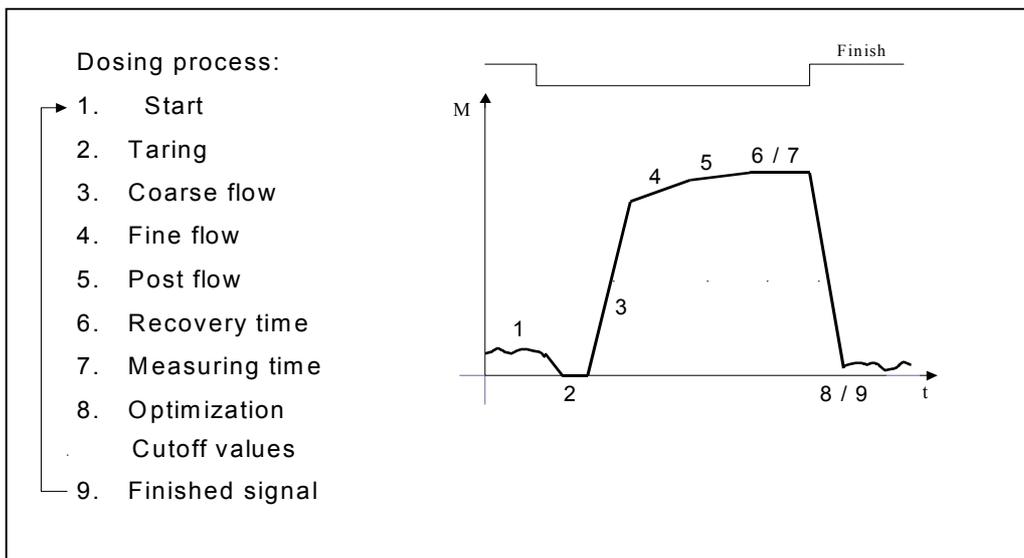Figure 4 shows a typical sequence for a dosing process with an FIT® load cell:

Figure 4:   Dosing process

The dosing process starts with taring and then the coarse and fine flow valves are opened. The filling weight is permanently monitored at the set measuring rate. Once the adjustable coarse cutoff value has been reached, the coarse flow valve closes, the fine flow valve closes after the fine flow cutoff value is reached. After an adjustable post flow and recovery time, checkweighing takes place.

If the optimization function is activated, after checkweighing, the cutoff values for coarse flow and fine flow are corrected.

Figure 5:   Using FIT load cells in a filling machine (KRONES AG)

As a typical application, Figure 5 shows FIT$^{®}$ load cells in a filling machine for soybean oil. 77 FIT$^{®}$ load cells were installed, the filling time for 800g is 3-4 seconds.

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