Keysight Technologies
Strain-Measurement Application Using U2300A Series Data Acquisition Devices with VEE Pro

Application Note

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Introduction

This application note is designed for users who wish to test the strength and reliability of concrete and metal structures using the Keysight Technologies, Inc. U2300A Series USB multifunction data acquisition (DAQ) devices. Users can measure both dynamic (vibration) and static (strain) measurements of a structure using the Keysight USB multifunction DAQ solution.

The U2300A Series USB DAQ devices provide fast and accurate measurement of up to a 3 MS/s sampling rate for a single channel and offers resolution of 12 bits to 16 bits. The U2300A Series family consists of seven modules that are ideal for design-validation and manufacturing engineers who conduct data logging, measurement, or monitoring in a broad range of industries.

The U2300A Series can function as standalone or modular devices that use the standard Hi-Speed USB 2.0 interface, which offers ease of connectivity and portability. The U2300A Series is compatible with a wide range of Application Development Environments such as Keysight VEE Pro, NI LabVIEW, and Microsoft Visual Studio.

Keysight U2300A Series USB Multifunction DAQ devices will be the right fit for strain gage measurement. Combined with a third-party component as the bridge-completion module and an amplifier for signal conditioning, it completes Keysight's strain-gage measurement solution. Keysight's solution allows users to measure using a combination of strain gages and piezo sensors on 64 channels. This enables users to make more varied and reliable measurements and allows cross verification of the vibration and strain gage test.
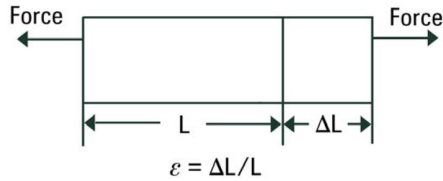
Strain Overview

Strain

Strain is the amount of deformation of an object due to applied force. When external forces are applied to a stationary object, stress and strain result.

Strain (ε) is defined as the fractional change in length, as illustrated in Figure 1.

The equation of strain is $\varepsilon = \Delta L / L$, as shown in Figure 1 and it is observed that strain is a ratio, thus making the value dimensionless.

Strain gage

A strain gage is a device used to measure deformation of an object. Strain gages are designed to convert mechanical motion into an electronic signal.

Strain measurement

Strain measurements rarely involve quantities larger than a few milistrain. Therefore, accurate measurement of very small changes in resistance is required to measure the strain. Strain gages are almost always used in a bridge configuration with a voltage excitation source in order to measure small changes in resistance.

Strain gage transducers usually employ four strain-gage elements electrically connected to form a Wheatstone bridge circuit.

A Wheatstone bridge circuit, as shown below, consists of four resistance arms with a voltage, V_{IN}, that is applied across the bridge.

As illustrated in Figure 2, if voltage, V_{IN} is applied between points A and C, then the output between points B and D will show no potential difference if R_1, R_2, R_3 and Rg are equal. The bridge is considered balanced when $R_1/R_2 = Rg/R_3$, the voltage output V_{OUT} will be zero.

However, the bridge will become unbalanced and a voltage will exist at the output terminal if Rg changed to a Figure 2. Wheatstone bridge circuit value other than R_3.

Figure 1. Definition of strain
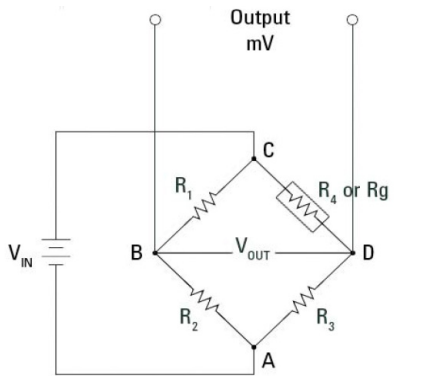
$$V_{OUT} = V_{IN} [\{ R_3 / (R_3 + Rg) \} - \{ R_2 / (R_1 + R_2) \}]$$

Figure 2. Wheatstone bridge circuit diagram and the voltage output formula

The nature of this Wheatstone bridge circuit makes it suitable for the detection of strain. The gage factor (GF) is related to the change in Rg as follows:

Strain, $\varepsilon = (\Delta Rg / Rg) / GF$

Strain gages occupy one, two, or four of the arms. One strain gage in the Wheatstone bridge is a quarter bridge, followed by half or full bridges. The number of active strain gages that should be connected to the bridge depends on the application.

For example, to effectively double the bridge output for the same strain, it may be useful to connect gages that are on opposite sides, one in compression and the other in tension.

Usually two gages are wired in compression and two in tension in a four-element Wheatstone bridge. The output will be proportional to the sum of all the strains measured separately, if R1 and R3 are in tension (positive) and R2 and R4 are in compression (negative).

The quarter bridge has one active leg with a changing resistance. Expression for a quarter bridge for the output voltage as a function of the resistance change ΔR is:

$$V_0 = \left(\frac{R_3}{R_1 + R_3} \right) - \left(\frac{R_4}{R_2 + R_4} \right) V_i$$

$$= \left(\frac{R}{(R - \Delta R) + R} \right) - \left(\frac{R}{R + R} \right) V_i$$

$$= \left(\frac{R}{2R - \Delta R} \right) - \left(\frac{1}{2} \right) V_i$$

$$= \left(\frac{\Delta R/R}{2(2 - \Delta R/R)} \right) V_i$$
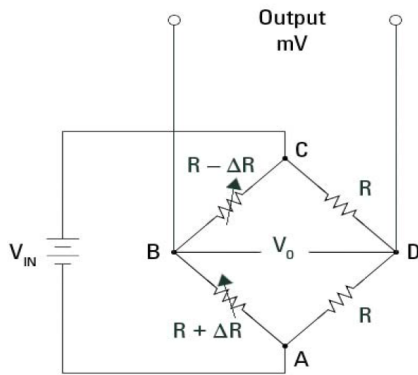
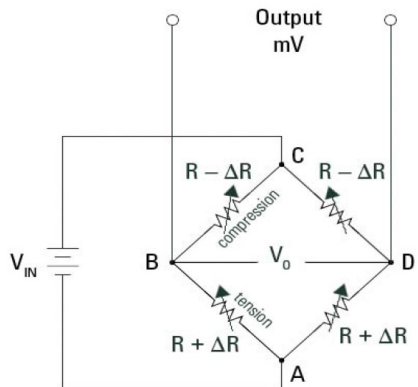$$\approx \frac{\Delta R}{4R} V_i$$

Figure 3. Half-bridge circuit diagram

Ideally, the strain gage resistance will change only in response to applied strain. However, the strain gage material responds to changes in temperature. In order to further minimize the temperature effect, two strain gages can be used in the bridge.

Making both gages active in a half-bridge configuration can double the sensitivity of the bridge to strain. As illustrated in the following half-bridge circuit diagram, Figure 3, it yields an output voltage that is linear and approximately doubles the output of the quarter-bridge circuit.

The sensitivity of the circuit can be further increased by making all four of the arms of the bridge active strain gages in a full-bridge configuration. Figure 4 illustrates the full bridge circuit:

When selecting a strain gage, the primary considerations are the operating temperature, the nature of the strain to be detected, and the stability requirements.

Figure 4. Full-bridge circuit diagram

Signal Conditioning for Strain Gage

Strain gages usually carry low-level signals. Therefore, it is imperative to have the signal amplified by accurate instrumentation before it is digitized by DAQ devices. Furthermore, low-level signals are more susceptible to noise interference. The noise interference can be suppressed by implementing such methods as low-pass filer, signal averaging, and instrumentation amplification.

The extremely low strain-gage signals can be conditioned by the instrumentation amplifiers before feeding into analog-to-digital converters (ADCs). Furthermore, the amplifier gain can be adjusted to provide the full scale output of the strain gage.

Strain Measurement Application

Below is the list of setup requirements for strain measurement. The following instruments and software are required in order to perform the measurements:

– Keysight U2356A USB Multifunction DAQ device
– Keysight VEE software
– Terminal block and SCSI-II 68-pin connector
– USB type mini-B cable
– Strain gage sensor
– Bridge Completion Module
– Amplifier

Ensure that your instrument's firmware and software are upgraded to the latest version, which is available at:

www.keysight.com/find/U2300A
www.keysight.com/find/VEE

Setting up the PC, DAQ, Sensor, and Signal Conditioner

Instructions

1. Connect the U2356A Multifunction DAQ device to a PC that is loaded with the Keysight VEE software and Keysight I/O Libraries Suites, via USB type mini-B interface cable. Refer to *Keysight U2300A USB Multifunction Data Acquisition Devices User's Guide and Keysight VEE 8.0 Online Help File* for detailed instructions on installations.
2. Connect the DAQ device to the terminal block via SCSI-II cable.
3. Connect the bridge completion module to the analog output of the terminal block for biasing purpose.
4. Attach the strain gage sensor on the beam of the bridge completion module as shown in the application block diagram below.
5. Connect the amplifier to the terminal block for piezo signal conditioning. Refer to following block diagram for more information.

Figure 5 is specifically designed for one strain-gage sensor and 63 piezoelectric sensors to go with the U2356A DAQ device. An external adapter is used to power up the amplifier and filter circuits.
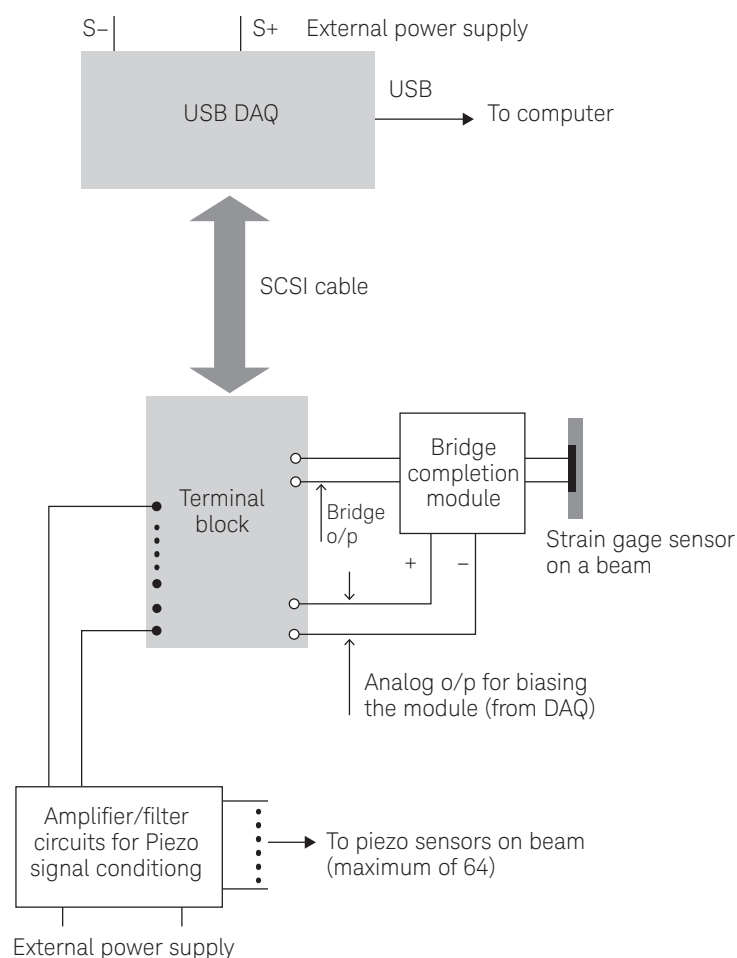
Figure 5. Strain gage measurement application setup block diagram

Setting Up Keysight VEE Pro

Once the hardware setup for strain gage measurement is complete, proceed to set up the application software to capture the acquired data. This application note uses Keysight VEE as the application software; however, users may choose to use other application software.
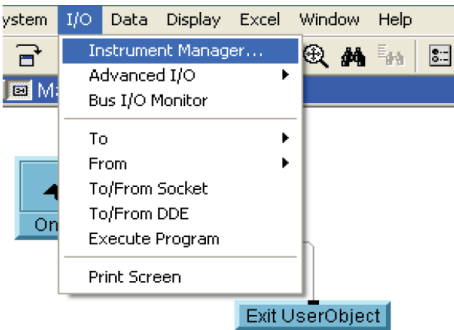

Figure 6. I/O menu of Keysight VEE Pro

Instructions

It is assumed that the PC is equipped with the Keysight IO Libraries Suite and Keysight VEE Pro 8.0.

1. Launch the **Keysight VEE Pro 8.0, go to Start > All Programs > Keysight VEE Pro 8.0 > VEE Pro 8.0**.
2. Select I/O menu on the menu bar and select Instrument Manager as shown in Figure 6. The **Instrument Manager** dialog box will appear as shown in Figure 7.
3. Click **Find Instrument** and the Instrument Manager will search for any instrument that is connected to the PC. Once it identifies es the instrument, the Identify Instrument dialog box will appear.
4. Click Yes to proceed.

The Keysight VEE pro has now established the connection with the DAQ system setup on the PC and is ready for the strain-gage measurement capturing base on the user's preferred program.
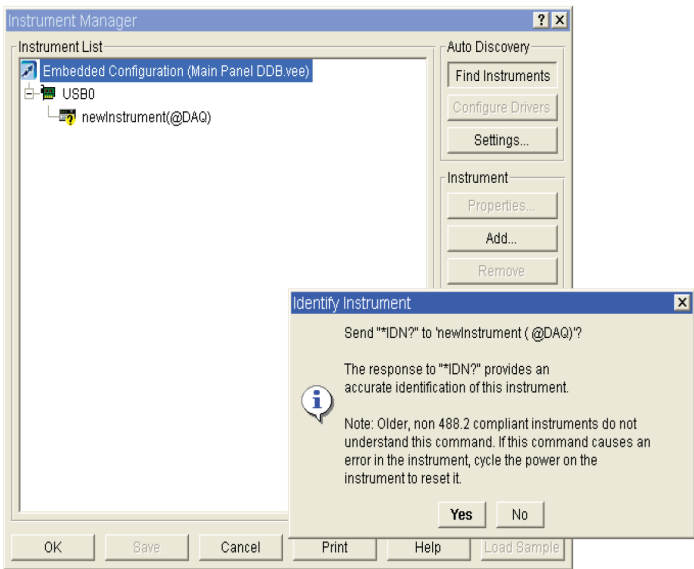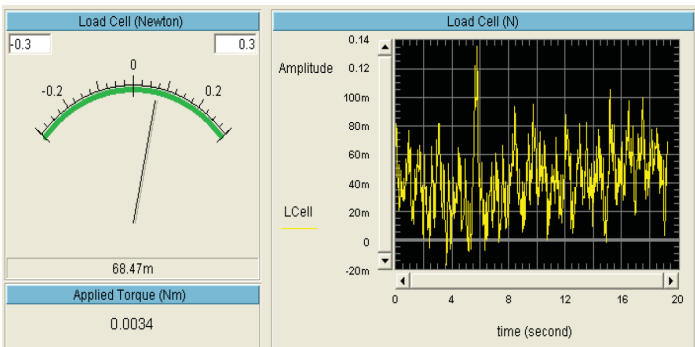

Figure 7. Keysight VEE Pro Instrument Manager

Figure 8. Sample screenshot of captured strain measurement, which is the result of the test on the strength and reliability of the concrete and metal structure. At rest position, the load cell output voltage V is read and stored in the DAQ as reference. When the force is exerted on the concrete, the load cell detects the force and the reading V is measured and plotted against the force applied to the concrete. The V is proportional to the force acting on the load cell.

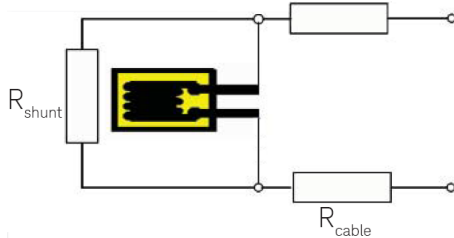## Shunt Calibration for Strain Gage Instrumentation

Figure 9. Quarter bridge connection circuit diagram

The need for calibration arises frequently in the use of strain gage instrumentation. Calibration is essential to scale the instrument sensitivity so that the correspond output will accurately predetermined the input.

It is very unlikely that the bridge will output exactly zero volts when no strain is applied during bridge installation. A strain gage bridge is balanced when the host mechanical structure is unloaded and unstressed.

Users may choose to use hardware and software to achieve zero volts when no strain is applied.

Shunt calibration is the known electrical unbalancing of a strain gage bridge by a fixed resistor that is placed or 'shunted' across one leg of the bridge.

The strain gage calibration can be achieved with an external shunt. As shown in Figure 9, it is a quarter bridge connection with its connection cable.

A high-resistance resistor is connected parallel to the strain gage to achieve a specific measurement bridge imbalance.

Conclusion

There are many solutions offered today for both dynamic (vibration) and static (strain) measurement. However, the Keysight U2300A Series USB Multifunction DAQ devices offers portability, easy setup, and cost effectiveness. The concrete and metal structures may be situated anywhere in the world, so in addition to performing reliably the test systems need to be easy to transport and set up. Keysight USB Multifunction DAQ devices provide these capabilities at a very attractive price.

One of the key differentiators of the Keysight U2300A Series USB Multifunction DAQ device is its ability to provide a multi-channel, high-speed transfer rate thanks to the USB 2.0 (Hi-Speed USB) standard supported by the device. It also provides high sampling rates with more sampling points collected in a second. This increases the chance of catching even the smallest of errors and reduces the debugging time.

In the past, a solution for dynamic and static measurement using multi-channel was extremely expensive for 16 channels PXI DAQ. However, with the Keysight USB Multifunction DAQ, a 64-channel, single-ended input, 500 KS/s system, great cost savings can be achieved for applications where many systems need to be deployed at the same time at many different locations.

Reference

– *Keysight U2300A Series USB Multifunction Data Acquisition Devices User's Guide*, Part-Number U2351-90002
– *Omegadyne Pressure, Force, Load, Torque Databook*, OMEGADYNE, Inc., 1996
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– *Instrument Engineers' Handbook*, Bela Liptak, CRC Press LLC, 1995
– *Marks' Standard Handbook for Mechanical Engineers*, 10th Edition, Eugene A. Avallone, and Theodore Baumeister, McGraw-Hill, 1996
– *McGraw-Hill Concise Encyclopedia of Science and Technology*, McGraw-Hill, 1998
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– *Van Nostrand's Scientific Encyclopedia*, Douglas M. Considine and Glenn D. Considine, Van Nostrand, 1997.

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