6ME3A: Mechatronics

Data Acquisition & Related Instrumentation

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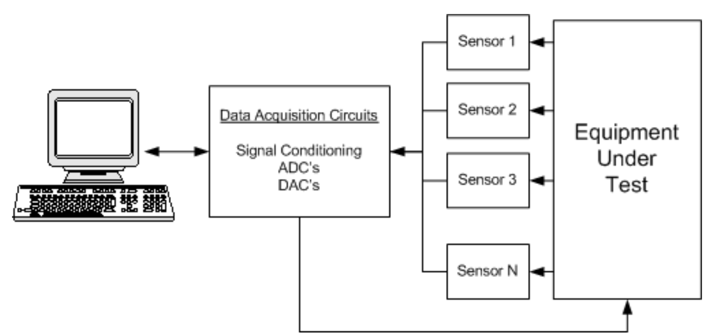
Unit-IV

Contents
Data Acquisition and related Instrumentation: Introduction to Data Acquisition Measurement Techniques: Sensors and Transducers, Quantizing theory, Analog to Digital Conversion, Digital to Analog (D/A) conversation, Signal Conditioning.
Real time Instrumentation: Computer-Based Instrumentation Systems, Software Design and Development, Data Recording and Logging.

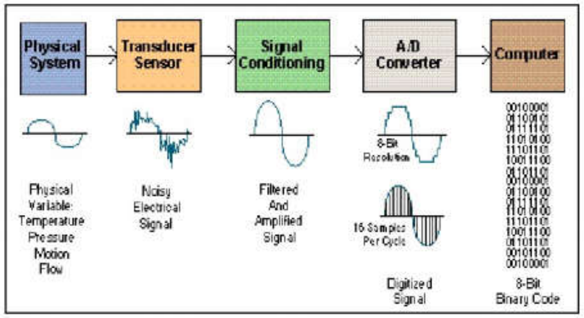
Data Acquisition (DAS or DAQ)

- The purpose of a data acquisition system is to capture and analyze some sort of physical phenomenon from the real world.
- Light, temperature, pressure, and torque are a few of the many different types of signals that can interface to a data acquisition system.
- A data acquisition system may also produce electrical signals simultaneously. These signals can either intelligently control mechanical systems or provide a stimulus so that the data acquisition system can measure the response.
- A data acquisition system provides a way to empirically test designs, theories, and real world systems for validation or research.

Test section to DAS to Logger



DAS: Block Diagram



DAS: Block Diagram

Physical System → Sensors Transducer → Signal Conditioning → A/D Converter → Computer

- Sensing
- Electrical Signal Conditioning
- Multiplexing, Sample and Hold
- A/D conversion
- Interfacing with computer
- Storage, processing and display in the computer with software

The **signal conditioner** accepts the electrical output of the transducer and transmits the signal to the comparator in a form compatible with the reference input. The functions of the signal conditioner include:

- Amplification/attenuation (scaling)
- Isolation
- Sampling
- Noise elimination
- Linearization
- Span and reference shifting
- Mathematical manipulation (e.g., differentiation, division, integration, multiplication, root finding, squaring, subtraction, or summation)
- Signal conversion (e.g., DC–AC, AC–DC, frequency–voltage, voltage–frequency, digital–analog, analog–digital, etc.)
- Buffering
- Digitizing
- Filtering
- Impedance matching
- Wave shaping
- Phase shifting

Data Acquisition

- Since data acquisition devices acquire an electric signal, a transducer or a sensor must convert some physical phenomenon into an electrical signal.
- In case of thermocouple, as the temperature increases, the voltage produced by the thermocouple increases.
- A software program can then convert the voltage reading back into a temperature for analysis, presentation, and data logging.
- Many sensors produce currents instead of voltages.
- A current is often advantageous because the signal will not be corrupted by small amounts of resistance in the wires connecting the transducer to the data acquisition device.
- A disadvantage of current-producing transducers is that most data acquisition devices measure voltage, not current.

Data Acquisition

- The heart of a data acquisition device is a digital-to-analog converter (DAC), an analog-to-digital converter (ADC), or some combination of the two.
- An ADC has a finite list of values which represents voltages.
- The purpose of the ADC is to select a value from this list, which is closest to an actual voltage at a specified time. The value is then transferred in binary format to a computer.
- Alternatively, a DAC can produce an analog voltage from a list of binary values.
- The voltage generated by a basic DAC stays the same until it receives another value from the computer.
- In order to acquire and produce analog waveforms, the DAC and ADC must activate at precise intervals.

Data Acquisition

- The data that is transferred from the ADC and to the DAC travels to the computer over a bus.
- A bus is a group of electrical conductors that transfer information inside a computer.
- Some common examples of a bus are PCI (Peripheral Component Interconnect) and USB (Universal Serial Bus).
- The bus can carry both control information and binary measurement data to and from measurement hardware.
- One of the most important considerations in selecting a bus is bus transfer rate, usually expressed in megabytes per second (Mbytes/s).
- Data acquisition devices often have on-board memory to serve as a holding place for data when the bus is not available.
- In very fast data acquisition routines, the memory can hold all the data, and at the end of the acquisition, all the data can be transferred to the computer for processing.

Data Acquisition

- When data is acquired at high speeds on multiple channels, it is often important to understand the phase relationship from one signal to the next.
- If the signals are generated or acquired on multiple data acquisition devices, there are a number of ways to synchronize the systems and preserve relative phase relationships.
- One way is to share the ADC and DAC clock between the data acquisition devices.
- The real-time system integration bus (RTSI) is a bus that can connect multiple devices together to share timing circuitry among multiple devices.
- Phase-lock looping (PLL) is a more sophisticated synchronization method.
- A reference signal is supplied to all the data acquisition devices, and the internal clocks stay in phase with the reference signal.

Data Acquisition

- The difference between an actual analog voltage and the closest voltage from the list of binary values is called the quantization error.
- In a perfect digitizing measurement system free of noise, the quantization error would solely explain any difference between the actual voltage and the measured voltage.
- No measurement hardware and no environment, however, are perfect.
- The accuracy of an instrument describes the amount of uncertainty when considering quantization error, unavoidable system noise, and hardware imperfections.
- Accuracy is sometimes confused with precision.

Data Acquisition

- The accuracy of a data acquisition system can change with temperature, time, and usage.
- Data acquisition hardware can store on-board correction constants for offset and gain errors.
- An offset error is a constant difference between the measured and actual voltage, regardless of the voltage level.
- A gain error increases linearly as the measured voltage increases.
- Some data acquisition hardware also include an accurate voltage source on-board that can be periodically used as a reference to correct the gain and offset error parameters.

Data Acquisition

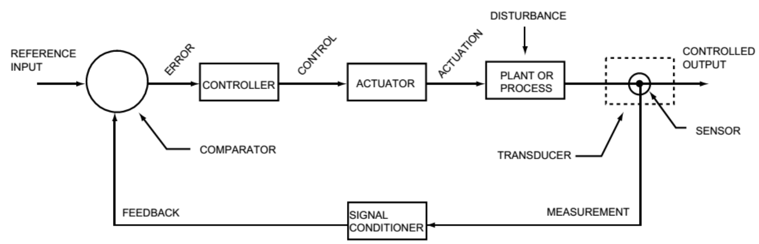
- Data acquisition software supplied by manufacturer or programmed by end user in suitable platforms using variety of programming languages.
- The application is then ready for an end user to easily control and acquire data from the hardware—a custom instrument built specifically for the user's needs.

Measurement Techniques: Sensors & Transducers

Error Signal

- An automatic control system is said to be *error actuated* because the **forward path** components (*comparator, controller, actuator*, and *plant* or *process*) respond to the error signal.
- The error signal is developed by comparing the measured value of the **controlled output** to some **reference input**, and so the accuracy and precision of the controlled output are largely dependent on the accuracy and precision with which the controlled output is measured.
- It follows then that measurement of the controlled output, accomplished by a system component called the **transducer**, is arguably the single most important function in an automatic control system.

Automatic Control System



Transducer and Sensor

- A transducer senses the magnitude or intensity of the controlled output and produces a proportional signal in an energy form suitable for transmission along the feedback path to the comparator.
- The element of the transducer which senses the controlled output is called the sensor; the remaining elements of a transducer serve to convert the sensor output to the energy form required by the feedback path.

Motion and Force Transducers

- Force is closely associated with motion, because motion is the result of unbalanced forces, and so force transducers are discussed concurrently.
- Rectilinear/Linear Motion
  - Straight line motion within a stationary frame of reference
- Angular/Rotation/Rotary Motion
  - Circular Motion about a Fixed Axis

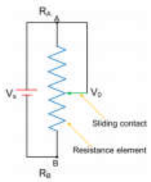
Rectilinear displacement: $x(t) = \int v(t)dt$	Rectilinear velocity: $v(t) = \frac{d}{dt}x(t)$	Rectilinear acceleration: $a(t) = \frac{d}{dt}v(t)$
Angular displacement: $\theta(t) = \int \omega(t)dt$	Angular velocity: $\omega(t) = \frac{d}{dt}\theta(t)$	Angular acceleration: $\alpha(t) = \frac{d}{dt}\omega(t)$

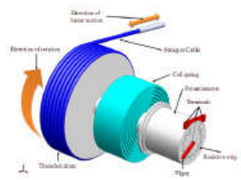
Displacement (Position) Transducers

- Displacement transducers may be considered according to application as gross (large) displacement transducers or sensitive (small) displacement transducers.
- The demarcation between gross and sensitive displacement is somewhat arbitrary, but may be conveniently taken as approximately 1 mm for rectilinear displacement and approximately 10′ arc (1/6°) for angular displacement.
- The predominant types of gross displacement transducers are:
  - Potentiometers
  - Variable differential transformers (VDT)
  - Synchros
  - Resolvers
  - Position encoders

Potentiometer

- Potentiometer-based transducers are simple to implement and require the least signal conditioning, but potentiometers are subject to wear due to sliding contact between the wiper and the resistance element and may produce noise due to wiper bounce.
- Potentiometers are available with strokes ranging from less than 1 cm to more than 50 cm (rectilinear) and from a few degrees to more than 50 turns (rotary).



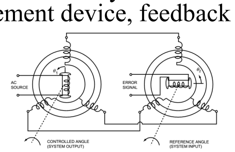


Variable differential transformers (VDT)

- VDTs are not as subject to wear as potentiometers, but the maximum length of the stroke is small, approximately 25 cm or less for a linear VDT (LVDT) and approximately 60 degree or less for a rotary VDT (RVDT).
- VDTs require extensive signal conditioning in the form of phase-sensitive demodulation of the AC signal; however, the availability of dedicated VDT demodulators in integrated circuit (IC) packages mitigates this disadvantage of the VDT.

Synchros: a transformer

- Due to inherent physical properties and mechanical & electrical designs, synchros make possible the accurate transmission and reproduction to a remote location of any data or information which can be converted to angular rotation.
- Synchros are rather complex and expensive three-phase AC machines, which are constructed to be precise and rugged.
- Synchros are capable of measuring angular differences in the positions (up to ±180°C) of two continuously rotating shafts.
- In addition, synchros may function simultaneously as reference input, output measurement device, feedback path, and comparator.




Resolvers

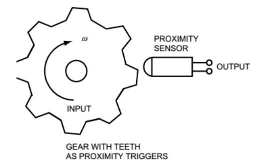
- Resolvers are simpler and less expensive than synchros, and they have an advantage over RVDTs in their ability to measure angular displacement throughout 360°C of rotation.
- Dedicated ICs are available for signal conditioning and for conversion of resolver output to digital format.

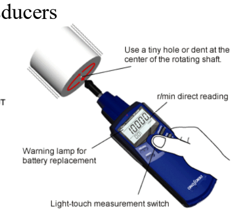
Position encoders

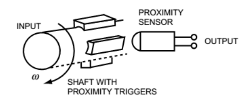
- Position encoders are highly adaptable to digital control schemes because they eliminate the requirement for digital-to-analog conversion (DAC) of the feedback signal.
- The code tracks are read by track sensors, usually wipers or electro-optical devices (typically infrared or laser).
- Position encoders are available for both rectilinear and rotary applications, but are probably more commonly found as shaft encoders in rotary applications.

Velocity Transducers

- Signal conditioning techniques make it possible to derive all motion measurements—displacement, velocity, or acceleration—from a measurement of any one of the three.
- The analog transducers frequently used are:
  - Magnet-and-coil velocity transducers
  - Tachometer generators
  - Counter-type velocity transducers

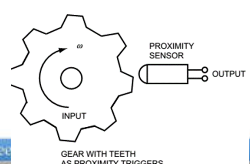






Velocity Transducers: Magnet-and-coil velocity transducers

- The operation of magnet-and-coil velocity transducers is based on Faraday's law of induction.
- For a solenoidal coil with a high length-to-diameter ratio made with closely spaced turns of fine wire, the voltage induced into the coil is proportional to the velocity of the magnet.
- Magnet-and-coil velocity transducers are available with strokes ranging from less than 10 mm to approximately 0.5 m.



Velocity Transducers: Tachometer generator

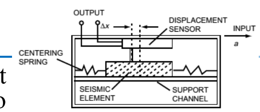
- A tachometer generator is, as the name implies, a small AC or DC generator whose output voltage is directly proportional to the angular velocity of its rotor, which is driven by the controlled output shaft.
- Tachometer generators are available for shaft speeds of 5000 rpm, or greater, but the output may be nonlinear and there may be an unacceptable output voltage ripple at low speeds.
- AC tachometer generators are less expensive and easier to maintain than DC tachometer generators, but DC tachometer generators are directly compatible with analog controllers and the polarity of the output is a direct indication of the direction of rotation.

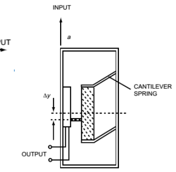
Velocity Transducers: Counter-type velocity transducers

- Counter-type velocity transducers operate on the principle of counting electrical pulses for a fixed amount of time, then converting the count per unit time to velocity.
- Counter-type velocity transducers rely on the use of a proximity sensor (pickup) or an incremental encoder:
  - Electro-optic
  - Variable reluctance
  - Hall effect
  - Inductance
  - Capacitance

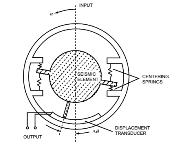
Acceleration Transducers

- As with velocity measurements, it is sometimes preferable to measure acceleration directly, rather than derive acceleration from a displacement or velocity measurement.
- The majority of acceleration transducers may be categorized as seismic accelerometers because the measurement of acceleration is based on measuring the displacement of a mass called the seismic element.

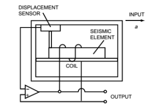




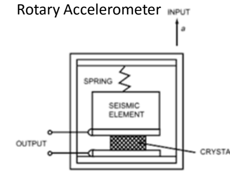
Rectilinear Acceleration Transducers



Rotary Accelerometer



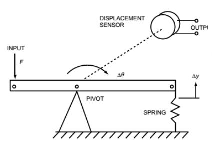
Force balance accelerometer



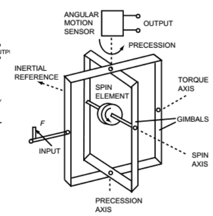
Piezoelectric Accelerometer.

Force Transducers

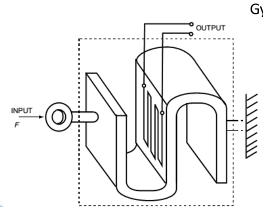
- Force measurements are usually based on a measurement of the motion, which results from the applied force.
- If the applied force results in gross motion of the controlled output, and the mass of the output element is known, then any appropriate accelerometer attached to the controlled output produces an output proportional to the applied force (F = Ma).



Spring Scale



Gyroscope



Load Cell

Process Transducers

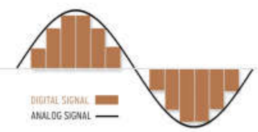
- This type of transducers are being used in measuring and controlling the process variables most frequently encountered in industrial processes, namely,
  - Fluid pressure
  - Fluid flow
  - Liquid level
  - Temperature

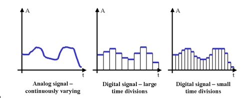
Analog vs. Digital signals

- An Analog signal is any continuous signal for which the time varying feature (variable) of the signal is a representation of some other time varying quantity, i.e., analogous to another time varying signal. It differs from a digital signal in terms of small fluctuations in the signal which are meaningful.
- A digital signal uses discrete (discontinuous) values. By contrast, non-digital (or analog) systems use a continuous range of values to represent information. Although digital representations are discrete, the information represented can be either discrete, such as numbers or letters, or continuous, such as sounds, images, and other measurements of continuous systems.

Analog Signal & Digital Signal

- Analog and digital signals are used to transmit information, usually through electric signals.
- In both these technologies, the information, such as any audio or video, is transformed into electric signals.
- The difference between analog and digital technologies is that in analog technology, information is translated into electric pulses of varying amplitude.
- In digital technology, translation of information is into binary format (zero or one) where each bit is representative of two distinct amplitudes.





Properties of Digital vs Analog signals

Digital information has certain properties that distinguish it from analog communication methods. These include

- Synchronization – digital communication uses specific synchronization sequences for determining synchronization.
- Language – digital communications requires a language which should be possessed by both sender and receiver and should specify meaning of symbol sequences.
- Errors – disturbances in analog communication causes errors in actual intended communication but disturbances in digital communication does not cause errors enabling error free communication. Errors should be able to substitute, insert or delete symbols to be expressed.
- Copying – analog communication copies are quality wise not as good as their originals while due to error free digital communication, copies can be made indefinitely.
- Granularity – for a continuously variable analog value to be represented in digital form there occur quantization error which is difference in actual analog value and digital representation and this property of digital communication is known as granularity.

	Analog	Digital
Signal	Analog signal is a continuous signal which represents physical measurements.	Digital signals are discrete time signals generated by digital modulation.
Waves	Denoted by sine waves	Denoted by square waves
Representation	Uses continuous range of values to represent information	Uses discrete or discontinuous values to represent information
Example	Human voice in air, analog electronic devices.	Computers, CDs, DVDs, and other digital electronic devices.
Technology	Analog technology records waveforms as they are.	Samples analog waveforms into a limited set of numbers and records them.
Data transmissions	Subjected to deterioration by noise during transmission and write/read cycle.	Can be noise-immune without deterioration during transmission and write/read cycle.
Response to Noise	More likely to get affected reducing accuracy	Less affected since noise response are analog in nature
Flexibility	Analog hardware is not flexible.	Digital hardware is flexible in implementation.

	Analog	Digital
Uses	Can be used in analog devices only. Best suited for audio and video transmission.	Best suited for Computing and digital electronics.
Applications	Thermometer	PCs, PDAs
Bandwidth	Analog signal processing can be done in real time and consumes less bandwidth.	There is no guarantee that digital signal processing can be done in real time and consumes more bandwidth to carry out the same information.
Memory	Stored in the form of wave signal	Stored in the form of binary bit
Power	Analog instrument draws large power	Digital instrument draw only negligible power
Cost	Low cost and portable	Cost is high and not easily portable
Impedance	Low	High order of 100 megaohm
Errors	Analog instruments usually have a scale which is cramped at lower end and give considerable observational errors.	Digital instruments are free from observational errors like parallax and approximation errors.

Thank You

For

Your Attention