Section 6 - Electronics

6.1. Power for Excitation

Piezoresistive transducers are passive devices and require an external power supply to provide the necessary current (I_x) or voltage excitation (E_x) to operate the transducer. These energy sources must be well-regulated and stable, since they may introduce sensitivity errors and secondary effects at the transducer which will result in error signals at the output.

The excitation across the piezoresistive elements causes a finite current to flow through each element. The I^2R heating results in an increase in temperature of the elements slightly above ambient which increases the resistance of the elements. The power supply compliance voltage and regulation must be able to maintain constant voltage excitation on this varying resistance. Most Kulite transducers require 10.00 Vdc excitation, but can be operated at higher or lower voltages.

When exciting an unamplified pressure transducer, you may choose to ground one side of the excitation source, but do not ground either of the output leads. DO NOT GROUND BOTH INPUT AND OUTPUT LEADS. GROUNDING BOTH SIDES WILL SHORT CIRCUIT ONE STRAIN GAGE, PRODUCING ERRONEOUS OUTPUT SIGNALS. If floating both input and output of the pressure transducer ensure that common mode voltage of the power supply does not exceed 50V. Accidental short term application of excitation voltage to the output leads will not damage the transducer, but it should not be operated while connected backwards.

6.1.1. DC Power Supplies

Most Kulite piezoresistive pressure transducers require a constant-voltage supply for excitation. A constant-current supply should not be used unless the transducer is specifically designed or compensated for operation in this mode. Because the typical four-element transducer may not be perfectly balanced or matched, variations in excitation voltage or current, including ripple, will result in an error output signal. It is necessary, therefore, that a stable and well-regulated power supply be employed.

A number of important characteristics must be considered in the selection of a suitable power supply. Among these are:

- Line Regulation
- Load Regulation
- Ripple and Noise
- Temperature Stability
- Time Stability
- dc Isolation

The output of the transducer is differential, so the signal conditioner input should not be grounded. This requires that the power supply be well insulated from ground. Not only must the power supply be well insulated to prevent dc leakage currents flowing through the transducer, but in addition ac coupling to ground and power line must be minimised to

prevent line transients and dynamic around loops from generating error signals. Recommended grounding point is at the signal conditioner output.

To calculate power supply requirements, the required current is calculated from:

Where:

I_i = Input current
V_i = Excitation voltage
R_i = Input Resistance

When powering more than one unit with a single power source, use the parallel combination of input resistance for all units used.

$$I_i = V_i / R_c$$

R_c = Parallel combination of Input Resistance

Typical current requirement is 8 mA per transducer.

6.1.1.1. Constant-Current Power Sources

In many applications, the effects of long-line resistance and/or extraneous inputs are not negligible. The resistance of a long line will change with temperature, and the voltage drop along the line will vary as the transducer resistance or load changes. For these applications, constant-current excitation provides an output that is less dependent on these effects than is voltage excitation. In addition, current excited bridges are more linear than voltage-excited bridges when the percent variation of bridge resistance is relatively large.

The bridge output tends to be proportional to absolute resistance variations when the excitation source is current; and proportional to a unit resistance variation when the excitation is voltage. Thus, resistance gages or transducers which are to be used in a constant-current system must be compensated and calibrated with constant-current excitation over their full range of operation. Piezoresistive pressure transducers, specifically designed for operation with constant-current systems, are only available as specials from Kulite.

6.1.1.2. External Sensing

The voltage drop along long lines between a constant-voltage supply and transducer results in a reduced and sometimes unpredictable voltage at the transducer. Errors and spurious signals may appear 'at the transducer output due to variations in the resistance of these lines caused by temperature changes.

Many constant-voltage supplies provide for external voltage sensing leads which connect directly to the transducer, independent of the power or excitation leads. Low current in the sensing leads reduces the voltage drop along these lines and the effects of changes in resistance. Thus, the voltage across the transducer is maintained constant and independent of resistance and current variations on the power leads.

Input resistance of a pressure transducer may vary significantly over its operating temperature range. This change results in a relatively large change in input current, and proportional change in power-line voltage drop. With external sensing wires, the power supply controls and maintains the voltage at the transducer at a constant level.

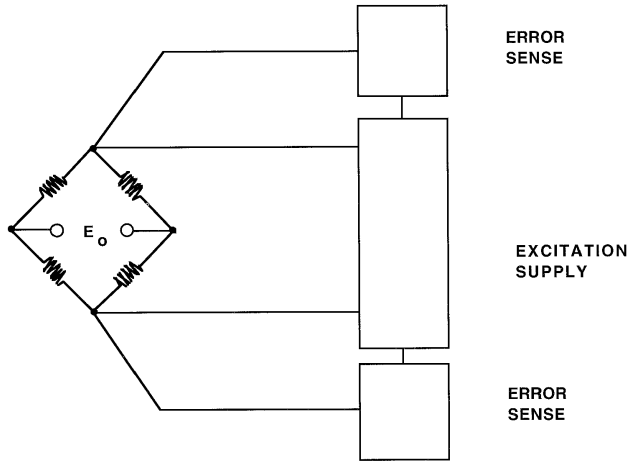

Figure 6-1: 6-Wire Connection to Wheatstone Bridge

6.1.2. AC Excitation

Kulite piezoresistive transducers may be excited with an ac carrier signal. The amplitude of the signal must be stable and the frequency should be five to ten times the maximum frequency of interest. Kulite piezoresistive transducers may be operated with up to 150% rated excitation voltage. With sinusoidal excitation voltages, the peak carrier signal will almost reach this limit. Therefore, it is recommended that the rms value of the carrier voltage be limited to the dc rated excitation voltage or less.

6.2 Signal Conditioning

The millivolt output pressure signal of the typical pressure sensor can be conditioned to interface with virtually any data acquisition system ECU, FADEC, EICAS or any other control or monitoring device.
A voltage, current, frequency or digital output can be provided as an option. Kulite has developed an in-house capability to design and produce microcircuitry, ASIC based designs and hybrid electronic modules as well as discrete component designs, including surface mount devices, to temperatures in excess of 365°F (185°C).
Kulite also has the capability design mechanical packages that place the solid state electronics in a stress free environment, thus allowing customers to use transducers in severe temperature and vibration environments.

6.2.1 Analogue Amplifiers

Many pressure transducers are available with integral electronics modules which amplifiy the millivolt output from the sensing Wheatstone bridge to a higher voltage level. The electronics can be supplied to operate from either a regulated or an unregulated supply. A typical regulated input voltage is 10 volts dc and frequently specified unregulated voltages are 12 volts dc ± 4 volts, 28 volts dc ± 4 volts and 10 to 40 volts dc. The output voltage range is usually 0 to 5 volts but options include output ranges of 0.5 to 4.5 volts, 0 to 10 volts, etc.

6.2.2 Digital Corrected Analogue Output

For applications which require the highest accuracy, Kulite have developed a range of pressure transducers which incorporate a microprocessor which provides digital compensation for the which represents an improvement over a passive compensated pressure transducer of at least 5 times.

6.2.3 Digital Output

Kulite provides microprocessor based electronic packages which amplify the millivolt sensor output, digitise the amplified voltage and output the digital data stream in one of several industry standard formats, such as RS485, CanBus, etc.

6.2.4 Pressure Switch Output

Pressure switches usually employ electromechanical technology of bellows or bourdon tubes which are connected via a mechanical linkage to a microswitch. Kulite have designed a range of solid state pressure switches which are based on the integrated silicon pressure sensor design connected to an electronic switching module. The reliability of the solid state switch is often an order of magnitude greater than the electromechanical equivalent. For aeroengine applications which frequently require pressure switches to operate at temperatures in excess of 200°C, unamplified pressure transducers can be used which input to the engine electronic control system (EEC). The software within the EEC can be designed to set the switch point and the required level of hysteresis. Thus one pressure transducer can be used for many switch applications with different switching characteristics which are programmed in software.

6.2.5 Solid State Replacements for Electro-Mechanical Pressure Transducers

In the past such practical implementations of pressure transducers used potentiometers, LVDTs (Linear Voltage Differential Transformer), synchros, variable reluctance systems, etc. All these pressure transducers used a Bourdon tube moving a mechanical part of a system, which resulted in a change of the electrical output. Some of these early transducers employed mechanical designs comparable in complexity and ingenuity with the most expensive Swiss watches. Unfortunately, none of these types of transducers escaped the inherent disadvantages of mechanical systems with moving parts. Kulite transducers employ a different approach, as explained in earlier sections of this handbook. The pressure-sensing element is a solid-state component, to which an electronic circuit is added which produces a normalized, compensated output. The piezoresistive bridge is arguably the most widely used, reliable and versatile sensing element available. Kulite has developed a range of electronic interfaces which operate with the Kulite piezoresistive silicon pressure sensing bridge to replace all the various obsolescent technology, electro-mechanical pressure transducers. These solid state replacement pressure transducers can be designed by Kulite to be form, fit and functionally identical to the old pressure transducers but have the reliability, performance and cost advantage of Kulite’s new generation of transducers. References to a paper which gives more details about Kulite’s developments in this area are given in section 9.3.6

6.2.6 Wireless Transmission

In applications where a cable connection to a pressure transducer is either undesirable or impractical, Kulite have developed a range of pressure transducers which transmit the pressure data via an rf link to a ground station. The communications standards which can be employed include IEEE 802.11b (WiFi), IEEE 802.15 (ZigBee), Bluetooth, ISM frequencies 868/ 915 MHz, 2.4 GHz. Power for the pressure transducer and the processing electronics and transmitter can be provided by replaceable or rechargeable batteries, inductive coupling or optical power transmission.

6.3. Readout and Recording Devices

A detailed discussion of readout and recording devices is beyond the scope of this handbook. However, some characteristics of these devices are important to overall system performance and

The category of readout and recording devices encompasses all types of meters, oscilloscopes, analysers, recorders, voltage controlled oscillators, and shaker control systems which receive their inputs from the transducer/amplifier system. Meters may have analogue or digital displays, and recording devices may use direct, AM, FM, or digital recording. Some analysers and control systems digitise and process data in "real time" while some process delayed, sampled, and/or hatched data.

However, regardless of the readout, recording or analysis techniques used, all of these "downstream instruments" have input impedance, frequency response, dynamic range, noise, and overload characteristics which may significantly alter the data. Instruments which digitise the analogue data and then process it digitally provide additional opportunities for Murphy's law to come into play. Some of these characteristics will be discussed in this section.

6.3.1. Input Characteristics

Input impedance, frequency response, dynamic range, noise, and overload response characteristics of downstream instrumentation are sometimes overlooked when putting together the total measurement, recording and analysing system.

The input impedance must be high enough to prevent overloading, slew rate limiting, and distortion. A rule of thumb is that input impedance of any instrument should be at least 100 times the output impedance of the preceding device. Most instruments in use today have input impedances of a megohm or more. Preceding instruments have output impedances of 1 k ohm or less, so this is seldom a problem.

Frequency response of the meter, analyser or recorder is often different from that of the transducer/amplifier system. If it is wider, then all frequencies will be processed undistorted. However if it is narrower, or if it distorts at some frequencies, its frequency response over the frequency range of interest must be known. Also, the user must know how the instrument treats frequencies outside its flat frequency band. Does it roll them off? How steeply? Or, does it amplify or distort them? Or, does it fold them back into the pass band and create new frequencies ("aliasing")?

Dynamic range, noise, and overload response characteristics are all important to the amplitude accuracy of the data. The noise level should be less than half of the lowest expected signal level, and preferably even less than that. Overload "headroom" should be sufficient to accurately process any possible overrange signal in the frequency band of interest. Finally, overload response must permit any distortion (such as clipping) of the overrange signal to disappear as soon as the signal is again within the dynamic range of the instrument.

6.3.2. Meter Characteristics

Most meters (regardless of their scaling) sense and respond to either the average or the rms value of the input. They therefore have some time constant or averaging time associated with the reading. Even direct reading galvanometer-type meters cannot respond instantaneously; they have a response time. This averaging time or response time gives the effect of a low pass filter by responding less to higher frequency inputs.

Some meters incorporate peak detecting circuitry; they provide an output proportional to the peak signal detected during some time interval. Other meters provide a sample-and-hold feature which allows manual or automatic time period sampling and readout of the average or peak detected during the sampling period.

The two greatest error sources when using a meter are (a) using it for readings in the lower (least accurate) part of its scale, and (b) not using a true rms meter for reading the rms value of a non-sinusoidal signal.

6.3.3. Errors in Digitising

Whenever an analogue signal is digitised, the possible digitising errors are added to all of the other potential errors in the system. The two most common digitising errors are aliasing and accuracy errors.

Aliasing refers to the phenomenon of creating new frequencies during the digitising process. This happens when the sampling (digitising) frequency is not high enough relative to the highest frequency present in the analogue signal.

The process of sampling generates heterodyne frequencies equal to the sum and the difference of the data frequency and the sampling frequency. If the difference frequency, $f_s - f_d$ falls in the frequency range of interest, it is called an alias frequency. In order to avoid alias frequencies, f_s must be at least 2 x f_d where f_d is the highest frequency present in the input.