DIGITALIZATION OF INTERNAL WIND TUNNEL BALANCES

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Abstract

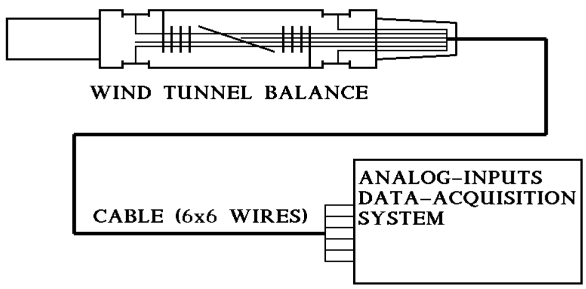
A current research and development project in VTI is aimed at producing multi-component strain-gauge wind tunnel balances with serial digital outputs, instead of the commonly used analog outputs from the strain gauge bridges on the balance. The "digitized" balances should provide better immunity to electrical noise and a complete separation of the calibration characteristics of the balance from the characteristics of the wind tunnel data acquisition system. Two design variants are being pursued and the components are currently being individually tested. The tests will continue with the characterization of the completed balances in a thermal chamber and a calibration of the balances followed by wind tunnel tests of standard models. The project follows the trend of "digitalization" of various kinds of transducers used in wind tunnel testing, and suggests that a change of the paradigm of a wind-tunnel data-acquisition system seems to be pending, the large number of high-accuracy analog-input channels being more and more replaced by different digital interfaces to intelligent sensors.

1 Introduction

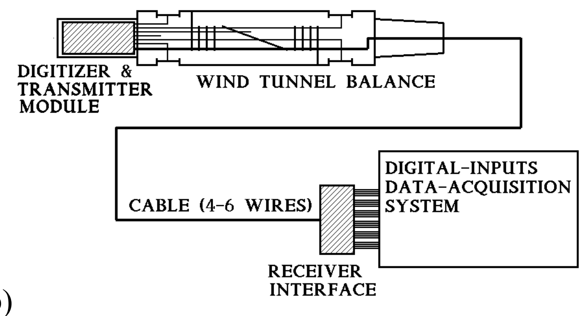
Internal wind tunnel balances are multi-component force sensors that are used to measure aerodynamic loads on test objects in wind tunnels [1][2]. Measurement is commonly achieved by acquiring and processing the signals from strain-gauge bridges installed on the balance and sensing the minute elastic deformations of specially shaped parts of the balance subjected to load. The balances usually measure six components of load which are resolved, in the data processing, into three orthogonal components of force and three components of moments.

Typical internal wind tunnel balances exhibit accuracy between 0.05% and 0.1%FS for each measured load component. However, in order to fully utilize such accuracy a balance must be connected to a high-quality data-acquisition (DAQ) system with stable bridge excitation and with amplifier/digitizer accuracy of about 0.02% to 0.05%FS. Additionally, measurement may be complicated by the measurement uncertainty of the DAQ system itself, by the thermal drifts of the strain-gauge bridges, by the thermoelectric effects in the cables and connectors and by the noise picked-up by the (sometimes tens of meters long) cabling from the balance to the DAQ system. Moreover, the cable for connecting an internal wind tunnel balance to a DAQ system usually has 6 to 8 conductors (wires) per strain-gauge bridge, i.e. for a six-component balance, a total of about 36-48 relatively thin and fragile wires which are difficult to connect and test and can be easily damaged during the installation and operation.

On the other hand, a trend has been present for some time of introducing "smart" sensors which contain microcontrollers and produce output in a digital format, typically in a serial form. Typical examples of such sensors are high-accuracy digital-output pressure transducers which have been commercially available for some years. However, wind tunnel balances, which are not mass-produced standardized items but highly "personalized" instruments, have not hitherto been included in this trend. Yet, a capability to use internal wind tunnel balances with digital outputs would bring a number of benefits. Instead of 36 conductors, the electrical connection of a wind tunnel balance with digital output would comprise just 4-6 conductors which would be much easier to route through the model support of a wind tunnel. Besides, the possibility of picking up the noise and thermoelectric effects in the long cables would be eliminated. Contrary to a classical six-component strain-gauges wind tunnel balance, a digital-output balance would not be connected to the analog-inputs part of the DAQ system but directly to the digital part of the system, completely bypassing the analog part as the source of additional uncertainty. A digitizing and encoding electronic module would be located in the balance itself (Fig. 1).



a)



b)

Fig. 1. Concept of a classical six-component internal wind tunnel balance connected to analog input channels on a DAQ system (a) and of a digital-output balance with integrated digitizer/transmitter electronic module, conne-cted to the digital part of a DAQ system (b)

2 The Idea of a Digital Wind Tunnel Balance

About 20 years ago, Military technical institute (VTI - Vojnotehnički institut) in Beograd, Serbia, in cooperation with the Mihajlo Pupin Institute (IMP), Beograd, produced a pair of rotary shaft balances for measurement of forces and moments on the propellers of a wind tunnel model. The balances comprised miniature 46 mm dia. 4-channel 12-bit data-acquisition modules [3] (Fig. 2) located in the propeller hubs (Fig. 3). Wireless serial data transmission to the stationary part of the model was performed optically, using LEDs on the rotating part and a circular array of photodiodes on the rotating part in a kind of "optical slip-ring" arrangement. Although the project was only partially successful, mostly because of the problems related to providing reliable battery power for the digitizing modules in the rotating propellers, it was noted that the modules themselves actually performed quite well.

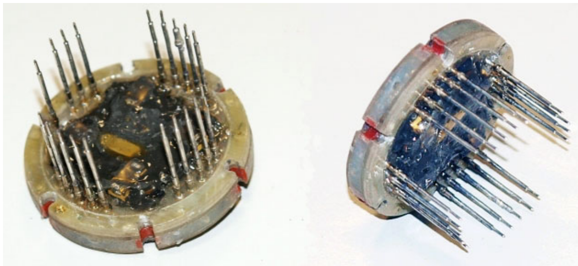


Fig. 2. Two IMP-built 46 mm dia., 4-channel integrated digitizing modules for the propeller rotary shaft balances built in VTI, with optical serial data transmission

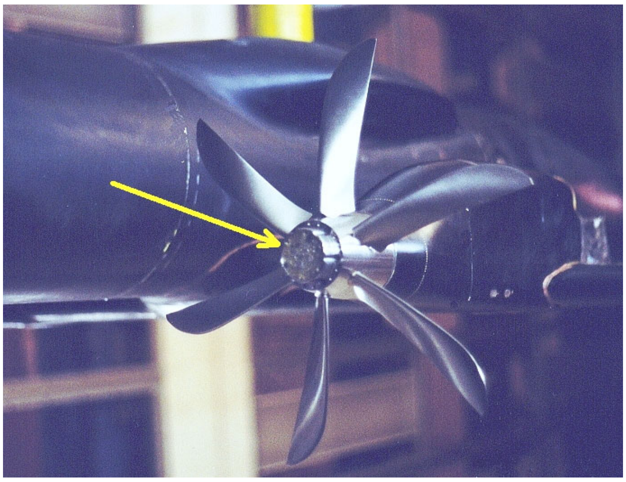


Fig. 3. Placement of the digitizing module of a rotary shaft balance in the propeller hub on a wind tunnel model

The trend of digitalization of wind tunnel instrumentation was continued with the application of 0.01%FS-accurate digital-output pressure transducers in the primary measurement systems of the T-38 wind tunnel in VTI [4], which reduced the uncertainty of measurement of flow parameters in the wind tunnel test section by almost an order of magnitude.

Electronic components were used again in a wind tunnel balance in VTI in a successful recent project of an experimental high-stiffness balance in which the output from a strain gauge bridge on a very rigid “flexure” for the measurement of axial force was amplified from 0.3 mV FS to 15 mV FS using a miniature zero-drift amplifier on the balance (Fig. 4). The amplifier is transparent to the user who can use the balance just as if it was instrumented with standard strain-gauge bridges.

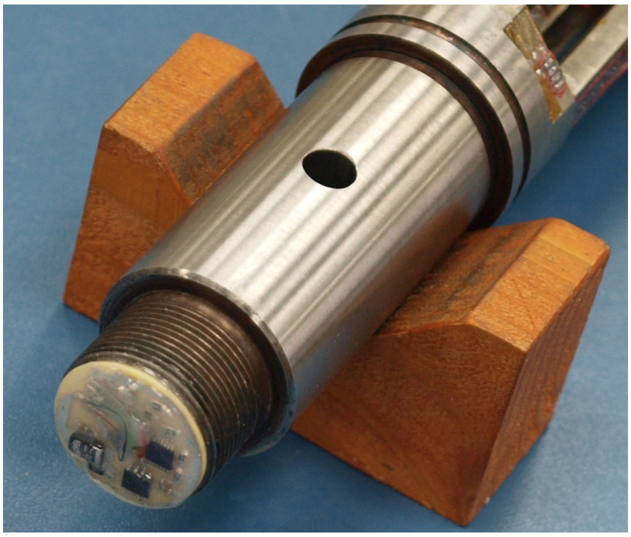


Fig. 4. A miniature, 50× gain, zero-drift, differential-output amplifier and its excitation-voltage regulator installed on the front face of a 44 mm wind tunnel balance

On the basis of these developments, a project was started in VTI of producing and evaluating monolithic internal wind tunnel balances with integrated electronic modules which will perform local A/D conversion of output signals from the strain-gauge bridges and create multiplexed serial digital output. The intention is to attempt to create instruments which will elevate the quality of measurements of forces and moments in wind tunnel tests in VTI, produce instruments less susceptible to electric noise and separate the calibration characteristics of the balances from those of the wind tunnel data acquisition system(s). Similar solutions are still rare, the only known example being the design [5] from CARDC, China..

3 The Development

Two wind tunnel balances with digital outputs are being developed and evaluated. In the first design, six commercially available 20 mm dia. puck-shaped A/D conversion modules (Fig. 5, [6]) are being added to an existing 38 mm, 3 kN six-component monolithic wind tunnel balance produced in VTI (Fig. 6). The modules are stacked six-high (Fig. 7) in a 22 mm dia. × 35 mm cylindrical housing attached to the rear face of the balance-sting taper interface (a suitable sting support exists with a cavity permitting such attachment). The digitizing modules, which provide ratiometric 24-bit A/D conversion, are cheap, easy to implement and very compact but use a query/response communication protocol through a RS-485 line with a large overhead and are limited, if acceptable resolution and accuracy is desired, to less than 100 samples/second/channel, which may not be sufficient in some applications.

Fig. 5. Commercially available 20 mm dia. single-channel 24-bit digitizing and data transmitting module [6]

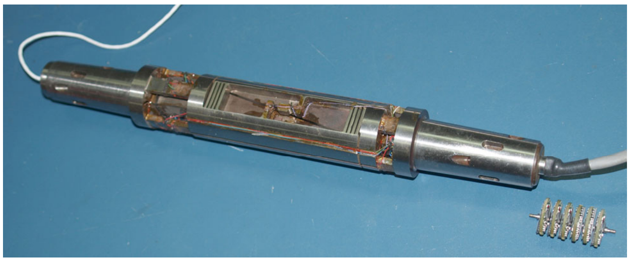


Fig. 6. 38 mm six-component monolithic wind tunnel balance to which a stack of six digitizing modules (lower right corner) is being added. The existing analog cable will be removed and the digitizing block added to the end of the balance-sting taper interface

Fig. 7. Stack of six digitizing / data transmitting modules to be installed on a 38 mm 3 kN wind tunnel balance. A single RS-485-compatible serial line will connect the balance to the data acquisition system.

In the second design, an 8-channel, custom-built conversion module with 18-bit A/D convertors and a PIC-based controller is used. The design features a preamplifier and an A/D convertor for each channel (Fig. 8). Conversion is ratiometric, relative to the bridge excitation voltage.

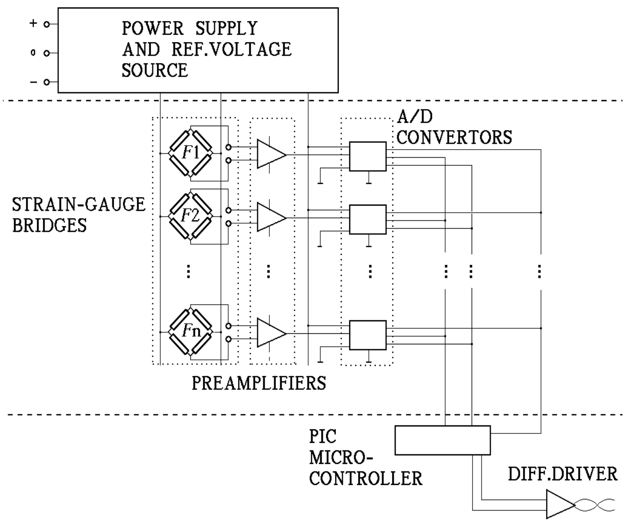


Fig. 8. Conceptual schematics of the PIC-controlled 8-channels 18-bit digitizing module

The A/D convertors are controlled by a PIC microcontroller, using the SPI interface. All A/D convertors are sampled simultaneously and there is no time skew between samples acquired on different channels. Also, there is no multiplexing of analog signals. Instead, digitized data are multiplexed and sent to the DAQ system in a continuous streaming serial mode through a differential line driver. Several data formats will be tried during the testing, including a Manchester-encoding-based stream and a more-conventional RS-485-compatible byte stream. Variations of data formats will be accomplished by re-programming of the PIC microcontroller.

Target sampling rate is above 1000 samples/second/channel (transfer rate about 140 kbit/s), i.e. it is an order of magnitude higher than with the first balance, which should make digital-output balances suitable for dynamic measurements [7] as well, but at the cost of an in-house design and build of the relatively complex electronic module.

The components of the digitizing module are distributed on 3 printed-circuit boards (Fig. 9) that fit into a 30 mm dia. × 80 mm metal housing to be placed in a suitable cavity in the front end of a specially designed 45 mm monolithic wind tunnel balance, inside the cylindrical balance-model interface (Fig. 10).

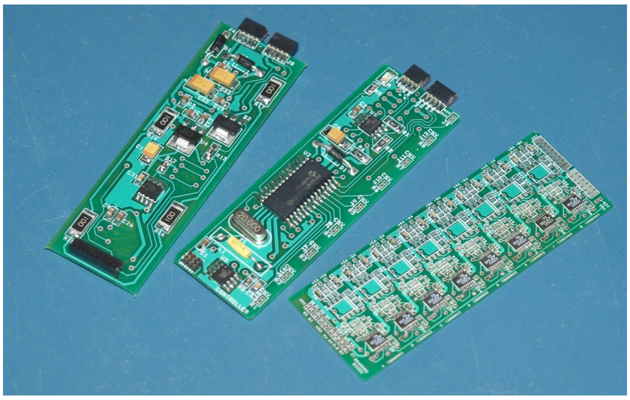


Fig. 9. Partially assembled printed-circuit boards of the digitizing module

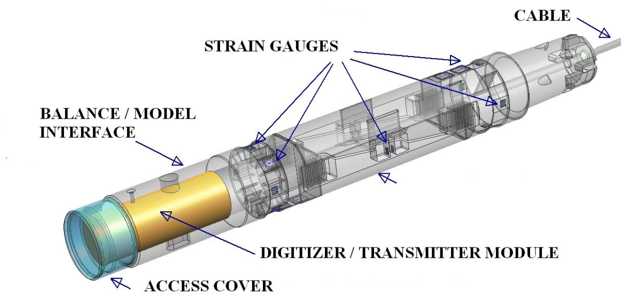


Fig. 10. Placement of the digitizing electronic module inside the balance-model interface of a 45 mm, 5 kN six-component wind tunnel balance

4 Interfacing to a DAQ system

Typical wind tunnel DAQ systems, including the ones used in VTI, do not have suitable provisions to receive serial data from a digital balance. Therefore, a special interface is being produced, based on the similar custom-built interfaces already in use in VTI [4] for integrating the serial-digital-output pressure transducers with the wind tunnel data acquisition system(s). The interface comprises a power supply for the balance, a differential receiver and a PIC microcontroller (Fig. 11). The microcontroller converts the serial data stream from the balance into 16-bit wide parallel-data words which are read by the DAQ system. In order to reduce complexity and the number of outputs, there is *only one* 16-bit-wide output to the DAQ system, although the experimental digital balances will measure six components of loads and two temperatures. The advantage is taken of the multiple-sampling-rates capability of the DAQ systems and of the fact that the DAQ systems produce a "strobe" or "clock" pulse every time when an input is sampled. The strobe pulse is used to multiplex the data from 8 measurement channels in the balance to the single 16-bit digital input channel of the DAQ system, which is read 8 times in a scan list. With a suitable configuration of the software controlling the acquisition, this setup can appear to the user as 8 independently read input channels, same as if the data were read from a "classical" analog balance.

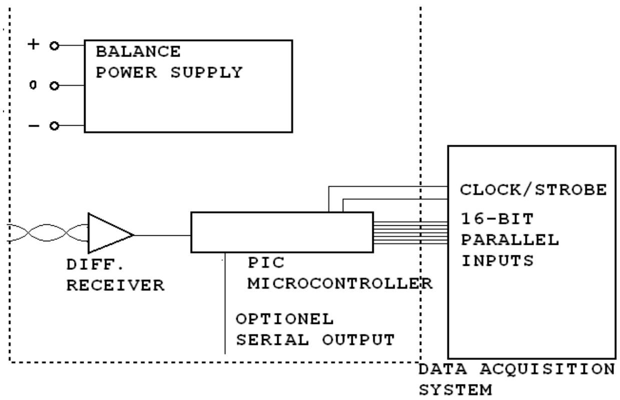


Fig. 11. Conceptual schematics of the receiver module with the interface to a data-acquisition system

5 Verification of the designs

The evaluation of the designs will consist of the initial calibration of the balances *without* the digitizing modules (work is in progress), in order to characterize the strain-gauge bridges and the bodies of the balances, followed by the calibration of the balances *with* the digitizing modules installed and connected. Besides, the balances are to be characterized in the thermal chamber both with and without the digitizing modules. A choice will be made of the solution more suitable for further developments. Final evaluation of at least one of the balances is to be performed by its use in a wind tunnel test of a standard model [8]. However, the schedule of this test may depend on wind tunnel availability.

6 Further investigations

Complete verification of the concept of a wind tunnel balance with digital outputs can be achieved only after an extended period of use. Certain points are worth considering, e.g:

• Long-term stability of a wind tunnel balance with a built-in digitizing module has yet to be determined. While the calibration of a strain-gage balance and strain-gage bridges in general is known to be stable over many years [9][10], it is customary to calibrate most electronic measuring devices at one-year intervals. However, with advanced balance-calibration methods [11]-[13], a possible need for periodic recalibration of a balance is not considered to present a serious drawback.

• Sensitivity of the electronic modules in the balance to harsh conditions in the test section of a high-pressure blowdown wind tunnel such as the T-38 testing facility [14] of VTI has yet to be determined.

• Repairs of a digital balance can be complicated if the electronic module in it is not designed to be removable, because the semiconductor electronic components can not withstand the temperatures needed for the curing of adhesives used for strain gages.

• Classical "analog" balance, being essentially a simple, passive device with all components cemented to the body of the balance, is more robust than a design with an electronic module.

7 Change of the DAQ-system paradigm

For years, a typical wind tunnel data acquisition system comprised a number of high-accuracy analog input channels, often with programmable gains, filters and sensor excitations. Sometimes an additional, separate, analog-inputs module was provided for measurements requiring very high sampling rates.

On the other hand, the number of digital inputs read synchronously with the analog inputs was relatively low, the sensors of this type being usually restricted to several absolute or incremental encoders. Digital inputs were typically of the 16-bit or 32-bit-wide parallel type. Another use of digital inputs was to record various “events” during a wind tunnel run.

With the advance of sensor technology, however, a number of “smart” transducers featuring integral microprocessors and digital outputs became available in the recent years. Contrary to the parallel type of typical digital inputs usually available on the data acquisition systems, the new transducers typically feature serial outputs in the SSI, SPI, CAN, RS-485 or other formats. A typical example of such transducers are the high-accuracy (0.01%FS) pressure sensors [15][16] with RS-485 outputs, suitable for application in the measurement of the flow parameters in the test section of a wind tunnel. More than 10 such transducers are currently used in the standard transducer setup in the T-38 wind tunnel of VTI, replacing he previously used analog-output pressure transducers. Another example are the absolute-position encoders [17] with SSI outputs (a serial output interface and data format), applicable to measurement of model-support position.

Therefore, the number of serial-digital-input channels in a wind tunnel data acquisition is likely to significantly increase in the near future, while the requirements for analog inputs can be expected to decrease, practically changing the paradigm of a wind tunnel data acquisition system as a measurement device with a large number of high-accuracy analog inputs. Yet, the data acquisition systems currently available on the market seem to be lacking in the choice of provisions for different formats of digital inputs, particularly if synchronicity between the data acquired on the analog and digital inputs has to be ensured (i.e. if the analog inputs and the serial digital inputs are to be “in the same scan list”). This problem has been solved n VTI by using a number of custom-built microcontroller-based serial-to-parallel convertors translating the serial data coming from the various digital-output transducers into 16-bit-wide parallel digital inputs on the wind tunnel data acquisition systems. However, a more systematic solution would be preferable.

8 Conclusions

A current research and development project in VTI is aimed at producing two designs of monolithic internal wind tunnel balances with integrated electronic modules that will provide multiplexed serial digital output instead of independent analog outputs from strain gauge bridges. Assembly of the components is in progress, and will be followed by a number of tests. It is expected that digital outputs will provide certain benefits in the exploitation of the balances in wind tunnel tests, the most important being a better immunity to noise, and the separation of the calibration characteristics of the balances from those of the DAQ system.

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