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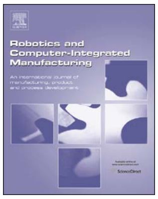

An Intelligent, multi-transducer signal conditioning design for manufacturing applications

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ABSTRACT

This paper describes a flexible, intelligent, high bandwidth, signal conditioning reference design and implementation, which is suitable for a wide range of force and displacement transducers in manufacturing applications. The flexibility inherent in the design has allowed more than 10 specialised transducer conditioning boards to be replaced by this single design, in a range of bespoke mechanical test equipment manufactured by the authors. The board is able to automatically reconfigure itself for a wide range of transducers and calibrate and balance the transducer. The range of transducers includes LVDT, AC/DC strain gauge and inductive bridges, and a range of standard industrial voltage current interface transducers. Further, with a minor low-cost addition to the transducer connector, the board is able to recognise the type of transducer, reconfigure itself and store the calibration data within the transducer, thereafter allowing a plug-and-play operation as transducers are changed. The paper provides an example of the operation in typical manufacturing test application and illustrates the stability and noise performance of the design.

1. Introduction

The advantages of smart or intelligent sensors have long been recognised in a wide range of applications (e.g. [1–3,5–7]). Amongst the potential advantages, intelligent sensors can provide measurements with higher signal to noise ratios (since the signal conditioning can be located close to or within the transducer) and they can be made to automatically adapt to a particular transducer's characteristics, allowing balancing or calibration to take place at the transducer. In doing so, intelligent sensors can reduce the complexity and cost of the overall system (see [3] for an extensive list of their perceived advantages).

However, the majority of the intelligent sensors include signal conditioning circuitry which is specific to a single type of transducer. Also with the notable exception of the approach taken in [4], far less attention has been paid to the design of flexible conditioning circuitry which could interface to a wide range of industrial transducers.

This paper describes a single reference design and board intended to address the practical needs of flexible signal conditioning for a wide range of transducers common to industrial measurement applications.

The structure of the paper is as follows. Section 2 briefly describes the operating requirements of two applications, in order to illustrate the flexibility of the design in a manufacturing context. Section 3 provides an overview of the principal features of the design. Section 4 then describes the structure of the design in detail, with respect to the applications given in Section 2. The paper concludes with a brief overview of the application of the design in practice.

2. Application areas

Phoenix manufacture bespoke test equipment to evaluate the mechanical properties of a wide range of products and materials. The following test applications are described to illustrate the requirements made of the design.

One of the most typical cases for moderately fast Phoenix test systems are compaction simulators used in the pharmaceutical industry (see Fig. 1). Compaction simulators evaluate the effect of different force/displacement profiles, on the compaction of powders in the production of tablets. These generally have maximum actuator velocities between 1.5 and 3 m/s and a data acquisition period being no less than 100 ms in duration. The test performed by these machines typically consists of a force/displacement profile made of 4096 points independently of the test's duration.

For a test duration of 100 ms, it would follow that the equivalent data acquisition rate would be close to 40 kHz. However, the limited bandwidth of the loading frame restricts the useful bandwidth of the signal to 20 kHz. Simple compaction simulators use strain gauge load

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Fig. 1. Compaction simulator.

cells for force measurement and linear variable differential transformers (LVDTs) for the displacement measurement, using a typical excitation frequency of 5 kHz and a 2-pole anti-aliasing filter with a roll-off at 250 Hz. In order that the load measurement channel should have a similar frequency response to that of the displacement, a matching filter is often fitted to the load amplifiers. In such a case there is a considerable loss of high frequency detail in the acquired signal. The compaction simulators developed by Phoenix improve upon this by using magnetostrictive or inductive displacement sensors which have a bandwidth of 10 kHz. Because the sensor bandwidth is higher, the displacement filtering does not need to be so severe, and so the filtering of the load channel can be reduced to match. This enables the fine detail to be retained in the acquired signal. However, whilst strain-gauged load cells are applicable for such tests, they are not the best choice for very high-speed impact test measurements.

The test machines with the most demanding requirements tend to be those used for ‘single-shot’ tests. These vary widely in their performance requirements, but the essence of such a machine is that it is configured to perform a single high-speed impact test. Typical applications are the testing of material properties during forging, ballistics, and crash conditions in automotive applications. For such tests the emphasis is upon the control of the correct actuator velocity rather than upon the need to follow a sophisticated displacement profile as is the case in a compaction simulator. In common with compaction simulators, single-shot machines require high bandwidth displacement transducers and so magnetostrictive or inductive transducer types are used for the reasons explained above.

However, a single-shot machine differs from the compaction simulator in that the bandwidth of the load measurement must be significantly wider, owing to the impulse nature of the impact. In such cases, conventional strain-gauge cells often fail to meet the bandwidth requirements and also tend to ‘ring’ when struck (often at frequencies in the hundreds to thousands of hertz). To overcome this limitation, piezoelectric cells with charge amplifiers are often employed to measure the impact forces. Since piezoelectric cells have higher bandwidths, owing to their higher stiffness, they also have a reduced ringing response. The charge-amplifiers used with such cells typically have bandwidths of up to 20 kHz, which is sufficient to characterise most impacts. However, unlike strain gauge load cells, piezoelectric load cells also exhibit significant static drift and thus the amplifier must be balanced (or 'zeroed') immediately before each test event.

The applications above illustrate the requirements of a flexible signal conditioning design, since for these two applications alone the signal conditioning is required to contend with a range of transducers (in these cases LVDT, magnetostrictive, inductive, strain gauge and piezoelectric with charge amplifier), two different forms of balancing requirement, three different forms of excitation and two bandwidth requirements. The following section provides an overview of the features of the design and, in addition, illustrates how the design fulfils the requirements described above. Section 4 provides a detailed description of the architecture of the design.

3. Features of the design

Fig. 2 illustrates where, in a larger system diagram, the signal conditioning design would operate. It can be seen in Fig. 2 that each design can serve up to a maximum of two transducers and that the conditioned analogue signal is available as an output from the board. Thus by combining the board with alternative analogue to digital converters (ADCs) of differing specification, a range of bespoke modules can be created, further increasing the flexibility of the design. In addition, the board has limited built-in self-test and self-diagnosis and can communicate the results over the bus or via a local USB connection to the wider system or to a maintenance engineer.

The design is able to automatically reconfigure itself for a wide range of transducers and then calibrate and balance the transducer in question. The range of transducers that the design can work with includes (but is not limited to) LVDT [3,4] (both single-sided and complementary excitation), AC/DC strain gauge (including pressure transducers, extensometers) potentiometric displacement transducers (both linear and rotary) and inductive bridges (both full and half bridges). The board can interface to a range of standard industrial voltages (e.g. 0 to 5VDC, 0 to 10VDC, −10 to +10VDC, un-scaled DC outputs) and current-source transducers (both 4–20 mA and 0–20 mA). To allow the automatic balancing of the transducers which require external excitation (e.g. LVDTs), the design can also be configured to provide a range of excitation/supply voltages for the transducer (e.g. 5 or 10 kHz 1–5 V RMS AC single-sided or complementary, 5 or 10 V DC single sided or complementary 5 V DC supply, 24 V DC supply, ± 15 V DC supply) for transducers.

The design described here differs from previous designs [4,8–10] in that its architecture is based around a single analogue signal path under the control of a microcontroller. In order to achieve the accuracy requirement for such applications, the board uses a novel two stage Vernier-like gain stage within the analogue signal path. This approach provides a higher bandwidth path and lower noise levels than typically found in monolithic switched-capacitor designs. The higher bandwidth admits the possibility of transient measurement (i.e. impact testing), not typically found in previous designs.

The microcontroller can be configured externally, via the bus or USB connection. It can also configure itself automatically based upon the transducer attached. With the minor low-cost addition of a 1-wire