ENERGY MANAGEMENT SERIES

15

FOR INDUSTRY COMMERCE AND INSTITUTIONS

Measuring, Metering and Monitoring

To the Reader

These manuals provide detailed information on a wide range of energy management topics. Because they were produced in the late 1980s, they contain references to energy prices and to some energy management techniques that are out of date. Nonetheless, the manuals provide practitioners with useful mathematical equations and general information on proven techniques and technologies, as well as examples of ways to save energy.

Avis au lecteur

Ces manuels contiennent de l'information détaillée sur de nombreux aspects de la gestion de l'énergie. Comme les manuels ont été produits à la fin des années 80, les références aux prix de l'énergie et à certaines techniques de gestion de l'énergie ne sont plus à jour. Le lecteur y trouvera toutefois des équations mathématiques utiles et des renseignements généraux sur diverses techniques et technologies éprouvées, ainsi que des exemples de mesures à prendre pour économiser l'énergie.

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PREFACE

Much has been learned about the art and science of managing energy during the past decade. Today, energy management is a seriously applied discipline within the management process of most successful companies.

Initially, in the early 1970's, energy conservation programs were established to alleviate threatened shortages and Canada's dependency on off-shore oil supplies. However, dramatic price increases quickly added a new meaning to the term "energy conservation" — reduce energy costs!

Many industrial, commercial and institutional organizations met the challenge and reduced energy costs by up to 50%. Improved energy use efficiency was achieved by such steps as employee awareness programs, improved maintenance procedures, by simply eliminating waste, as well as by undertaking projects to upgrade or improve facilities and equipment.

In order to obtain additional energy savings at this juncture a greater knowledge and understanding of technical theory and its application is required in addition to energy efficiency equipment itself.

At the request of the Canadian Industry Program for Energy Conservation, the Commercial and Institutional Task Force Program and related trade associations, the Industrial Energy Division of the Department of Energy, Mines and Resources Canada, has prepared a series of energy management and technical manuals.

The purpose of these manuals is to help managers and operating personnel recognize energy management opportunities within their organizations. They provide the practitioner with mathematical equations, general information on proven techniques and technology, together with examples on how to save energy.

For further information concerning the manuals listed below or regarding material used at seminars/workshops including actual case studies, please write to:

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INTRODUCTION

Measuring, Metering and Monitoring equipment is essential to present day homes and workplaces. The simplest of examples are measurement of temperature for the operation of a furnace, refrigerator or stove, and the measurement of time with a clock. Many kinds of highly technical instruments evolved because of the fundamental need for measurement in most activities and the human drive for discovery, invention and development.

Consider the evolution of Measuring, Metering and Monitoring equipment. People originally made judgments on many things such as distance, "two moons travel", and volume, "a handful or basketful". Eventually, precise units of measurement were needed for functions such as the division of land into lots or the measuring of weights and volumes necessary for trading. This created the need to develop standards for units of measurement. Instruments were required to measure these standard units. Thus, standards of measurement and the corresponding instruments developed together.

Energy is an important part of daily life and its cost is significant. This module provides measuring, metering and monitoring equipment information which, when used, can improve energy utilization and save dollars. Establishing and implementing an Energy Management Program is an organized way of saving energy and dollars. Measuring and monitoring equipment provides the data necessary for such a program.

The following steps in an *Energy Management Program* demonstrate the important uses of measuring and monitoring equipment.

- Determine where energy is being used and how much. This is achieved by measuring the energy delivered or consumed.
- Assess the current operation and determine where it should be modified.
- Establish energy performance goals.
- Implement operating improvements and compare the results on a continuous basis with the previous operation. Measurement data is required to evaluate performance improvements. The improvements might also include the addition of automatic controls and these devices depend upon good measurement.
- Formalize the process of collecting energy related data to track the energy utilization and make meaningful comparisons with the previous use of energy. This is the basis of an Energy Accounting System and the source of all this data originates from measuring and metering equipment.

Meters are used to measure the flow of steam, water, oil, natural gas and electricity. Thus, this form of measurement is sometimes referred to as *metering*.

Measurement data are used to assess the effectiveness of energy use in the operation of equipment or processes. *The functions of data gathering, interpretation, and analysis are called monitoring*. Equipment is available to assist the monitoring function by recording the data over time, and in some cases, by manipulating it to provide information in a more useful form. This category of instrumentation is referred to as monitoring equipment.

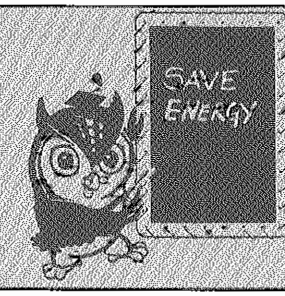
The subject of Measuring, Metering and Monitoring is covered in sufficient detail to permit a preliminary assessment of how this type of equipment assists with the *management of energy*. When an energy saving opportunity has been identified, it may be possible to assess the requirements, select the instrument, determine the financial payback of the investment, and implement the measurement activities. In some cases it may be necessary to seek expert help to finalize the analysis and details for implementation.

An understanding of the material presented in this module is essential for reading and using Automatic Control, Module 16 of this series. These two modules plus Process Insulation, Module 1, have something in common with respect to saving energy. That is, the savings do not result from the use of measuring instruments, controllers or insulation, but rather from the improved operation of the equipment or processes to which the instruments or insulation are applied.

This module has been divided into the following sections to explain the purpose and uses of Measuring, Metering and Monitoring equipment.

- *Fundamentals* of measurement and accuracy and the identification of measurements which should be made for the proper management of energy.
- *Equipment/Systems* which describes the types of measuring, metering and monitoring instruments including charts of features and relative cost.
- *Energy Management Opportunities* are described with some worked examples to demonstrate the vital and diversified role of measuring and monitoring equipment in saving energy and dollars.
- Appendices include a glossary of terms, tables, conversion factors and a checklist to assist in making Energy Management Opportunity assessments.

FUNDAMENTALS

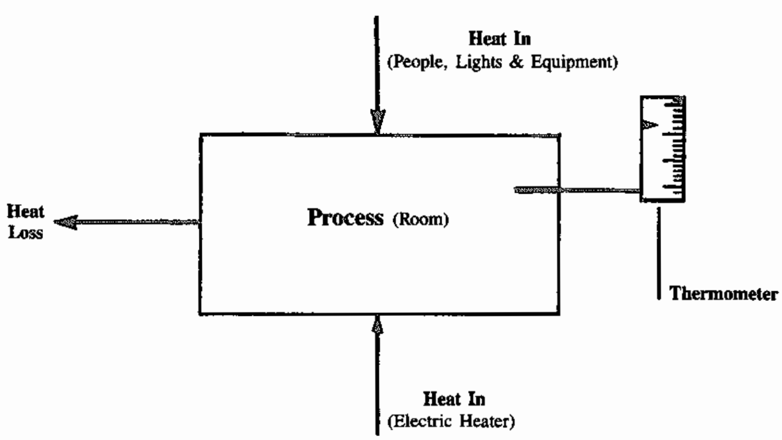


Measurement covers an impressive cross section of daily influences from the measurement of time, temperature within buildings, and data for the operation of manufacturing and processing plants, to highly scientific measurements in medical and space technology. Measurement is important in managing the use of energy to save money in Industrial, Commercial and Institutional facilities.

Purpose

Measuring, Metering and Monitoring equipment is used to provide reliable data for the operation of building facilities, equipment and processes. The following identifies the most common uses for data.

- Provide process variable information such as temperature, flow, pressure and level.
- Establish the overall performance of a facility for comparison with the previous operation and/or the operation of similar equipment or processes.
- Determine the energy performance of the operation and make comparisons with data from similar operations. This activity forms the basis of Energy Accounting.



Process Example
Figure 1

Process Terminology

An understanding of basic terminology is necessary for selecting and using instruments. Terminology is explained throughout the module and many terms are defined in the Glossary. The following list explains some of the key terms.

- A *process* is a plant facility or operation where there is a change of matter or conversion of energy. This is a much broader definition of process than the often perceived meaning of a conversion operation within a chemical plant. A process example could be a room that is heated by an electric heater (Figure 1). The heat loss is a composite of the individual heat losses. The heat input comes from sources such as people, lights and equipment (uncontrolled) plus an electric heater which converts electrical energy to heat energy. A thermometer provides an indication of the room temperature. The heater could be turned on and off manually or operated automatically by means of a thermostat which is a temperature measuring and controlling device.
- A *process variable* is a quantity or condition that influences a process. In the foregoing example, the process variables would be the total heat flow from the room, the uncontrolled heat gain and the heat input from the heater.

- A *measured variable* is a quantity, property or condition that is measured. In the foregoing example the measured variable is the room temperature.
- A *sensing element* is a device which is responsive to the value of the measured variable. In the example, the thermometer is a sensor that is responsive to temperature changes.
- It is important to be aware of another measurement characteristic called *time lag*. This is the delay that can exist between the time a measured quantity starts to change and when the instrument senses this change. This time lag is particularly noticeable in temperature measurement since it often takes the heat some time to penetrate the walls of the measuring element. Consequently, when making observations or adjustments the process must be stabilized to ensure that the correct temperature is measured.

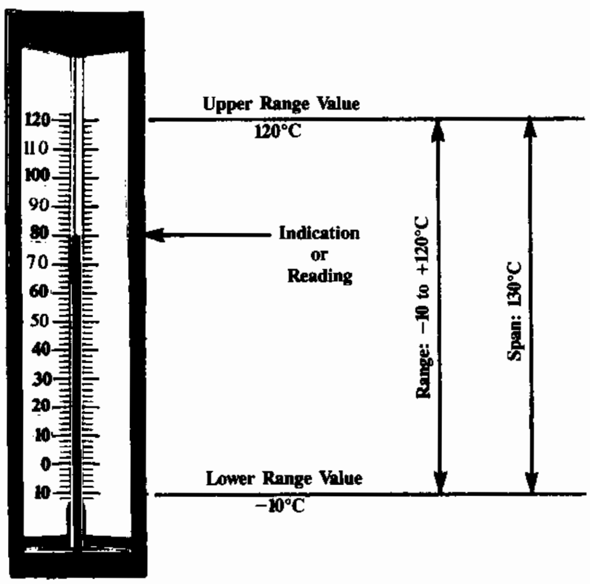
Measurement and Monitoring Benefits

Measuring process variables and then monitoring the data offers many benefits. The following is a partial list of the benefits of measuring and monitoring.

- *Facilitates decision making related* to improving operations.
- Permits *consistency of operation*, even with personnel who do not have much experience.
- Operating equipment performance can be calculated to *expose the misuse of energy*.
- Forms the *basis for good manual control* of equipment and processes.
- *Automatic control* would not be possible without the measuring element which determines the value of the process variable such as temperature, flow, pressure and level. Similarly, more complex processes could not be optimized to save energy without reliable data.
- *Energy management programs* depend on reliable data to assess current operation, compare with what should be achievable, and to develop action plans which will improve the energy utilization. *Energy accounting* is an integral part of an energy management program and depends on reliable data being consistently obtained in consecutive accounting periods.

The owner of an apartment building is, in effect, selling heat to the tenants. It is interesting to note that this is comparable to an industrial plant where steam is "sold" to several departments. In each case the owner wants to get the maximum value from each unit of fuel. Measurement of the energy used and steam produced quantifies the conversion efficiency to ensure maximum benefit. Measurements of outdoor and indoor temperatures help to assess the energy consumption relative to the need. The measurement of temperature within a facility also permits better control of energy use.

Measuring the indoor and outdoor temperatures provides data which is used to calculate the building heat loss. Heat loss calculations may reveal that improvements such as additional insulation are justified. The Energy Management Opportunities section includes examples that demonstrate how measurements save dollars.



Thermometer
Figure 2

Standards

Human interaction necessitated standards for weight and volume measures to assist with trade, and for length to establish property lines. Other measurements have similarly evolved so that now there are universal standards for all physical quantities. Detailed information regarding standards of measurement can be found in physics textbooks. The following describes some of the measurements which evolved with the development of standards.

Acceleration	Force	Resistance
Audible Sound	Frequency	Shape
Calorific Value	Gloss	Specific Gravity
Capacitance	Hardness	Specific Heat
Chemical Composition Properties	Humidity	Spectroscopic Composition
Color	Impedance	Speed
Combustible Content	Inductance	Temperature
Compression	Infrared Light	Tension
Conductivity	Level	Thickness
Consistency	Mass	Time
Crystalline Properties	Moisture Content	Torque
Current	Molecular Weight	Turbidity
Density	Moment	Ultrasonic Sound
Dimension	Nuclear Radiation	Ultraviolet Light
Displacement	Oxidation	Vacuum
Ductility	pH Concentration	Velocity
Electrical Quantities	Position	Viscosity
Enthalpy	Pressure	Visible Light
Entropy	Properties	Voltage
Expansion	Radiant Heat	Volume
Explosibility	Reduction	Weight
Flow	Reflectance	

Accuracy

Terminology

Proper measurement allows the facility operation to be organized in specific terms (e.g. stop something when the temperature rises to 85°C). This means that less training and experience are required to effectively operate the facility. Also, the operation can be refined through progressive measurements and observations of the process variables. Efficiency targets can be realistically set and actual performance comparisons made. It is important to know how measurement accuracy is expressed so that the measuring instruments can be selected according to the process requirements. Reference to the thermometer (Figure 2) will help to identify some of the measurement terms.

- When the thermometer is used to measure the room temperature the room temperature is called the *measured variable*.
- Each instrument has a minimum measuring capability which is called the *lower range value*. In Figure 2 it is −10°C.
- Each instrument has a maximum measuring capability which is called the *upper range value*. In Figure 2 it is 120°C.
- The region between the lower and upper extremes represents the *range* when expressed in the actual temperature units of −10 to +120°C. The *span* is also represented by this region, but it is expressed in the number of units of measurement between the lower and upper range values (i.e. 130°C).
- The thermometer scale allows the reading of intermediate temperatures between the lower and upper range values. Because of this scale, the thermometer can be called a *temperature indicator*. The actual temperature value of 80°C is the *indication or reading*. This could also be called the *indicated value*.
- The *ideal or true value* of a measured variable is the actual value relative to the standard of measurement. For the same example the ideal or true value would be the actual temperature in °C as defined by this unit of temperature measurement.

Instrument Error Sources

Measurement error is the difference between the true value of the variable and the indicated value. *The magnitude of error is a combination of limitations of the reference standard used to calibrate the sensor, the range of the measurement, and sensor errors*. The limitations of a measuring standard is beyond user control. The choice and proper use of calibration equipment should be established consistent with accuracy needs.

An understanding of the source of sensor errors and how accuracy is expressed will help with the selection of instruments. The following are the most important error sources.

- The moving parts of sensors are subject to problems such as friction.
- The conditions around the sensors (i.e. ambient) such as temperature, pressure, and humidity can affect parts of the measuring instrument.
- Inability of the observer to accurately read the indicator of the instrument.
- The nature of the measured variable can have a significant effect, in particular, on a single measurement. For example, the temperature of a process might regularly cycle between two temperature extremes. There is a lag between the time a sensor is subjected to a new temperature and when the value is indicated. If the temperature is always cycling the true temperature will never be obtained. Multiple readings will help to achieve a representative value.
- The aging of instrument components can be a source of error, but periodic calibration minimizes this effect.

Manufacturers specify instrument accuracies under certain operating conditions. These conditions will vary according to the manufacturer and the type of instrument, but the accuracy guarantee would be based on such things as ambient conditions and factors directly related to the measured variable.

Measurement Accuracy

In the thermometer example (Figure 1), *accuracy* is an expression of how far the temperature reading differs from the actual temperature under specified operating conditions. Actually, it is an indication of inaccuracy, but by convention it is called accuracy. The *accuracy of a measuring sensor is expressed in terms of the measured variable*, either in the units of measurement or as a percentage. The accuracy of instruments is defined by manufacturers using several different methods.

- As a *per cent of span*. The accuracy guarantee of the thermometer could be ±2 per cent of span. The maximum error of the indication would then be 130°C x .02 = 2.6°C so that there could be as much as ±2.6°C error between the actual temperature and the temperature reading.
- As a *per cent of the upper range value*. An accuracy of ±2 per cent stated this way results in a maximum error of 120°C x .02 = 2.4°C so that a reading would be ±2.4°C of the actual temperature. When instrument accuracy is stated as a per cent of span or upper range value there is an accuracy benefit to restricting the range. Keep the range of the measurement as small as is consistent with expected extreme values of the measured variable for the process operation.
- As a *per cent of the actual output indication or reading*. An accuracy of ±2 per cent stated this way would result in a maximum error of 80°C x .02 = 1.6°C. Thus the reading at 80°C would be ±1.6°C of the actual temperature.

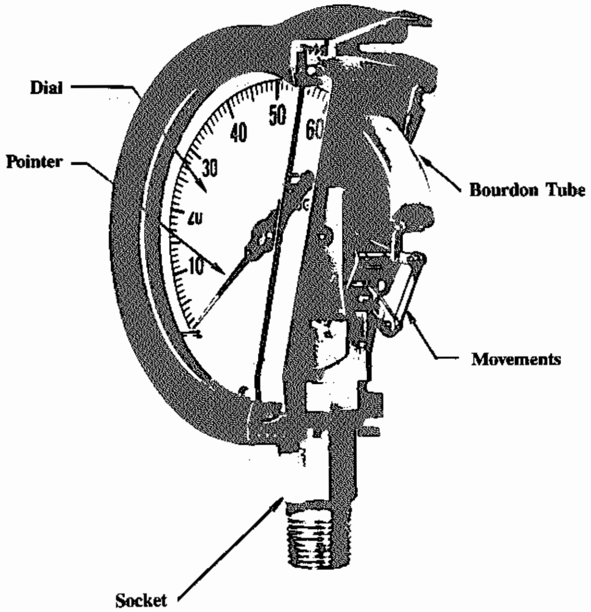
From the foregoing examples, 2 per cent instrument accuracy could result in temperature errors of 2.6°C, 2.4°C or 1.6°C. Determine how much the increased measurement accuracy will improve the process operation and the value of this benefit in dollars. It will then be possible to compare benefits against the higher cost of more accurate instruments.

Repeatability

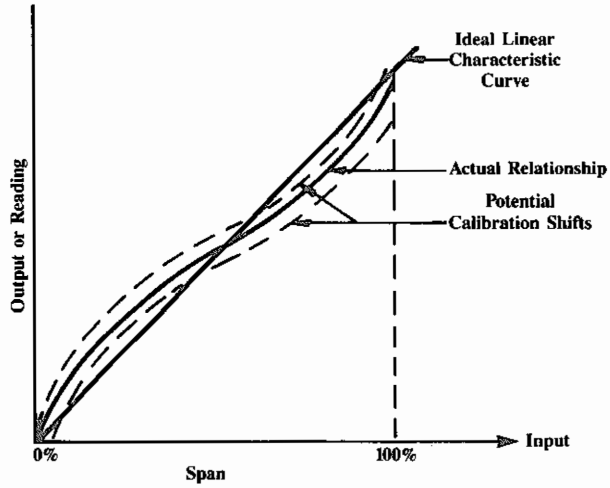
With experience in operating a process, personnel may determine that the best operation is achieved when a thermometer reads 90°C, even though the actual temperature was several degrees from 90°C. A highly repeatable thermometer would satisfy this requirement regardless of the overall accuracy guarantee of the instrument.

Dead Band

The concept of dead band is easily demonstrated by the action of a pressure gauge (Figure 3). An increase in pressure causes the Bourdon tube to uncoil, and this movement through a link rotates the gears. While the pressure is increasing the gears will be moving and the teeth will be tightly meshed. When the pressure starts to fall the rotation direction of the gears will change. Because there are some imperfections in machining there will be some gear tooth clearance to be taken up before the output pointer moves. The change in the input pressure before the pointer begins to respond is called dead band. *Dead band* is the amount that the input may be varied upon reversal of direction before it is possible to observe a change in the output. The effect of this characteristic can be reduced by not reading the instrument immediately after a reversal in the input. With experience the required delay in reading the instrument will be apparent.



Pressure Gauge
Figure 3



Instrument Calibration Curve
Figure 4

Calibration

Calibration is the act of adjusting an instrument so that the measured range and the accuracy of the output is suitable for the application within the capability of the instrument. Most instruments have zero and range adjustments. The zero adjustment produces a parallel shift of the calibration curve and the range adjustment changes the slope of the curve.

A glass stem thermometer does not have a range adjustment, but if mounted on an indicator card there is zero adjustment. If the scale card on the thermometer (Figure 2) is dislodged it is necessary to recalibrate the thermometer. This could be done by inserting the thermometer in an ice water bath and adjusting the scale so that the 0°C mark was at the liquid level indication point. This "zero adjustment" is a single point calibration which is the simplest type. If the instrument had a range adjustment, the calibration procedure would involve the immersion of the temperature element in boiling water to make a range adjustment, and then the immersion in ice water for the zero adjustment to be made. This process would have to be repeated to ensure that the calibration was correct at the two extremes of the measured range.

Instrument calibration can be used to minimize the instrument measuring error represented by the deviation of an instrument calibration curve from a specified ideal linear characteristic curve (Figure 4). The actual temperature curve is a function of the instrument mechanism and little can be done to change the shape. However, the position and slope of the curve, with respect to the ideal curve, can be shifted by instrument calibration. This may be advantageous because the area of least error is where the actual and the ideal curves cross. If the crossover point can be moved to the position where most of the measured variable readings are taken, the overall output error is reduced.

System Accuracy

Often the measurement of a variable involves more than one instrument. For example, a remote flow measuring system includes a flow transmitter measuring the differential pressure across an orifice plate located in the process pipe, and an indicator in a control room some distance from the transmitter. Each of the devices has accuracy limitations. This means that there will be an overall system accuracy which is a function of the accuracy of the three devices. System accuracy cannot be calculated with certainty, but it can be determined by a system calibration check. Without this, it can only be assumed that the system accuracy is somewhere between the sum of the accuracies for each of the three devices and the accuracy of the least accurate device.

Monitoring

Measurement benefits, standards and accuracy characteristics have now been described. These principles, along with the information in the Equipment/System section, can be used to properly select measuring instruments.

The act of monitoring always includes some form of data gathering, but this activity can vary significantly. Some examples of monitoring are listed.

- Mentally noting a temperature indicated on a thermometer.
- Manually recording a temperature on a log sheet.
- Obtaining a permanent record of a measurement by recording the value on a recorder chart.
- By connecting the sensor to a computer, the measured variable will be automatically read by the computer on a periodic basis and printed out in the form of a daily report.

The benefits of data gathering occur only when the data is interpreted and used. Typical examples of follow-through actions are now described.

- A heater fan is turned off after the room temperature has been noted.
- Boiler operating data is recorded so that the efficiencies can be calculated for different firing rates. This information is then used to compare the operation with previously achieved efficient operation and corrective action taken if the comparison is not favourable. The efficiency versus load profile might also be used to select the most efficient combination of boilers for the current plant steam load.
- The collected data might be analysed as part of an energy audit program.
- The data could be used to satisfy the information requirements of an energy accounting system. This type of system formalizes the use of energy-related data so that energy performance targets can be established and the results monitored. The energy utilization can be compared with previous reporting periods to track the current plant performance and the performance of implemented energy conserving measures. This subject can be reviewed in detail by reading the Energy Accounting Manual in this series.

Energy Audit Methods

Walk Through Audit

A *walk through audit* is a visual inspection of a facility to observe how energy is used or wasted. In most Industrial, Commercial and Institutional facilities a walk through will identify *Energy Management Opportunities*. This audit is usually more meaningful if a "fresh pair of eyes", new to the facility but generally familiar with energy management, is involved. Obvious things such as a tank overflowing or water running to a drain can be directly observed by the operator, but could be more consistently monitored with relatively simple and inexpensive instrumentation. There will also be applications which cannot be effectively monitored by personnel, but with the addition of simple measuring devices could be properly maintained. Examples in this category are enclosed equipment such as air filters, and inaccessible equipment where the addition of pressure, temperature or flow metering could quickly identify an energy wasting operation.

Diagnostic Audit

In most cases the justification for the addition or upgrading of *measuring, metering and monitoring* equipment will not be obvious until a detailed analysis is made of instrument costs and the resulting energy savings. This type of analysis is known as *a diagnostic audit*. The diagnostic audit involves a preliminary examination to identify possibilities, and additional investigation of opportunities that look promising. The result of this detailed analysis permits an informed decision of acceptance or rejection of the Energy Management Opportunity.

A *Checklist* has been developed to assist in conducting a diagnostic audit. The purpose of this checklist is to stimulate thinking about the use of measuring and monitoring instruments, and to identify how the principles presented in this module can be advantageously applied.

The checklist encourages these audit steps:

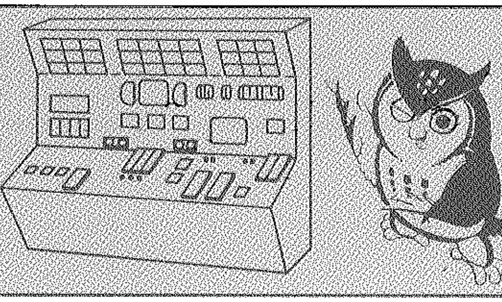
- List the existing *measuring, metering and monitoring* equipment.
- Examine the suitability of the existing equipment.
- List the additional measuring or upgrading of instruments that would be useful.
- Estimate savings or increased throughput.
- Estimate the cost of new or upgraded equipment.
- Determine whether costs appear to be justified and reject those that are not.
- Establish the steps to be taken and the people to contact for a detailed evaluation.

Summary

The following key subjects have been covered in this section.

- A measurement has real meaning only if it is compared to a standard. The usefulness of a measurement can increase as it becomes more accurate.
- Accuracy is often improved by reducing the range, so the range of an instrument should be kept to a minimum consistent with the expected variations of the measured variable.
- Repeatability is often more important than absolute accuracy.
- System accuracy is a function of the accuracy of the components and this can be reliably determined only by system calibration.
- Measurement must be combined with monitoring to be meaningful.
- Measurement is a requisite for control.

EQUIPMENT SYSTEMS



This section describes measuring, metering and monitoring instruments with emphasis on those associated with energy management. Measuring instruments are grouped according to what they measure (e.g. flow, temperature) or by what they do (i.e. hardware classification). The general hardware classifications would include instruments such as a direct-connected indicator, recorder or transmitter.

Instruments are described under the major categories of flow, temperature, pressure, level, weight, electrical measurements and flue gas analysis. The principles of operation, significant characteristics and instrument uses are presented for the foregoing classes of measurements. "Characteristics/Relative Cost Comparison" tables are also provided. While these tables will not necessarily permit the final selection of instruments, they should provide guidance in selecting the most logical types of instruments for a specific application. This should permit the appropriate instrument suppliers to be contacted for more detailed discussion on the selection.

Process Measurements

The measurement of pressure in a Bourdon tube is an example of a direct process measurement. The Bourdon tube, which is the sensor, directly converts the pressure to an indication of pressure. However, many physical variables are converted into some other variable which either directly operates a readout device or is reconverted in a transmitter to produce a transmission signal. For example, a temperature change can create a differential expansion in a bimetallic strip, generate an electromotive force in a thermocouple, increase the pressure within a vapor-filled bulb or produce volumetric expansion in a mercury thermometer.

The number of practical measurement signals is much smaller than the number of physical variables described in Fundamentals.

Some of the practical measurement signals and their typical applications follow.

Current (Electronic Transmitters)
Force (Force Balance Detectors)
Frequency (Turbine or Displacement Flow Meters)
Impedance (Electronic Sensors)
Light or Electron Beam Motion (Oscilloscopes, Galvanometers)
Liquid Displacement (Manometers, Thermometers)
Motion (Motion Balance Sensors)
Pressure (Pneumatic Transmission, Liquid Filled Capillary Elements)
Pulse Duration (Telemetering)
Pulse Code (Computers, Data Loggers)
Voltage (Potentiometers)

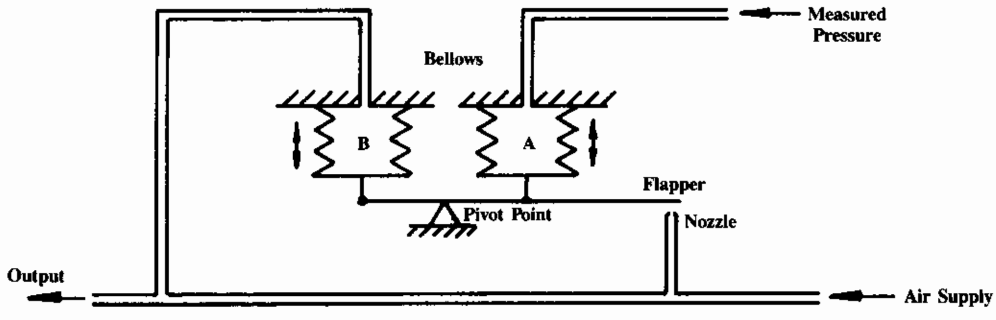
Transducers have been developed to convert most of the physical variables into measurement or transmission signals. Multiple signal combinations can be economically combined with microprocessor-based circuitry.

Measuring Equipment

Measuring, metering, monitoring and automatic control equipment in varying combinations is required to operate a process efficiently. The prime requirement for all of these functions is an instrument that can accurately sense the measured variable and display the value, or transmit a signal for interpretation by other devices. An instrument, as a primary element, is composed of some type of sensing device in contact with the fluid or substance, an amplification unit and the physical unit which indicates the measurement or translates the sensing impulse into some kind of power or motion. Instrumentation has been developed to sense and indicate nearly all known physical or chemical characteristics.

Direct Connected Devices

The originally developed sensing elements were self-contained units which sensed the measured variable and displayed it in units such as °C, kPa and kg/h. With time it became apparent that benefits would result from the use of transmitters and transducers that permitted remote indicators, more complex control loops and central control rooms.



Simplified Diagram of Motion Balance Pneumatic Transmitter
Figure 5

Transmitters and Transducers

A *transmitter* is defined as "a device that senses a process variable through the medium of a primary element, and has an output whose steady state value is a predetermined function of the process variable". The primary element may be separate or an integral part of the transmitter.

A *transducer* is a device which receives information in the form of one quantity and converts it to information in the form of the same or another quantity. An example would be the conversion of a 4-20 mA signal from a transmitter to a pneumatic signal.

A pneumatic transmitter is a device that senses a process variable and translates the measured value into an air pressure which is transmitted to various receiver devices for indication, recording, control and/or alarm purposes.

Pneumatic transmitters, developed in the late 1930s, permitted grouping of controllers without the need for bringing potentially flammable or toxic fluids inside a control room. Furthermore, the use of air pressure provided a safe signal medium for hazardous environments.

A "live" zero pneumatic pressure signal such as 21 kPa(gauge), provides a definite indication of air supply failure, since the output would drop to 0 kPa(gauge). By 1950 most instrument manufacturers adopted a 21 to 103.5 kPa(gauge) range and by 1958 formal recognition of this was made by the Scientific Apparatus Makers Association (SAMA).

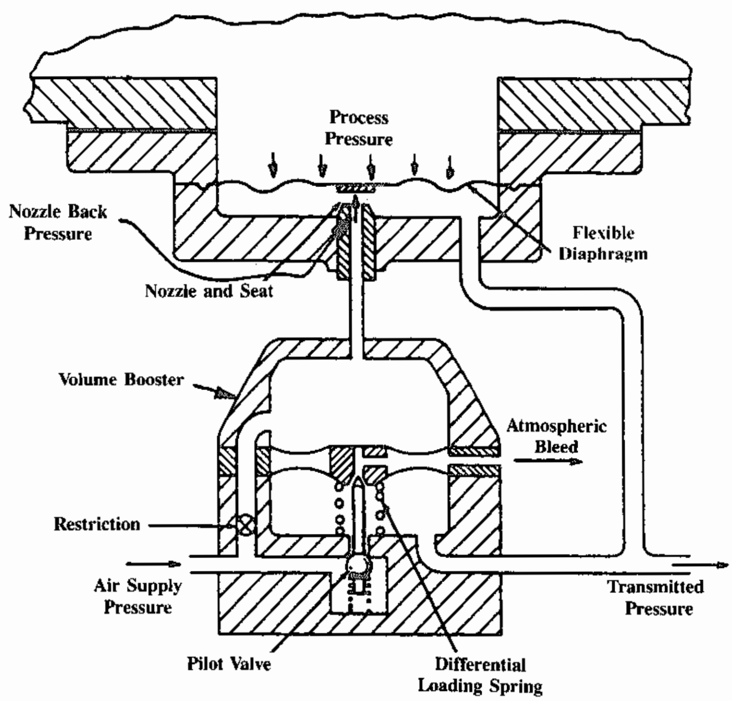
A simplified example of a motion balance pneumatic transmitter mechanism is shown in Figure 5. Bellows "A" moves the flapper closer to the nozzle as the measured pressure increases. This causes an increase in the air pressure sensed by bellows "B" which moves the flapper away from the nozzle until equilibrium is restored. Thus, the output air signal will be proportional to the measured pressure.

Force balance transmitters are commonly used today. Reference to Figure 6 and the description below will provide a general understanding of the principles involved.

- Process pressure acts on the flexible diaphragm and the resulting force is counterbalanced by the nozzle back pressure acting upward on the diaphragm.
- Air, at a supply pressure slightly higher than the maximum process pressure to be measured, flows through the restriction, nozzle and seat to the underside of the diaphragm. This pressure is also the transmitter output signal.
- The volume booster and constant differential nozzle circuit provides additional air handling capacity to speed up response, minimize transmission lag and cope with air leakage.

- The differential loading spring provides, at balance, a force equal to 21 kPa(gauge) acting on the diaphragm. Therefore, the nozzle back pressure, which acts above the exhaust diaphragm, is always 21 kPa(gauge) higher than the process pressure to provide the "live zero" signal.

Electropneumatic transmitters are also called converters or transducers. They are extremely important, since they are the link between electrical measurement and pneumatic systems. A typical electropneumatic converter would have an input signal of 4 to 20 mA and air output of 21 to 103.5 kPa(gauge). This device would require a 140 kPa(gauge) instrument air supply.



Typical Force Balance Pressure Transmitter
Figure 6

Signal Transmission

Most measuring and controlling devices work together via a compatible signal transmission system. Just as English or French is a form of communication, so too are the 4 to 20 mA or 21 to 103.5 kPa(gauge) signal transmissions systems. For computers there are many forms of communications, such as serial, parallel, RS232, and BCD. Earlier, around the 1940s and 1950s, telemetry was the word used for instrument electrical or radio frequency signal transmission.

The scope of discussion in this module will be limited to pneumatic or electronic signal transmission types and a brief introduction to telemetry. The majority of instrument communication is based on pneumatic or electronic analog signal transmission for short to medium distances with telemetry being used for long distances.

Pneumatic or electronic transmission signals are not a choice between devices using different types of power supply but a choice between different characteristics that are selected because of the application. The advantages and disadvantages of pneumatic and electronic transmitters are provided in Table 1. SAMA has a standard for pneumatic signals of 21 to 103.5 kPa(gauge) and fortunately most manufacturers adhere to it. A similar standard for electronic signals is less strictly adhered to, although 4 to 20 mA is the most commonly used signal.

Telemetry is a form of signal transmission by radio for distances beyond 1500 m. An application of telemetry is the transmission of data from a space probe to earth.

PNEUMATIC VERSUS ELECTRONIC TRANSMITTERS

TABLE 1

	Advantages	Disadvantages
Pneumatic	• Low initial capital cost • Safe to use in hazardous areas • Compatible with most final control elements • Easy to understand • Immune to momentary electrical power loss	• Slower signal response • Limited transmission to 200 m • Cannot directly communicate with computers • Requires good quality instrument air equipment • Potential leaks in tubing and connections • Requires good maintenance to maintain operation
Electronic	• Transmission time lag negligible • Transmission distances to 1500 m • Compatible with most computer equipment • Signal conversion not required for primary elements such as: Magnetic Flow Meters, Turbine Flow Meters, Vortex Meters • Maintenance requirements are lower • Energy consumption costs are lower	• Higher installed capital cost • Special equipment required in hazardous areas • Vulnerable to electrical power interruptions • Vulnerable to some radio interference • Conversion to pneumatic usually required for final control elements • Higher skill level required for maintenance personnel • Test equipment is expensive • Specific cable installation requirements to prevent erroneous signals

Flow Measurement

Differential Pressure

Putting a finger partially over the end of a garden hose demonstrates that restricting the flow increases the velocity. Orifice plates, flow nozzles, venturi tubes, elbow meters, flumes and other configurations also cause a restriction in a pipe, duct or channel. The principle of operation is similar, so the description will be confined to an orifice. An orifice is a primary element which is a round flat metal plate with a hole. This plate is clamped between the pipe or duct flanges at right angles to the fluid flow to cause a restriction to the flow (Figure 7). An increase in fluid velocity through the orifice hole is accompanied by a decrease in static pressure, and the higher the velocity the lower the pressure. This results in a pressure difference across the orifice which will vary with the flow rate. This pressure difference can be converted to a flow indication by a flow measuring instrument.

There is a mathematical relationship between the flow through the orifice plate and the differential pressure measured across the orifice plate. This relationship can be taken directly from the curve (Figure 8) or from the equation:

$$\text{Per cent of differential pressure range} = \left(\frac{\%\ \text{Flow}}{100}\right)^2 \times 100$$

Table 2 shows that an orifice flow measurement provides 3:1 flow rangeability. This means that this form of flow measurement can be used to dependably measure flow from 100 per cent of design capacity to 33 per cent. The reason for this rangeability limitation will be explained by an example that shows the differential pressure implications of a 33 per cent of range flow measurement.

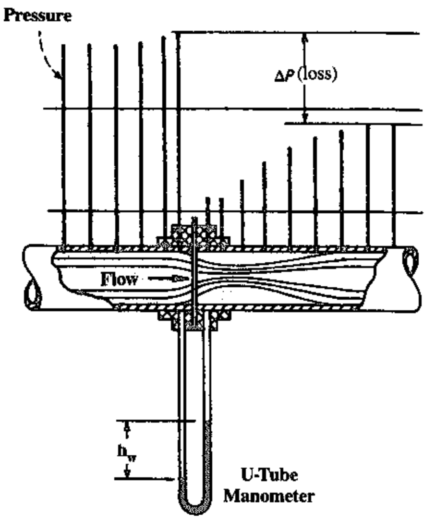
$$\text{Per cent of differential pressure range} = \left(\frac{33}{100}\right)^2 \times 100$$

$$= 10.9\%$$

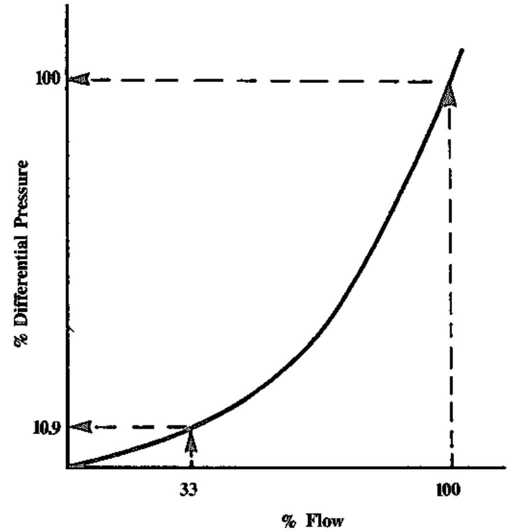
This calculated value can be checked with the Figure 8 curve by starting at the 33 per cent flow rate. Move vertically to the curve, then horizontally to the vertical side where 10.9 per cent differential pressure is read. The foregoing steps can be repeated to calculate the per cent differential pressure at 100 per cent flow.

$$\text{Per cent of differential pressure range} = \left(\frac{100}{100}\right)^2 \times 100$$

$$= 100\%$$



Orifice Flow Measurement
Figure 7



Flow/Differential Pressure Relationship
Figure 8

Figure 8 can be used again to confirm that 100 per cent of the differential pressure range occurs at 100 per cent of the flow range.

$$\text{Flow rangeability} = \frac{100}{33}$$

$$= 3$$

This can also be expressed as 3:1. However, the differential pressure rangeability requirement is much greater.

$$\text{Differential pressure rangeability} = \frac{100}{10.9}$$

$$= 9.2$$

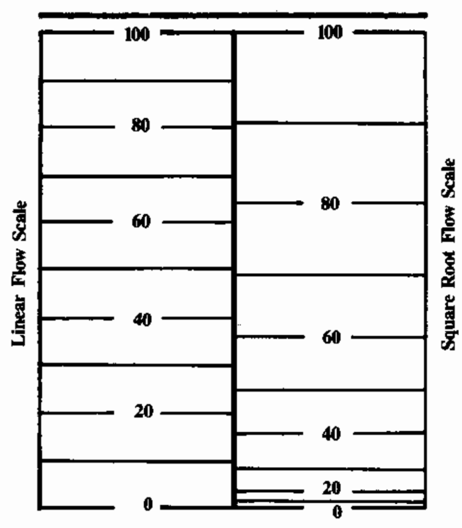
This can be expressed as 9.2:1. It is this differential pressure relationship that limits the use of this type of flow measuring device to a flow turndown of 3:1. If the flow decreases below this limit, the differential pressure becomes so small that the instrument does not measure it reliably and accurately. For example, the range of the differential pressure transmitter may be 30 kPa and the instrument accuracy guarantee might be ±1 per cent of range span. In absolute terms the error might be 30kPa x 0.01 = ±0.3 kPa. At the above calculated differential pressure range of 9.2 per cent, the differential pressure would be 30 kPa x 0.092 = 2.76 kPa.

$$\text{Measurement Accuracy} = \frac{\pm \text{ Error}}{\text{Actual Measured Variable Quantity}} \times 100$$

$$= \frac{0.3}{2.76} \times 100$$

$$= \pm\ 10.9\ \%$$

A differential pressure flow measuring device will have a square root flow scale (Figure 9). It should be noted that it is much easier to read higher flow values on the scale.



Linear Versus Square Root Flow Chart
Figure 9

The pressure profile (Figure 7) also shows that the pressure after the orifice does not return to the upstream value. This unrecovered head or pressure loss is an important consideration in the selection of any differential pressure flow measurement (Table 2).

There are flow devices which can extract the nonlinear relationship mechanically. They are often used to measure steam, water and natural gas flows for boilers and offer two advantages. The first is that the flow rangeability is extended to 4:1. The other benefit is that the the flow chart is linear instead of square root (Figure 9).

To ensure maximum accuracy from a flow measurement there must be a certain amount of straight pipe before and after the primary element. The length required will vary depending on the type of element and the piping arrangement. Table 2 identifies typical straight pipe requirements.

CHARACTERISTIC/RELATIVE COST COMPARISON
FLOW SENSORS
TABLE 2

TYPE	SERVICE	RELATIVE COST	ACCURACY ±% SPAN (UNLESS NOTED)	RANGE-ABILITY	PRESSURE LOSS	TYPICAL MINIMUM STRAIGHT LENGTH PIPE DIAMETER (UPSTREAM/ DOWNSTREAM)	OUTPUT SIGNAL CHARACTERISTIC
Orifice	Gas, Steam & Clean Liquids	M	1% to 3%	3:1	H	20/5	Square Root
Flow Nozzles & Venturi Tubes	Gas Clean Liquids Slurries (L) Viscous (L)	M/H	0.5% to 3%	3:1	M	20/5	Square Root
Elbow Tap	Gas Clean Liquids Slurries (L) Viscous (L)	L	5% to 10%	3:1	N	30/10	Square Root
Weirs & Flumes	Clean Liquids Slurries (L) Viscous (L)	M	2% to 5%	30:1	M	Open channel measurement Flow must be smooth on entry	Differs between various designs some are linear most are not
Pitot Tube	Air, Gas Clean Liquids	L	2% to 5%	3:1	L	40/10	Square Root
Turbine Meter	Gas Clean Fluids Viscous (L)	M	0.25% to 5% of Indication	10:1	H	15/5	Linear
Positive Displace-ment Meter	Gas Clean Liquids Viscous (L)	M	0.5% to 1%	100:1 Gas 10:1 Liquid	M/H	None	Linear
Variable Area	Gas Clean Liquids Viscous (L)	L/M	0.5% to 5%	10:1	M	None	Linear
Vortex Flowmeter	Gas, Steam & Clean Liquids	M	0.5% to 1%	10:1	H	15/5	Linear
Hot Wire Anemometer	Gas or Liquids	L	1% to 2%	20:1	M	5/3	Varies between different manufacturers
Magnetic Flow Meter	Conductive Liquids, Slurries (L)	H	0.5% to 2%	30:1	N	None	Linear
Sonic Flow Meter Transit Time	Clear Liquids	M/H	1%	20:1	N	15/5	Linear
Sonic Flow Meter Doppler	Clear Liquid - must contain bubbles - Slurries	M	2% to 10%	20:1	N	15/5	Linear
Solids Flow Meter (Weigh Scale)	Solids Slurries	M/H	2% to 10%	20:1	L	5/3	Linear
Metering Pump	Clear Liquid Slurries Viscous	L/M	0.1% to 1%	20:1	N	N	Linear

LEGEND

(L) — Limited   M — Medium   N — None
L — Low   H — High

Velocity Head

The total pressure of an air stream flowing in a duct is the sum of the static pressure exerted on the sidewalls of the duct and the velocity pressure of the moving air (Figure 10). The illustrated Pitot tube is a common device for measuring the velocity pressure. To ensure measuring accuracy many measurements must be taken in accordance with traverse details shown. The velocity pressure should be calculated for each traverse position and the readings averaged. The velocity pressure in a duct can be calculated.

$$Va = 0.764 \times \left(\frac{T \times Pv}{B}\right)^{0.50}$$

Where, Va = average velocity (m/s)

T = temperature (K)

Pv = velocity pressure (Pa)

B = barometric pressure (kPa(absolute))

0.764 = equation constant and conversion of units

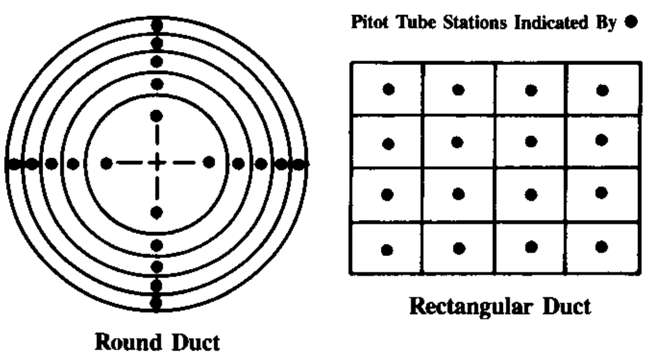
The volume flow rate can then be calculated.

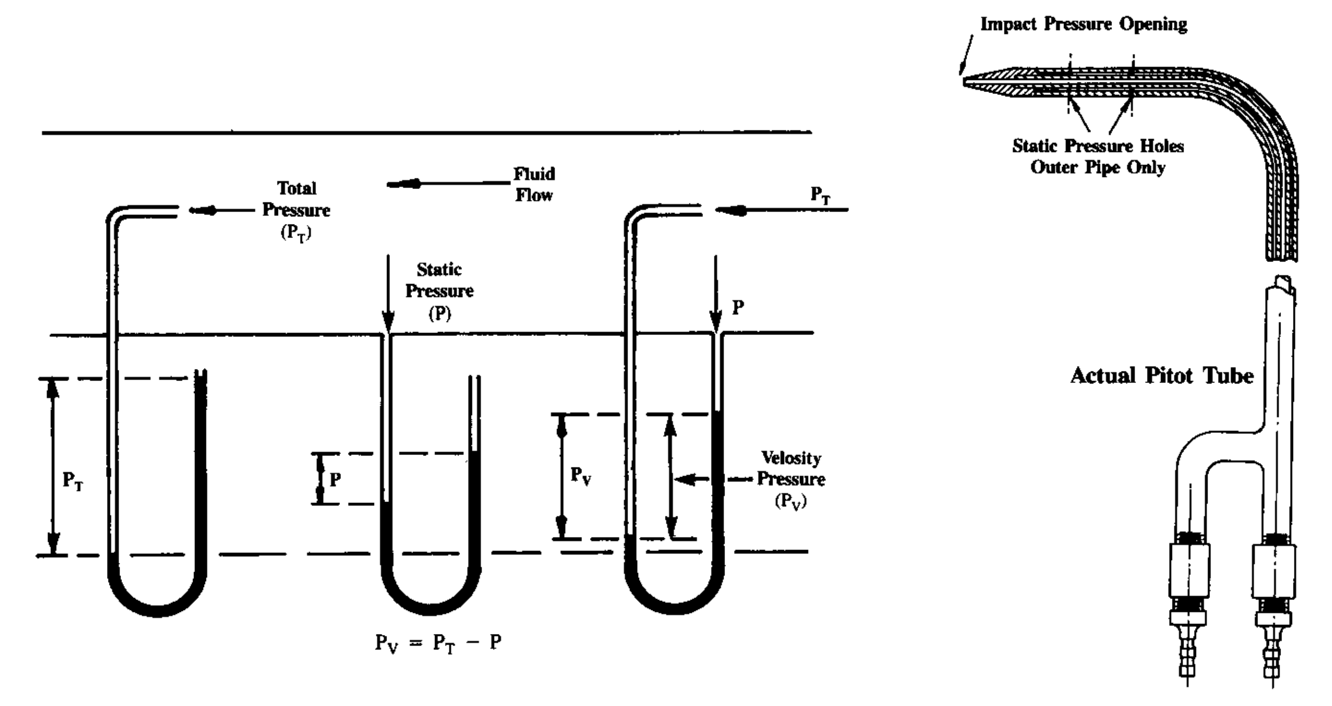
$$Q = Va \times Ad \times 1000$$

Where, Q = volume flow rate (L/s)

Ad = area of duct (m^2)

1000 = conversion of units





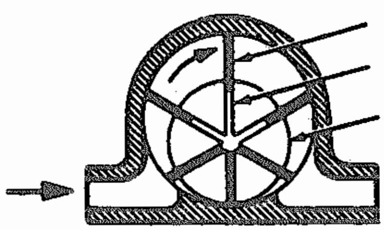
Pitot Tube Flow Measurement
Figure 10

A Pitot tube and manometer are often used to determine the flow of air in a duct in order to assess fan performance and for balancing the distribution of air in heating, ventilating and air conditioning (HVAC) systems.

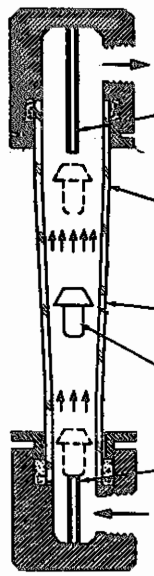
The air velocity can be measured within 2 to 5 per cent accuracy depending on the care taken with the traverse readings.

Turbine Meter

This instrument works on the windmill principle and can be used to measure liquid and gas flow in a pipe. A multibladed propeller on a free running bearing is inserted in the stream so that flow causes it to rotate. The speed of rotation is directly proportional to the flow rate, and can be converted to an electrical or mechanical output signal. Table 2 shows that these instruments have greater rangeability (10:1) than the differential pressure types (3:1), and greater accuracy.



Positive Displacement Flow Meter
Figure 11



Variable Area Flow Meter (Rotameter)
Figure 12

Positive Displacement Meter

Positive displacement meters operate by passing fixed volumes of fluid through the body of the meter and counting these incremental volumes. There are numerous designs, but the rotating vane model (Figure 11) is an easily understood example.

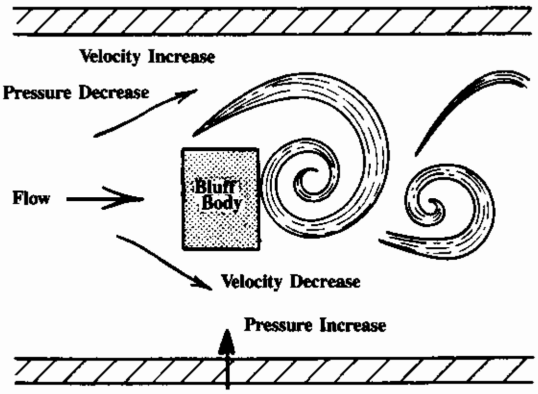
The rotor is free to turn and is caused to do so by the fluid flow against the vanes. The vanes, which slide in and out of the slots in the rotor, are constructed so that they completely seal against the meter body. Thus, a specific volume of fluid is isolated between two vanes and transported through the meter. This type of meter measures volume directly with good accuracy (0.5 to 1.0 per cent) over very wide flow ranges of at least 10:1 for liquids, and 100:1 for gases (Table 2). These meters are often used in applications where the measured flow is to be used for billing purposes.

Variable Area Flow Meter

The variable area flow meter, often called a rotameter, is a tapered, transparent meter tube with a float within the tube (Figure 12). This instrument is mounted vertically so that the flow enters at the bottom and exits from the top. The float restricts the fluid flow, creating a differential pressure across the float. This pressure difference and the buoyancy of the float counteracts its weight causing it to rise in the fluid. As flow increases so does the differential pressure causing the float to rise. As the float rises, the area around it increases because of the tube shape. This increase in area allows the pressure across the float to drop until the point is reached where it is in equilibrium. Thus, the position of the float in the tube is proportional to the flow, and the tube surface can be marked in flow units.

Vortex Flowmeter

Vortex flow instruments operate on the principle that an unstreamlined object (bluff body) inserted in the fluid flow will cause eddies or vortices (Figure 13). These vortices are shed alternately from each side of the bluff body to create an action similar to a flag fluttering in the breeze. The frequency of the vortices is proportional to the flow rate, and this can be detected and electrically converted to an output.



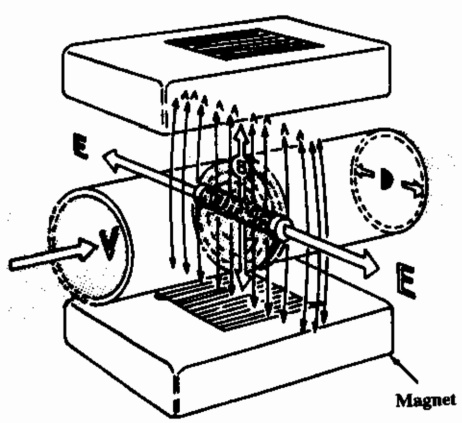
Vortex Flow Meter
Figure 13

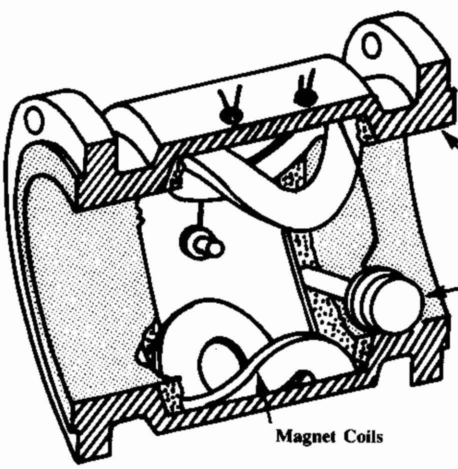
Nonintrusive Measurement

All of the flow measuring instruments discussed so far have some object in the fluid stream. For this reason they are called intrusive measurements. This can be a disadvantage because of unrecovered head losses and flow materials which plug or contaminate instruments and connecting lines. The following nonintrusive devices have been designed to eliminate these problems.

1. *Magnetic flow meters* work on the basis of Faraday's law of electromagnetic induction which states that a voltage will be generated in a conductor when it is moved through an electromagnetic field. The value of this voltage will be proportional to the conductance, which changes according to the volume of fluid flowing through the pipe, and the strength of the magnetic field. This is the working principle of an electrical generator and it can be used to measure the flow of a conductive liquid (Figure 14).

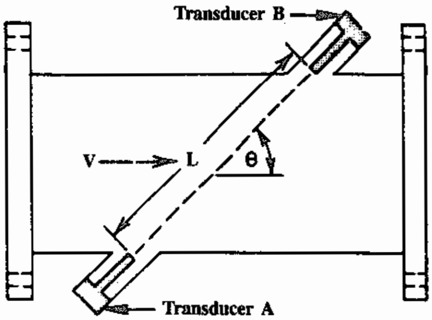
A magnet coil is mounted on each side of a pipe. When the coils are excited by a fixed voltage, a constant electromagnetic field is set up across the pipe. The flow of a conductive liquid through the pipe, thus through the magnetic field, acts like a conductor and a voltage is generated in the liquid. The voltage is proportional to the liquid velocity because the field strength is fixed. Two electrodes inserted into opposite sides of the pipe at 90° to the coils sense the voltage. The voltage can be amplified and used to drive an output device. These meters are expensive, particularly in large sizes, but they offer advantages such as unobstructed flow, no pressure drop, high rangeability, suitability for dirty fluids and bidirectional flow measurement.





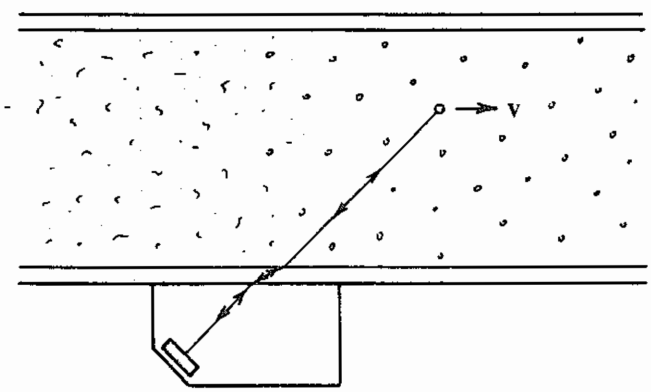
Magnetic Flow Meter
Figure 14

2. *Transit time sonic flow meters* are suitable only for liquid flow measurement. These units include two ultrasonic transducers which are mounted facing each other at an angle across a section of pipe (Figure 15). Each device sends out ultrasonic pulses and receives them from the opposite device. If the liquid in the pipe is stationary, the times for pulses to go from A to B and B to A are equal. When there is flow, the pulse travel time from A to B reduces and that from B to A increases. This time difference is proportional to the liquid velocity in the pipe, and can be converted to a flow output. These units can be quite accurate when designed for a specific application. However, they are adversely affected by particles or bubbles in the flow stream.



Sonic Flow Meter
Transit Time Method
Figure 15

3. The *Doppler type sonic flow meter* has a single transducer which is usually mounted on the outside of the pipe (Figure 16). There must be suspended particles or bubbles in the liquid for these units to operate properly. The device sends out ultrasonic pulses and senses the frequency reflected from the particles or bubbles in the flow stream. The frequency received is proportional to the velocity of the liquid flow and can be converted to a flow output. These units are portable and the transducer can be strapped to almost any section of pipe. The accuracy of the Doppler flow measurement is poor.



Sonic Flow Meter
Doppler Method
Figure 16

Pump

Positive displacement pumps can be used as metering devices. There are a number of controlled volume pumps which are suitable for metering service. These pumps have been designed for metering with the internal leakage controlled to suit the accuracy requirements. Diaphragm, piston, gear, peristaltic, and some screw pumps are used for metering. One of the advantages of metering pumps is that they can measure difficult-to-handle fluids such as slurries and very viscous liquids.

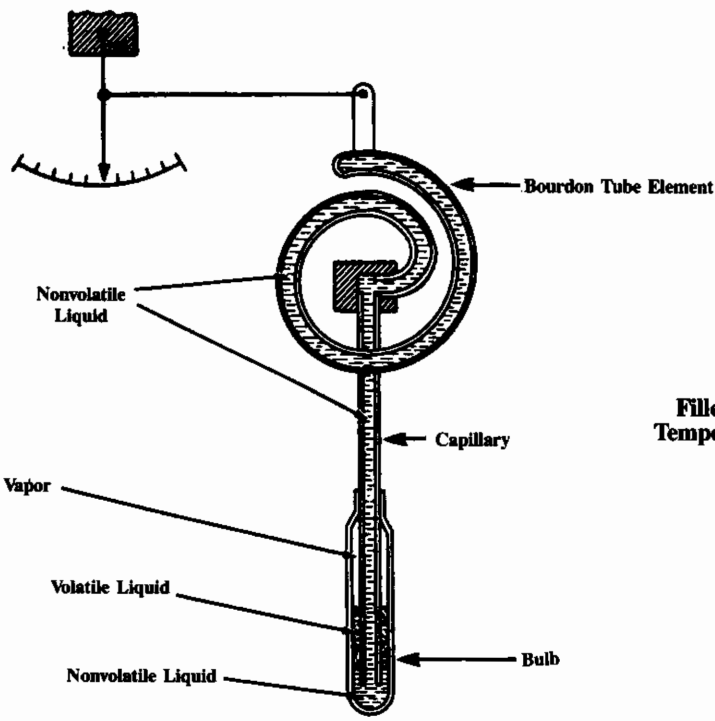
Temperature Measurement

The methods of measuring temperature are reviewed under the Mechanical and Electrical headings.

Mechanical

Most metals, gases and liquids expand and contract with temperature changes and this principle is utilized in many forms of mechanical temperature sensing systems.

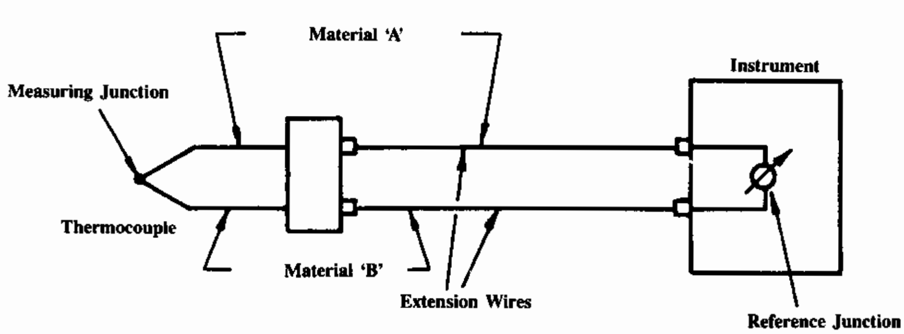
- *Filled thermal systems* are essentially pressure measuring systems consisting of a pressure gauge connected to a bulb by means of a gas-tight fine tube or capillary (Figure 17). The system is filled with a pressurized gas, liquid or vapor. The bulb is inserted in the medium to be measured, and changes in temperature are reflected by changes in the internal pressure, which cause the pointer to deflect. There are a number of classifications for slightly different applications. The suitability of a class for a specific application should be checked with the manufacturer. Table 3 lists some of the characteristics for each class.
- *Bimetallic thermometers* are constructed from two thin strips of metal with dissimilar coefficients of expansion bonded together in a coil. When the temperature changes, the metals expand or contract at different rates causing the coil to unwind or recoil. This movement is similar to a pressure gauge and can be used to position a pointer which provides a temperature indication.



Filled Thermal System Temperature Measurement
Figure 17

Electrical

- *Thermocouples* are based on the principle that a voltage proportional to the temperature is produced when two dissimilar metals are joined and the junction is heated. This simple principle (Figure 18) is widely used for remote temperature indication or recording.



Thermocouple Temperature Measurement
Figure 18

- *Resistance Temperature Detectors (RTDs)* are based on the characteristics of certain metals in which the electrical resistance increases as the temperature increases. This resistance change can be measured and converted to a temperature output. Metals commonly used for this purpose are platinum, nickel, an alloy of nickel and iron, and copper. These devices can be expensive because of the metals used, but they are accurate and have extremely good repeatability and long term stability. Platinum RTDs are the international standard for temperature measurement between -259.19°C and 630.75°C.
- *Radiation pyrometers* operate on the principle that objects radiate different amounts of energy according to their temperature. These instruments can measure radiation without making contact with the object being measured, and convert the measured signal to a temperature output. Normally, these units are hand held to make periodic checks, but they can also be permanently installed. There are a variety of types and uses which range from measuring the temperature of molten metal to making heat loss profiles of buildings.

Table 3 summarizes the characteristics and relative cost of many common temperature sensor types.

TEMPERATURE SENSORS
CHARACTERISTIC/RELATIVE COST COMPARISON
TABLE 3

TYPE	RECOMMEND RANGE LIMITS	RELATIVE COST	ACCURACY ±% SPAN	REPEAT-ABILITY	RESPONSE TIME
Glass Stem Thermometer	−50°C, +800°C	L	1% to 2%	E	G
Filled Thermal*					
Liquid	−30°C, +400°C		0.1% to 2%	F	G
Vapour	−15°C, +300°C	L/M	0.5% to 2%	F	F
Gas	−265°C, +800°C		0.5% to 2%	F	G
Mercury	−40°C, +650°C		0.5% to 2%	F	F
Bimetallic	−60°C, +425°C	L	1% to 4%	F	G
Thermocouple					
Type T	−150°C, +260°C		0.3% to 1%	G/E	E
Type J	−160°C, +800°C	L/M	0.3% to 1%	G/E	E
Type K	−150°C, +1500°C		0.3% to 1%	G/E	E
Type R & S	−15°C, +1700°C		0.3% to 1%	G/E	E
RTD					
Nickel	−150°C +260°C	L/M	0.1%	E	G/E
Platinum	−255°C +650°C	M/H	0.1%	E	G/E
Pyrometers					
Optical	+760°C, +3500°C	M/H	1% to 2%	–	F/G
Infrared	0°C, +3300°C		1% to 2%	–	E
Radiation	500°C, +3900°C	H	0.5% to 1%	G/E	G

* This type is non linear and may only be able to measure above or below the ambient temperature.

LEGEND

E	– Excellent	L	– Low	RTD	– Resistance Temperature Detector
G	– Good	M	– Medium		
F	– Fair	H	– High		

Pressure Measurement

Pressure can be measured with manometers, Bourdon tubes, bellows, diaphragms and strain gauges. The relationship of absolute and gauge pressures is demonstrated by means of a graph (Figure 19). Table 4 provides characteristics versus relative cost for various pressure sensors.

Manometer

Manometers measure the height of a column of liquid whose weight is in equilibrium with the applied pressure. The U-tube manometer (Figures 7 and 10) show how the displacement is measured directly as the height of the fluid column. This instrument has no moving mechanical parts and virtually no friction or inertia. The measurement accuracy is limited only by the accuracy of the reading and the density of the fluid. U-tube manometers are very often used as a calibration standard for other types of pressure instruments.

The pressure is normally expressed by the equation:

$$P = 0.102 \times h \times D$$

Where, P = pressure (Pa)

h = height of liquid (m)

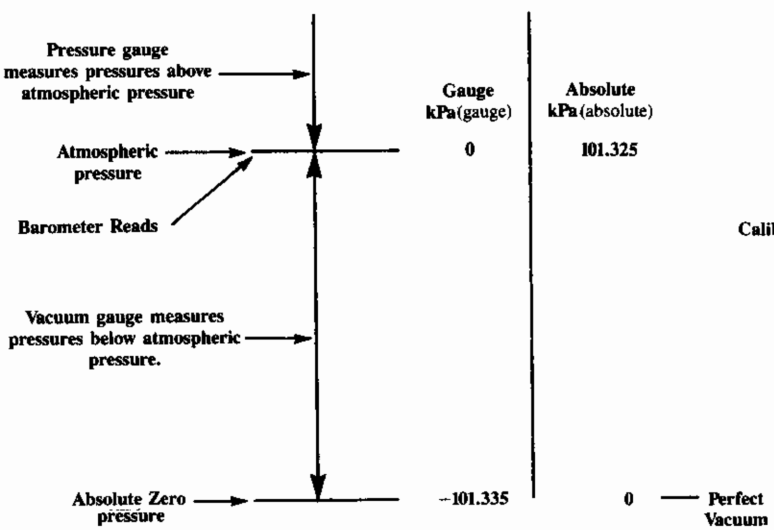
(This will normally be measured in mm which must be divided by 1 000 to get m)

D = density of liquid (kg/m^3)

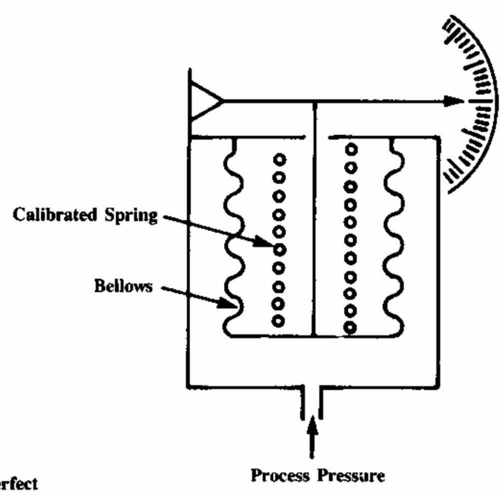
0.102 = conversion of units from kg/m^2 to Pa

If the high pressure side is filled with a liquid of significantly different density compared to that of the measuring liquid, the measurement must be compensated for the weight of this liquid and the equation becomes:

$$\text{Pressure} = (0.102 \times h \times \text{density of measuring liquid}) - (0.102 \times h \times \text{density of measured liquid})$$



Pressure Measurement Terms
Figure 19



Bellows Pressure Element
Figure 20

Bourdon Tube, Bellows & Diaphragm

Bourdon tubes, bellows and diaphragms work on the principle that the device will be deformed by a change in pressure, but the elasticity of the construction materials causes a return to the original shape when the pressure is removed. The operation of a Bourdon tube (Figure 3) is based on the fact that the tube responds to pressure, and the movement is transferred through a link and gears to position a pointer. The bellows type pressure sensor (Figure 20) is shown with a calibrated spring, but this is not always required. These instruments can also be constructed with two opposing bellows to measure differential pressure. A diaphragm is a flat surface with sufficient "give" at the edge to permit movement (Figure 6). The diaphragm is least sensitive to ambient temperature changes and elastic hysteresis, making it more accurate than the other mechanisms.

Strain Gauge

These instruments operate on the principle that the electrical resistance of a metal conductor will change under mechanical strain. Strain can be applied to a metal conductor by the pressure being measured. The resulting change in resistance can be electrically amplified and used to produce a pressure output. The advantage of this approach is that the strain can be obtained with virtually no movement of the pressure-sensing mechanism. This eliminates most of the mechanical inaccuracies of the bellows or Bourdon tube.

PRESSURE SENSORS
CHARACTERISTIC/RELATIVE COST COMPARISON
TABLE 4

TYPE	SERVICE		RELATIVE COST	ACCURACY ±% SPAN unless noted	MAXIMUM DESIGN PRESSURE kPa
	ABSOLUTE PRESSURE RANGE (kPa)	GAUGE PRESSURE RANGE (kPa)			
Manometer	0-410	0-410	L/M	0.1% to 1%	40 000 (normally used for low pressure)
Bourdon Tube		0-690 000	L/M	0.25% to 5%	690 000
Bellows	0-240	0- 14 000	M	1%	41 000
Diaphragm	0-350	0- 1 400	M/H	0.5% to 1%	10 000
Strain Gauge		0- 1 400 000	H	0.1% to 1%	1 400 000

LEGEND

L — Low
M — Medium
H — High

LEVEL SENSORS
CHARACTERISTIC/RELATIVE COST COMPARISON
TABLE 5

TYPE	SERVICE	RANGE (metres)	RELATIVE COST	ACCURACY ±% SPAN	DESIGN PRESS./TEMP.
Level Gauge (Sight Glass)	Clean Liquids Slurries (L) Viscous (L)	2.5	L/M	(±6 mm typical)	69 000 kPa 370°C
Float	Clean Liquids Slurries (L) Viscous (L)	Narrow to unlimited depends on type	L	0.5% - 1.0%	7 000 kPa 260°C
Displacer	Clean Liquids	3	L/M	0.5%	4 000 kPa 450°C
Surface Sensors (Yo-Yo)	Solids Clean Liquids Slurries (L)	30	M	1%-5%	2 000 kPa 150°C
Differential Pressure	Depends on Type Clean Liquids Slurries (L) Viscous (L) Solids (L)	Unlimited	L/M	0.3%-5%	Low to 100 000 kPa 100°C
Capacitance or Impedance Probes	Clean Liquids Slurries Viscous Solids(L)	45	L/M	0.5%-3%	7 000 kPa 800°C
Ultrasonic	Clean Liquids Slurries Viscous Solids	30 in air 600 in liquid	L/M	1%-3%	1 000 kPa 100°C
Radiation	Good for Hard to Handle Materials	15	M	1%-2%	NA 100°C
Bubbler	Liquid Tanks Pressurized or open to atmospheric	20	L	1%-2%	0 to 700 kPa 200°C
Weight	Liquid or Solids Good for Hard to Handle Materials (Solids)	Limited only by size of tank or bin	H	0.1%-1%	NA 500°C

LEGEND

(L) — Limited
L — Low
M — Medium
H — High
N — None

Level Measurement

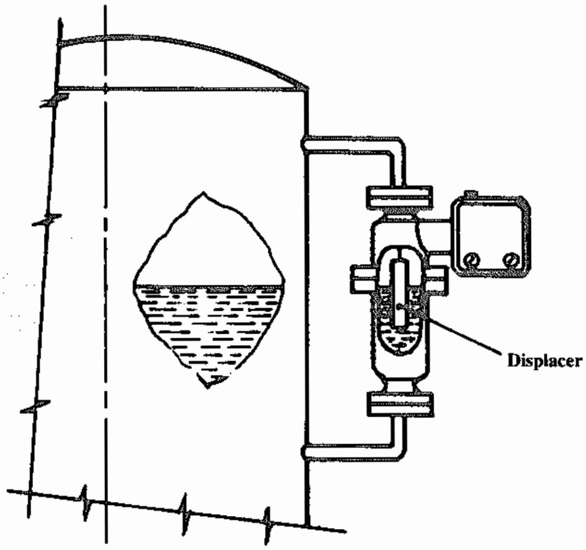
Level measurement can be simple, but there are a variety of complexities that can make the measurement difficult. Complicating factors, such as the following, should be carefully examined before selecting the instrument.

- Open tank or pressurized vessel.
- Turbulence.
- Characteristics of solids in bins.
- Interface detection.
- Frothing (foaming).
- Solidification.
- Composition change because of air bubbling.
- Shrink and swell effect in boilers.
- Material temperature.

Level measuring devices in this module are described under the headings of sight glasses, mechanical, pressure, and electrical types. Table 5 provides characteristics versus relative costs for various level sensor arrangements.

Sight Glass

This is simply an open glass tube connected to the bottom of a tank. The level of the liquid in the tube corresponds to the level in the tank and can be observed. A top connection is required if the tank is pressurized. Sight glasses can be designed for relatively high pressures by clamping a piece of heavy flat glass on the open side of a metal tube.



Displacer Level Measurement
Figure 21

Mechanical

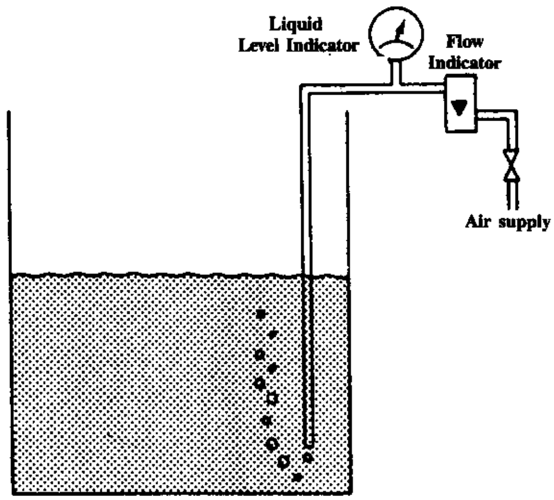
- A *float* is a basic mechanical level measuring device. The movement of the float via cables, linkage or other means can be converted to a level output.
- The operation of a *displacer* is based on Archimedes' Principle, that any item immersed in a liquid is buoyed by an amount equal to the weight of the liquid displaced. This means that a float or displacer of a material heavier than the liquid to be measured can be used to measure level (Figure 21). As the liquid rises around the displacer, the displacer becomes more buoyant. The resulting small movement of the displacer arm is proportional to level change and it can be amplified to produce an output. The main advantage is that the movement is quite small compared to that of a float for the same level variation.
- *Surface-sensor* instruments are used primarily to measure the level of solids in bins. The idea is the same as that used by early sailors when they were "sounding" for depth. A weight is lowered into the bin on a cable and the change in cable tension, when the weight contacts the surface, is detected by a weigh balance. Detecting the surface causes the cable to rewind and the length is measured by a counter on the rewind drum. These instruments are sometimes called "yo-yos" because of the continuous up and down action. Dust and product buildup on the cable or corrosion of the cable can cause problems.

Pressure

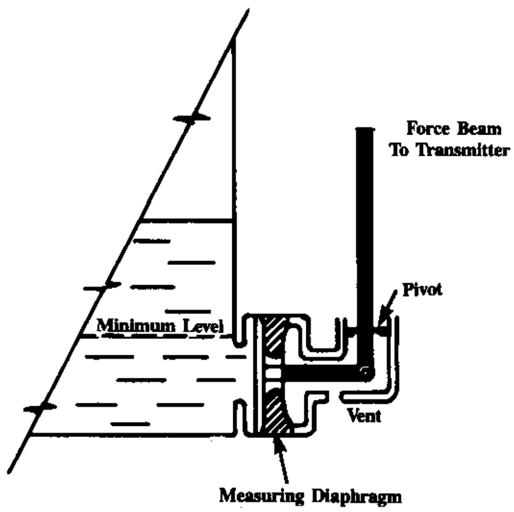
Liquid level can be determined by measuring pressure. A common example is the application of a head of liquid to a diaphragm, bellows or Bourdon which converts this head to a level output.

The bubbler arrangement (Figure 22) permits the measurement of level without exposing the instrument to the liquid. This technique might be used when the liquid is corrosive, where the connection to the side of a tank would become plugged, or where it was inconvenient to put a level sensing connection in the side of the tank. The system works because the air supply is regulated so that there is only a small flow through the air flow indicator to the bubble pipe. This means that the air pressure is only great enough to permit its escape from the end of the pipe. Thus, the measured air pressure would be essentially the same as the static pressure or head of the liquid.

A diaphragm level sensing element (Figure 23) is shown for an open tank installation. The liquid level creates a force on the diaphragm that causes the linkage to move, with the motion being transferred through the force beam to position a transmitting device proportional to level. A modified form of this instrument can be used to measure the level in a pressurized vessel. In this case, the housing on the side of the diaphragm away from the tank liquid would be modified to accept the pressure from the top of the vessel. Thus, the difference in pressure across the diaphragm would again be equal to the head from the liquid level.



Bubbler Level Measurement
Figure 22

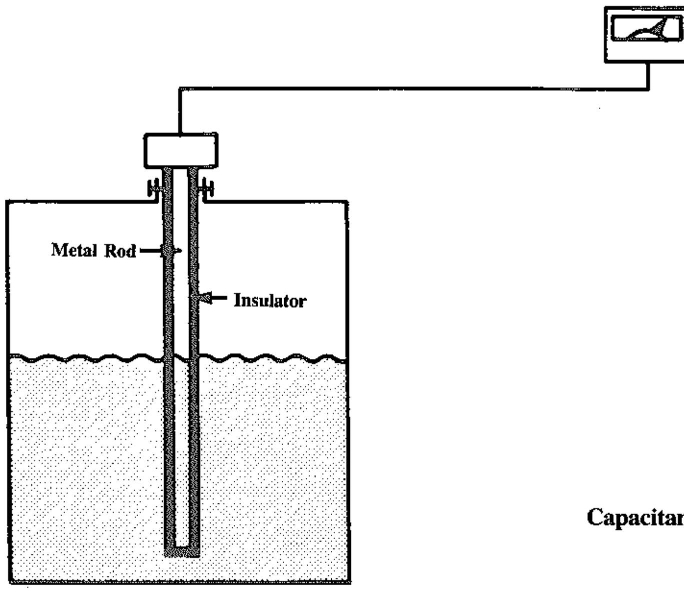


Diaphragm Level Measurement
Figure 23

Electrical

Several instruments use electrical principles to sense level.

- Capacitance probes determine the tank liquid level by measuring the capacitance between capacitor plates. A probe for liquids, which are good conductors, consists of a metal rod covered with an insulator (Figure 24). A rising conductive liquid increases the capacitance between the metal rod and the tank with conductive sides. A probe for dielectric (semiconducting) liquids consists of a metal rod inside a metal tube. The liquid rising between the rod and tube determines the capacitance which is measured.
- *Ultrasonic* level detectors are similar to sonic flow measuring devices. A pulse is emitted from a transducer and the reflection from the surface of the medium in the tank or bin is timed. These instruments can be used for liquids and solids and are also useful for detecting the interface between two dissimilar materials such as oil and water.
- *Radiation* detectors are useful for difficult-to-measure materials or situations where it is not possible to put a hole in the side of the vessel. A radioactive source is placed on one side of a vessel and a detector on the other. Some of the radiation is absorbed by the material in the tank and the amount of absorption changes as the level varies. Change in radiation is proportional to the change in level and can be converted to an output signal.



Capacitance Tank Level Measurement
Figure 24

Weight Measurement

The majority of weight measurements are made by mechanical lever scales or strain gauge load cells, although other techniques have been used. Table 6 provides characteristics versus relative costs.

- *Mechanical lever scales* work on the principle of balancing on opposite ends of a lever an unknown weight against a known or standard weight. Small standard weights can be used to measure quantities many hundred times their size. This works on the principle that force (weight) on one end of a lever, multiplied by the corresponding lever length to the balance point, equals the force on the other end multiplied by that lever length to the balance point.
- *Strain Gauges* can also be used to measure weight. A platform can be constructed so that it is supported at each corner by a vertical metal pin or a horizontal metal bar. A weight on the platform causes a strain on the pin or bar. This strain can be measured to provide an output signal proportional to weight.

WEIGH SCALES
CHARACTERISTIC/RELATIVE COST COMPARISON
TABLE 6

TYPE OF SCALE	RANGE	RELATIVE COST	ACCURACY OF SPAN	APPLICABLE TO OUTDOOR INSTALLATION	APPLICABLE TO DYNAMIC LOADS
Mechanical Lever Scales	0 - 0.5 kg to 0 - 25,000 kg	M - H	0.05% to 0.1%	Y	F
Strain Gauge Load Cells	0 - 0.5 kg to 0 - 5,500,000 kg	M - H	0.1% to 1.0%	Y	E

LEGEND

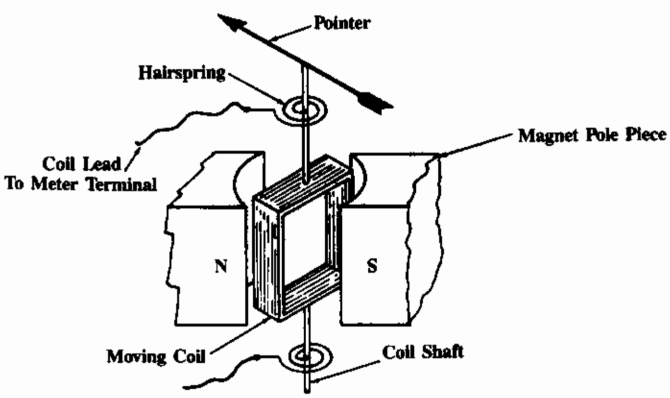
L — Low Y — Yes E — Excellent
M — Medium N — No G — Good
H — High F — Fair

Electrical Measurement

Terms

The basic electrical quantities of volts, amperes, watts, and watthours are terms that are familiar to most people. Since the meaning of these terms may not be well understood, a short description of them is provided. Reference should be made to an electrical text for detailed explanations.

- Volts are a measure of the electrical force or pressure.
- Amperes (Amps) are a measure of the flow of electricity.
- Watts are the product of volts times amperes and are a measure of electrical power (i.e. the rate that work is being done).
- Watthours are a measure of how much power has been consumed and are the basis of utility charges.
- Power factor is a less familiar, but very important term. Voltage and current cycle in an alternating current system. If voltage and current do not cycle together they are out of phase, and the useful power is reduced. As the phase shift increases, the amount of useful power decreases. Plants with equipment that cause too much phase shift are charged a penalty by the electric utility. Power factor correction methods are available and should be considered.
- Demand measurements are usually associated with watthour meters. Demand is the rate at which power is being consumed at any time. Large facilities are billed by the electric utility in two parts; the *energy* charge for the watthours consumed during the billing period, and the *demand* charge based on the maximum demand (watts) experienced during the period. It is important to keep the maximum demand (peak) as low as possible.



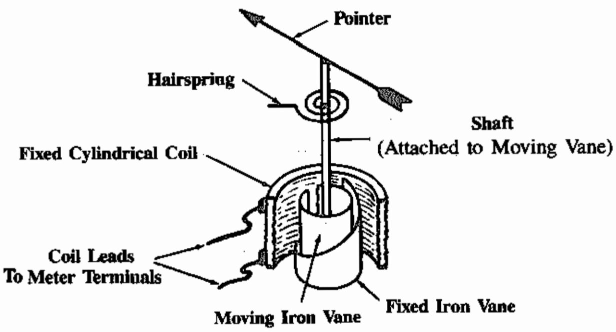
Permanent Magnet Moving Coil Meter
Figure 25

Meter Types

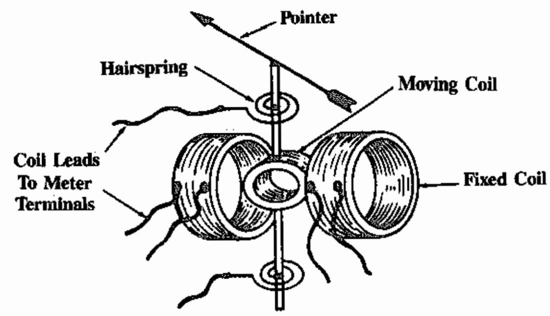
Most permanently installed electrical meters are the *moving coil, moving iron or electrodynamic types*. The principles of operation are described.

- *Moving coil meters* (Figure 25) operate on the principle of magnetic attraction and repulsion. Current passed through a coil produces a magnetic field. If this coil is mounted on a rotating shaft between opposite ends of a curved permanent magnet and current is applied, the shaft and coil will rotate. The magnetic field generated in the coil interacts with the field of the magnets to create a torque. A pointer attached to the shaft will indicate volts or amperes depending on how the meter is connected.
- *Moving iron meters* have two cylindrical iron vanes with one mounted inside the other (Figure 26). One vane is fixed, the other is free to rotate, and they are surrounded by a coil. Current passed through the coil will generate a magnetic field which magnetizes the two vanes. Repulsion of the like poles of these two magnets will generate a torque and cause the movable vane to rotate.
- The *electrodynamic meter* is a combination of the moving coil and moving iron types (Figure 27). The magnet and iron are replaced with coils so that there is a moving coil within or between fixed coils. When current is passed through the coils, magnetic fields are generated and interact to create torque. The meter indicates watts if one coil senses volts, and the other current.

A meter inserted in a circuit is an added parallel or series resistance. Therefore, the consumption of current and the resulting voltage drop caused by meters must be taken into consideration. It is not possible within this module to review all the combinations of possible connections. Thus, it would be wise to consult an expert before choosing an instrument for an electrical measurement.



Moving Iron Vane-Type Meter Movement
Figure 26

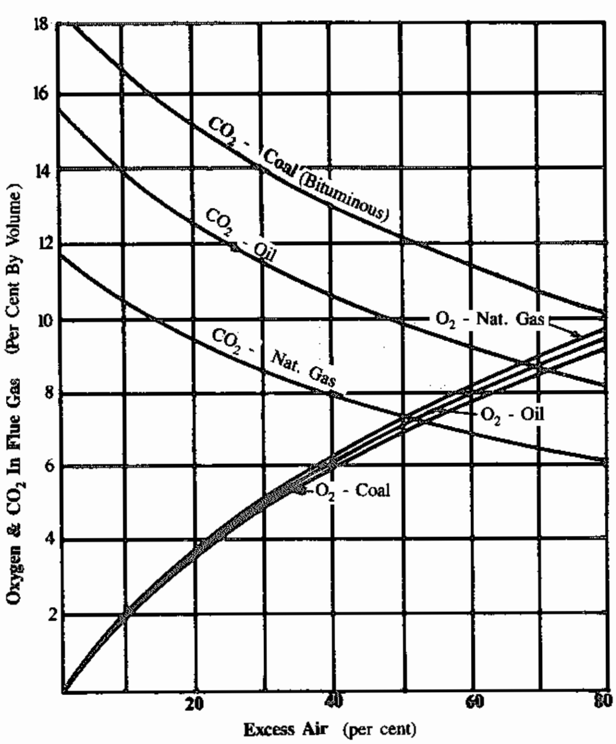


Electrodynamic Meter Movement
Figure 27

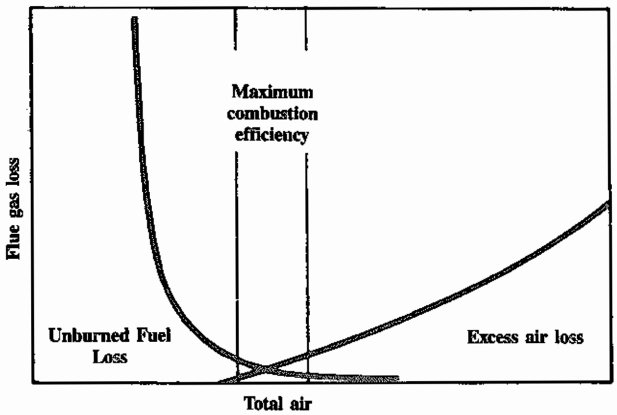
Flue Gas Analysis

Measuring products of combustion from a fossil fuel combustion system is important for determining efficiency. The three products commonly measured are Oxygen (O_2), Carbon Dioxide (CO_2), and Carbon Monoxide (CO).

The excess air for a combustion process can be established with an O_2 or CO_2 measurement (Figure 28). Review of the curves shows that fuel type is important in translating a CO_2 reading into excess air, whereas with O_2 the fuel effect is minor. CO is a combustible product which indicates unburned fuel. Figure 29 illustrates how quickly the heat loss increases as the excess air is reduced to the point of having significant CO in the flue gases. Some analyzers are designed to measure O_2 and CO which helps to locate the zone of maximum combustion efficiency shown in Figure 29.



Per Cent Oxygen and CO_2 Versus Excess Air
Figure 28



Zone of Maximum Combustion Efficiency
Figure 29

Gas analysis equipment is expensive and permanent installations are only justified for heating or process applications producing in excess of 10 000 MJ/h. However, for periodic checks of small installations, reasonably priced portable equipment can be bought or rented. Some plants will have Orsats, which require a manually drawn sample that is serially absorbed in three chemicals to identify the percentages of O_2, CO_2 and CO.

Oxygen Analyzers

Electrochemical detection O_2 measurement equipment is commonly used for gas analysis. The sample to be measured and a reference gas, usually air, are separated in a closed cell by a solid electrolyte made from zirconium oxide. Ionization of the sample and the reference gases at high temperature results in different O_2 ion concentrations on either side of the zirconium oxide separation. This difference in O_2 ion concentrations produces a potential across the electrolyte which is measured and amplified to produce an output signal proportional to the O_2 in the sample. This measures O_2 on a net weight basis in that any combustibles present are burned off using O_2 from the flue gases. The remaining O_2 is measured as a percentage of all constituents in the flue gas including water vapor. Typical ranges are 0 to 5 and 0 to 10 per cent O_2.

Catalytic Combustion is an older method of O_2 measurement which is still in use in many installations. Most portable instruments use this principle. The gas sample is mixed with a fuel and oxidized (burned) in a cell containing a resistance element coated with an oxidizing catalyst. The amount of heat generated from combustion is proportional to the amount of O_2 in the sample and the element resistance is proportional to temperature, which, in turn, is a function of the heat from combustion. The resistance can then be measured and used to produce an O_2 concentration output. Normally, there is a washer upstream of the analyzer to clean the sample and this also condenses water vapor, which means that the O_2 is measured as a percentage of all constituents excluding water vapor.

Carbon Dioxide and Carbon Monoxide Analyzers

The ability of a gas to conduct heat is a physical property of each type of gas. This *thermal conductivity* property can be measured by the cooling effect of a gas on a heated filament wire. The amount of cooling is proportional to the concentration and it changes the filament temperature and resistance. Resistance changes can be measured electrically and amplified to produce an output proportional to the CO_2 or CO concentration.

CO_2 is most often measured by means of the *infrared absorption* principle. When infrared beams are projected in parallel through a cell containing the gas to be analysed and a reference cell, there is a difference in the amount of infrared absorbed by the respective cells. This difference is proportional to the concentration of the measured gas and it can be detected and amplified to produce a proportional output. The same principle can be used to measure CO.

The previously described *catalytic combustion* principle can also be used to measure CO in ranges as low as 0 to 250 parts per million or 0 to 2 per cent.

Flue Gas Sampling Systems

The location where the sample is obtained should be carefully selected to ensure that representative readings are obtained. The desired gas sampling system will vary according to the selected gas analysis equipment and the plant arrangement. These details should be worked out with the equipment supplier, but the importance of a good gas sampling arrangement must be emphasized. Some of the important sampling system considerations are listed.

- Establish where representative samples can be obtained. By sampling the flue gases at the boiler outlet the problem of air infiltration distorting the measurement will be minimized.
- Reduce measurement lag by locating the sample point where the transport time (for the products of combustion) between the burner and the sample location plus the transport time of the flue sample gases between the sample point and the analyzer are all kept to a minimum.
- The sampling arrangement should not be susceptible to plugging by the dirty flue gases. It should also be well maintained to ensure that flue gas sample properly reaches the sensor.

Calibration

Typically, gas analysis equipment is not as stable as many types of temperature and pressure measurements. This means that the equipment should be calibrated frequently. The frequency will depend upon the importance of the readings to successful operation and the tendency of the calibration to drift. This could mean that the calibration check should be conducted weekly or, with experience, it might be determined that it could be extended to a monthly basis before the calibration drifted significantly. Gas analysis instruments are calibrated with bottled test gases having a certified composition similar to that of the measured gases. A frequently calibrated analyzer with good repeatability should provide satisfactory performance.

Monitoring

Monitoring, in the context of this module, means observing the data presented by the measuring instrument, and then taking some action. This may be as simple as watching the gauge glass on the side of a tank and manually shutting off a pump when the tank is full. However, there are many situations where more information is required to make a decision. A wide variety of equipment such as annunciators, indicators, recorders, data loggers, CRTs and computers are available to assist with the monitoring process. Table 7 provides features versus relative cost comparisons for a cross section of monitoring equipment.

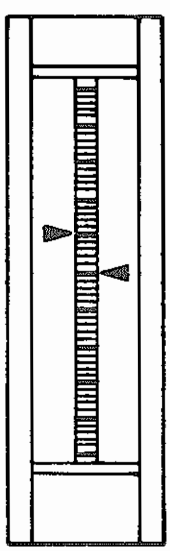
Switches

In many cases it is not necessary to know the actual value of flow, pressure, temperature, or power, but only that these measurements are above or below a certain value. In these cases a switch, set to activate at some preset value, may be sufficient. Switches can be used to activate a light, warning bell, annunciator or an on-off control system.

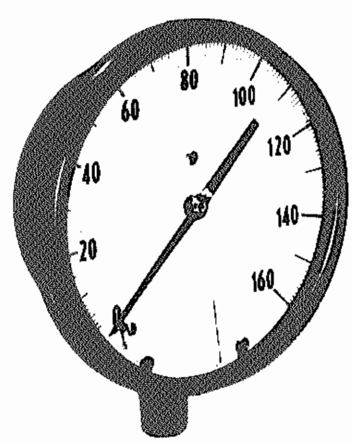
The activating mechanisms for switches are generally the same as those that have been discussed for indicators and transmitters. The same activating mechanism can be used for more than one device at the same time. For instance, the Bourdon tube in a device could measure and indicate pressure and, at the same time, mechanically position switch and transmitter hardware.

Annunciator

An *annunciator* is a packaged alarm system which is used to assist with the monitoring of a process. Key process variables are monitored continuously, but only brought to the operator's attention when the value of the measured variable goes beyond predetermined limits. If the process variable was temperature, a temperature switch could be installed and adjusted to activate a contact when a value was exceeded. Typically, this would cause a remote annunciator light to flash and a horn to sound. The light would indicate to the operator that the specific temperature had been exceeded. The operator could then acknowledge the alarm condition by silencing the horn and causing the light to be on steadily instead of flashing. When the temperature dropped below the alarm setting the light would automatically go off. Often there are a cluster of lights with engraved descriptions so that a quantity of process variables could be similarly monitored by one operator in a central location.



Vertical



Round

Indicators
Figure 30

Indicator

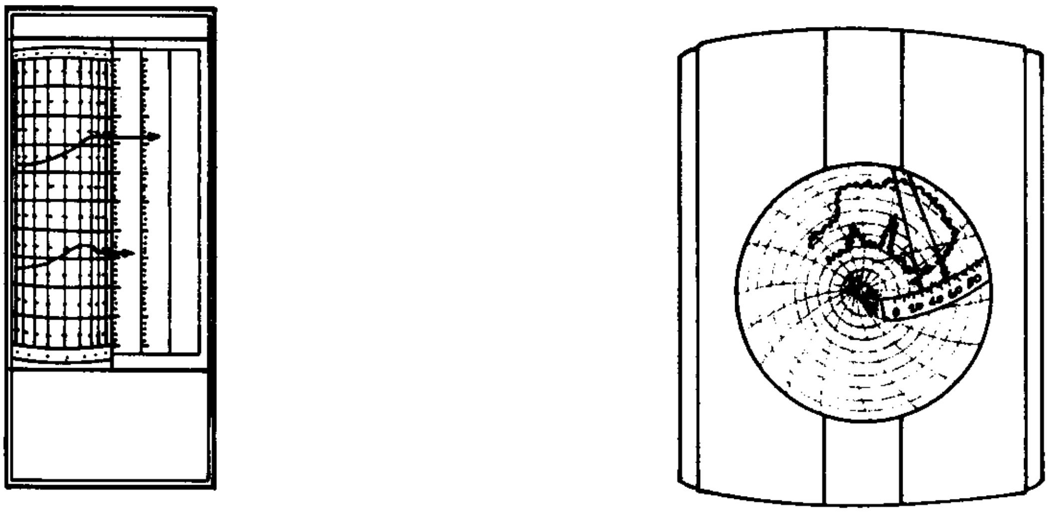
An indicator is the simplest, least expensive way of displaying the value of a measured process variable. Indicators can be directly connected to the process or receive a pneumatic or electronic signal from a transmitter to provide a remote indication. Indicator shapes are round or vertical strip (Figure 30).

Recorder

Recorders are commonly used to continuously record the measured value of process variables (Figure 31). The recorder charts are engraved so that the value of the variable and the time of day can be related. Recorders may have one pen representing a single process variable or they may have several pens each representing a different measurement. A colored pen is used for each measured variable.

Recorder charts may be circular or in strip form. While circular charts usually record a 24 hour period of operation, they may also record for 7 days. Normally, a strip chart is suitable for continuously recording a month of operation.

Recorders may be directly connected to a process or may receive a signal from a pneumatic or electronic transmitter. Direct connected recorders have the process sensing element as an integral part of the recorder. Most types of process measurements can be accomplished by means of a direct connected recorder. However, the trend is for recorders to be connected to the output signal of transmitters.



Strip Chart **Circular Chart**

Recorders
Figure 31

Totalizer

This is an indicator that counts the total number of units of a measured variable that have passed through a meter. An analogy is the automobile odometer which is a totalizer of kilometres travelled. The speedometer indicates the rate at which kilometres are being travelled and is comparable to an instantaneous flow indication.

Data Logger

A data logger collects and stores data on a predetermined frequency basis. It is an electronic instrument, usually microprocessor based, that is designed to monitor a relatively large number of measured variables. It automatically cycles to all connected input signals on a periodic basis. Each time it connects to an input it reads and stores the value. The value can be printed on a chart, put onto magnetic tape for long term storage, or activate an alarm. In addition to recording data, many loggers have the ability to manipulate data. They can totalize, average, select maximum and minimum values, multiply and divide by a factor or by another input. Advanced models may have more sophisticated capabilities.

Computers

A computer is an electronic device which can perform many functions. Given a set of process or program routines, a computer accepts inputs, processes the data and produces outputs. It is generally programmable and has input/output peripheral devices for communications and operator interface.

Although a data logger may be microprocessor based, it is not designed to be a computer. Some of the differences are as follows:

- A computer has greater data manipulation capability than a data logger.
- A computer can present data in a variety of report formats, while a data logger usually has only one report format.

- A computer has programming capability which is only limited by memory size, whereas a data logger has very limited programming capability.
- A computer has more output capability than a data logger.
- A computer has more display capability than a data logger.

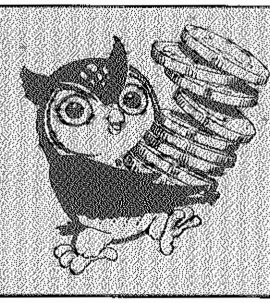
A Cathode Ray Tube (CRT) is a form of operator interface which is ideal for input/output operations when hard copies are not required. A printer terminal is used when hard copies are required. An operator can easily communicate with a computer by either a CRT or a printer terminal.

Some CRTs are specifically designed to display text and graphics. Dynamic graphic display is a particularly useful feature for data presentation.

MONITORING EQUIPMENT
CHARACTERISTIC/RELATIVE COST COMPARISON
TABLE 7

TYPE OF MONITORING	SERVICE	FEATURES	RELATIVE COST
Indicator	Visual indication of the instantaneous value of the measured variable	Circular or strip Digital display also common	low medium
Annunciator	Visual and/or audible signal to indicate measured variable is above or below a set value	• alarm mode • return to normal • audible silence • first out • equipment test	low to medium
Totalizer	Visual indicator showing total units of measured variable that passed through meter	• counter type dial • manual reset • auto reset • switching action	low
Recorder	Produces paper graph of measured variable versus time	• round chart • strip chart • multiple pens • variable time base	low to medium
Data Logger	Produce paper or electronic media record of multiple inputs — analog and/or digital	• multiple inputs • analog/digital • store data • manipulate data • activate annunciator	medium to high
Computer CRT	Similar to Data Logger	Similar to Data Logger plus • faster scan • more data manipulation • programming • improved display	high

ENERGY MANAGEMENT OPPORTUNITIES



Energy Management Opportunities is a term that represents the ways that energy can be used wisely to save money. A number of typical Energy Management Opportunities subdivided into Housekeeping, Low Cost, and Retrofit categories are outlined in this section including worked examples, or text, to illustrate the potential energy savings. This is not a complete listing of the opportunities available. However, it is intended to provide ideas for management, operating and maintenance personnel to identify other opportunities that are applicable to a particular facility.

It was previously pointed out that energy and dollar savings do not directly result from the use of measuring, metering and monitoring equipment. It is the application of instruments to other equipment and systems that creates the saving opportunities. This means that use of instruments to optimize equipment and process operation should be a background question when studying the other modules. A review of most other modules in this series will reveal that they contain a series of worksheets to provide order to the detailed calculations that are required to analyze applicable Energy Management Opportunities. It will be noted that most of the calculations in these worksheets require data obtained from measurements. The objective in this section is to provide overview examples of how measuring, metering and monitoring instruments facilitate energy and dollar savings. Detailed calculations, which would involve an understanding of other equipment and systems (e.g. HVAC systems, boilers, heat exchangers and air compressors) have been avoided. When properly applied, measuring and monitoring instruments create many energy and dollar saving opportunities. Each facility should be evaluated for the opportunities related to the use of measuring and monitoring equipment.

The following text briefly highlights several Energy Management Opportunities and is followed by worked examples or explanatory text to illustrate them.

Housekeeping Opportunities

Implemented housekeeping opportunities are energy management actions that are done on a regular basis and never less than once a year. With respect to instrumentation, this includes activities such as the periodic calibration of devices, evaluation of unacceptable process operation that might be attributable to poor measurement data, and the systematic collection, storage and use of data. Indirectly, instrumentation can be involved in many housekeeping energy management opportunities as the source of analysis data.

1. Calibration

Measuring, metering and monitoring equipment *must provide correct data to be useful*. There is no better way to develop trust in the data than by regularly calibrating the instruments. Instrument mechanisms are delicate and require regular maintenance. The amount of maintenance will vary considerably from instrument to instrument. For example, a simple manometer may only require a once per year check to ensure that the lines are clear and the liquid level is correct. As a contrast, a delicate on-line analyzer may require a daily general check and a weekly calibration with a test gas. Portable test instruments normally require more frequent checks because they are subjected to rough handling.

Simple checks can be done by general maintenance personnel or instruments can be sent out to repair shops on a periodic basis. It is also common practice to have a maintenance contract with an equipment supplier or contractor. Where the number of instruments is significant it may be cost effective to invest in test equipment or even establish an instrument maintenance department.

Calibration records are useful for assessing the performance of the instruments. They can identify the need for more or less frequent calibration checks, or possibly the need for instrument replacement.

2. Records

The maintenance of good records is vital to the usefulness of measuring, metering and monitoring equipment. Deviation of a measured quantity from the normal pattern is a method of identifying a problem. Off standard operation can only be identified if the normal pattern is known and for this, historical records are required. Important variables should be manually logged or automatically recorded and the data kept available for quick reference.

A rapid deviation from the normal pattern of measurement usually suggests a shift in calibration, or a process change. In either case, quick remedial action is desirable.

Housekeeping Worked Examples

1. Calibration

The effect of *instrument calibration shift* is demonstrated by this example.

In many boiler plants, particularly if steam loads are steady, combustion air flow to boilers is trimmed manually based on oxygen analysis data. Older analyzers have a tendency to drift from the correct calibration by as much as ten per cent within a month. With the normal instrument range of 0 to 10 per cent oxygen a ±10 per cent error could produce an oxygen reading 1 per cent lower than actual. This means that with a boiler set to operate at 3 per cent O_2, the actual value would be trimmed to 4 per cent O_2. A difference of 1 per cent O_2 is approximately equal to an increase in combustion air of 5 per cent and a decrease in boiler efficiency of 0.5 per cent. For a 25,000 kg/hr. boiler operating at 75 per cent of load, a 0.5 per cent decrease in efficiency costs approximately $2.26 per hour at a natural gas price of $0.14/m^3. At this rate it does not take long to pay for an hour of calibration time.

2. Records

A common problem in HVAC systems is the jamming of fresh air dampers in the open position. This condition might remain undetected for long periods because the heating system compensates for the additional cold air, resulting in little or no change in space temperature. However, if the heating medium is measured, the increased demand will be immediately evident. Use of records to make comparisons between present and past flow rates for similar ambient conditions would identify abnormal operation. The problem source can then be quickly identified and corrected.

Low Cost Opportunities

Implemented low cost opportunities are Energy Management actions that are done once and for which the cost is not great. This creates a distinct separation from the housekeeping activities which must be repeated regularly. The third and final classification of an energy management opportunity is *retrofit* and this is intended to cover any changes too large to be defined as *low cost*. The distinction between low cost and retrofit energy management opportunities will depend upon the size and nature of a facility, and must be established by the company or institution.

1. Instrument Accuracy Selection

Instrument accuracy affects the accuracy of the process measurements. This, in turn, could affect the quality of the process operation. The objective is to select the instrument accuracy so that optimum process operation is achieved without paying a premium for accuracy that is not needed.

2. Energy Efficient Design

The proper design of instrument measuring systems must include careful consideration of energy use. The extra time to properly evaluate the energy utilization should be invested before equipment selection and installation. However, there are Energy Management Opportunities within existing systems and these should also be assessed.

3. Installation

Correct an improper installation of measuring equipment in order to eliminate measuring inaccuracies. The changes could improve the operation sufficiently to provide an attractive financial payback.

4. Filters

Filters are common in air handling systems, process lines, as well as oil and water systems. All filters have one thing in common: they get dirty. Dirt causes a greater pressure drop across the filter which increases the load on the fan or pump per unit of volume.

A differential pressure device can be used to measure the pressure drop across the filter. This can be used to provide an indication or an alarm warning of a high differential pressure condition, to establish the need to initiate filter cleaning.

5. Gas Analysis Monitoring

Gas analyzers are used to determine the excess air and efficiency of equipment such as boilers so that operating refinements can be made to save energy and dollars.

6. Building Heating and Cooling Systems Monitoring

The proper operation of building heating and cooling systems, including the amount of outside make-up air, requires monitoring. This is necessary for obtaining the most efficient normal operation and quickly detecting equipment failures.

7. Abnormal Condition Detectors

Many types of inexpensive detectors are available to warn operating personnel about improper operation resulting from equipment failure or human mistake.

Low Cost Worked Examples

1. Instrument Accuracy Selection

A constant process temperature of 190°C is to be maintained. For each °C above this value one extra litre of oil per hour is required to maintain the process temperature. This represents $0.50 per hour per °C at a cost of $0.50 per litre of oil. Thermometers might be considered with one having an accuracy of ±2 per cent of the measured value and the other an accuracy of ±1 per cent. These two devices could have an output difference of 1.9°C for the same input. If the process temperature is measured with the ±2 per cent accuracy thermometer the process could be operating 1.9°C hotter than if it was measured with the ±1 per cent accuracy thermometer. This increase in accuracy should save $0.95 per hour in reduced oil consumption. If the cost difference between these two instruments is $100 it would be cost effective to select the most accurate one since the energy savings would pay for it within a week. A similar analysis for an accuracy improvement from ±2 per cent to ±0.5 per cent shows a saving of $1.42 per hour and the increased cost might be $500. The increase in accuracy is still cost effective, but the payback period is much greater owing to the extra cost for the high accuracy temperature measurement.

The significance of instrument accuracy is further demonstrated by this example. Great Lakes freighters have draft (level) measurement systems that allow them to trim fore and aft and side to side so that they can operate as closely as possible to the bottom of the Seaway Locks. An increase of 1 per cent in the accuracy of this measurement means that the vessel can operate 7.5 cm closer to the bottom. For a 230 m by 24 m vessel the 7.5 cm represents an approximate additional wheat load of 220 tonnes. This would indirectly save energy since the average amount of energy to move the cargo a tonne-kilometre would be less.

2. Energy Efficient Design

Pumping systems have not always been properly designed to minimize the use of energy. Consider the example of a water pump which was selected to deliver 319 L/s at a discharge head of 134 m. The pressure was measured at several points in the system to prove that the pump discharge head could be reduced by 12 m. This would reduce the pressure drop across a control valve, but still leave it with sufficient pressure drop for good control. This improvement would result in a 7 kW pump power reduction. Trimming the pump impeller would cost $500. The pump operates 6500 hours per year and electricity costs $0.05/kWh. The calculated savings would be:

$$\text{Annual dollar savings} = 7\ \text{kW} \times 6500\ \text{h/yr} \times \$0.05/\text{kWh}$$

$$= \$2{,}275$$

$$\text{Simple payback} = \frac{\$\ 500}{\$2{,}275}$$

$$= 0.22\ \text{years (3 months)}$$

The same system had a water flow measurement with a large unrecovered head loss across the orifice plate. It was calculated that unrecovered head loss could be reduced by 2.5 m at the normal flow rate. This would require a new orifice plate and the recalibration of the flow transmitter. The change would allow the impeller to be further reduced in diameter to achieve an additional reduction of 1.5 kW of pump energy. It should be noted that this would only require the impeller to be changed once at the previously stated cost of $500. The cost of replacing the orifice plate and recalibrating the transmitter would be $600 for a total cost of $1,100. The calculated combined savings would be:

$$\text{Annual dollar savings} = 8.5 \text{ kW} \times 6500 \text{ h/yr} \times \$0.05/\text{kWh}$$

$$= \$2,762$$

$$\text{Simple Payback} = \frac{\$1,100}{\$2,762}$$

$$= 0.4 \text{ years (5 months)}$$

If the pump had not been oversized originally the payback for the flow measurement change would still be attractive. This can be demonstrated by the equation:

$$\text{Annual dollar savings} = 1.5 \text{ kW} \times 6500 \text{ h/yr} \times \$0.05/\text{kWh}$$

$$= \$493$$

$$\text{Simple Payback} = \frac{\$1,100}{493}$$

$$= 2.2 \text{ years}$$

3. Installation

There are many potential examples of improperly installed measuring instruments that compromise the operation of equipment and systems. It is not practical to create simple payback calculations, but the following list provides examples of poor instrument installations which could adversely affect system operation and energy performance.

- A thermometer installed behind an internal baffle in a deaerator registers 8.5°C lower than the actual 110°C water temperature.
- Because of stratification, a thermocouple inserted 15 cm into the side of 1 metre wide duct measures 15°C less than the average 160°C temperature across the duct.
- Drilling burrs left on the inside of the pipe at the orifice taps cause fluctuating errors of 5 to 10 per cent depending on the flow rate.
- A steam flow orifice designed for 862.5 kPa(gauge) and operated at 690 kPa(gauge) results in a measurement that is 9 per cent greater that the actual flow.

The equipment installation should be investigated when there are apparent inconsistencies in measurements that cannot be attributed to changes in calibration.

4. Filters

In a ventilation supply system the differential across an air filter varies according to the condition of the filter. An increase of 125 Pa across the filter increases the fan motor load by 10 per cent. This increase in the power draw of an 18.5 kW motor results in increased operating costs of $1.80 per day based on a power cost of $0.05/kWh. A differential pressure indicator or differential pressure switch and alarm point could assist personnel in establishing the appropriate time to change filters.

5. Gas Analysis Monitoring

An oxygen analyzer can be used as a guide for manually trimming the fuel and air flows to a boiler to improve the excess air. Figures 28 and 29, in the Fundamentals section, illustrate the relationship of excess air and boiler losses. The relationship between excess air reduction and boiler efficiency improvement depends on the flue gas temperature, but the savings can be significant.

This example is quite different from the foregoing boiler application but it demonstrates the broader use of gas analysis equipment. In many warehousing facilities trucks are loaded at inside docks. The accumulation of pollutants from internal combustion engines is prevented by continuous ventilation. The cost of continuously discharging heated air to the outside can be significant. The installation of a Carbon Monoxide measuring system will allow the exhaust system to be shut off when fumes are below acceptable limits.

6. Building Heating and Cooling Systems Monitoring

Heating, ventilating and air conditioning problems are not unique to large complexes. Malfunctions are common in systems of any size containing heating and cooling coils. In facilities where maintenance personnel can inspect the equipment on a regular basis these problems can be detected by measuring important temperature, pressure and flow values. The installation of permanent instruments in strategic locations would be ideal, but expensive, and not necessary. The ducts can be fitted with test ports large enough for a manometer connection or to insert a thermometer or a Pitot tube. Maintenance personnel can then make periodic checks to identify problems.

7. Abnormal Condition Detectors

The following list provides examples of unnecessary use of energy.

- A loading door remaining open long after the truck has gone.
- Pumping into a tank while the tank overflows to a drain.

The cost of this type of carelessness can be substantial. A limit switch plus timer on the door and a high level switch on the tank wired to an annunciator could alert personnel to curb these practices.

Retrofit Opportunities

Implemented *retrofit opportunities* are Energy Management actions which are done once and for which the cost is significant. Measuring, metering and monitoring equipment can be applied to most types of equipment and processes. The examples illustrate a few ways in which measuring, metering and monitoring equipment can save energy and dollars. However, it is essential that each facility be examined for its own opportunities.

1. Metering

Metering equipment is installed to provide information that can be used to correctly operate a system, and over time, track its efficiency. These are valid reasons for the expenditure, but there can be additional benefits in using the metering information to also expose abnormal situations that result from some form of unexpected equipment failure or human error. Without the metering information, the fault could be undetected for an extended period.

2. Electrical Peak Demand

Measurements can be monitored with a data logging system. Typically, this involves a quantity of remote measurements that are transmitted to a central point to be logged and printed out every shift or day. The system can also have an alarm feature whereby measured variables that deviate beyond certain limits are alarmed, to get operator attention. This type of system can be used to monitor the total kW demand for a facility and to give advance warning of an undesirable level being approached. The operator can then take discretionary action to reduce the electrical load to maintain the electrical demand charges at an acceptable limit.

3. Boiler Optimization

It is vital, in these days of high energy costs, to ensure that all equipment is efficiently operated and maintained. This is particularly true of combustion equipment because of the large quantities of energy used.

Accurate monitoring of boiler performance requires the accumulation of a considerable amount of data and the solution of a number of time consuming equations. As a result, departure from optimum operation can be undetected for extended periods, even in plants where the operation, maintenance and control strategies, and procedures are of high quality. This is often because of the time restriction on personnel responsible for data gathering and performance monitoring.

With the advent of microelectronics, and the reduced cost associated with systems that automate the data gathering and/or calculation process, boiler optimization systems are now economically feasible. These systems provide management and operating staff with performance profiles of individual boilers and the complete plant. This allows personnel to recognize quickly any deterioration in performance and make the necessary adjustments to maintain optimum operation.

4. Design Fault Correction

There are situations where improper installations, which reflect design faults, must be corrected to achieve expected output or efficiency. Do not assume that the design is correct just because the facility has been operating for a period of time.

Retrofit Worked Examples

1. Metering

The *measurement of heat energy to each building in a large complex* represents an energy management opportunity which is demonstrated by this example. A one month investigation of three buildings on a university campus revealed that one building had two separate HVAC control problems. In the first instance, ice caused the outside air dampers to be fixed in the 75 per cent open position, and in the second case, a mixing damper operator failed. In each case, the amount of outside air entering the system greatly exceeded the necessary amounts. These problems resulted in increased steam consumption from 20 000 to 68 000 kg/day. This excess 48 000 kg/day steam production represented a daily fuel cost of approximately $500. Flow meters installed on the steam supply or condensate return lines of each building, with the output connected to a central monitoring system, would have immediately identified a sudden flow increase. Given the size of the campus (36 buildings and 144 separate heating systems) a conservative estimate of the annual saving for all buildings was $50,000.

A food processing plant example provides more evidence of the value of measuring and metering. In a vegetable oil processing plant many different grades and types of oil are produced by blending a variety of basic oils. This involves batch and dispatch operations where oil is pumped into and out of numerous tanks. These operations require very careful monitoring to ensure that quantities and inventories are correct. "Loss Monitoring" systems, that combine flow metering, tank weighing and data loggers, have been developed to provide the necessary monitoring. Although not directly related to energy use it is obvious that lost or spoiled product requires additional replacement energy.

2. Electrical Peak Demand

An examination of a university campus identified 250 fan motors associated with the HVAC systems. An evaluation of the complex's electrical load profile and the power used by the fan motors indicated an opportunity to reduce the electrical peak. Shutting down groups of fans for short periods of time would not have a noticeable effect on comfort, but it would reduce the peak by 200 kW. The installation of electrical demand meters in each building and having the output automatically monitored at a central control area would permit operating staff to load shed as required. This reduction would represent an average annual saving of $25,000.

3. Boiler Optimization

The following application was undertaken by a Federal Government Department responsible for a number of steam plants across Canada. Computer programs were written to provide the following.

- Calculate boiler efficiency using the direct method (heat out/heat in).
- Calculate boiler efficiency using the indirect method (heat balance).
- Store curves, in memory, which represent the ideal operation of each boiler at all loads and for all fuels.
- Compare the boiler efficiency calculations to the curve developed from boiler tests that represented the ideal operation.
- Produce a weekly report on the performance of each boiler with comparisons between the actual and target performance levels.

The computer input data for these calculations and reports were gathered by the plant operating staff and *manually* entered into the computer. This information generated weekly reports that assisted operating personnel in identifying any deterioration in boiler and instrumentation performance. It also stimulated a greater awareness of the correct operating parameters. This program was applied to six plants containing eighteen boilers and produced an estimated saving of 4 per cent of the total fuel cost.

A more sophisticated example of a boiler optimization opportunity was installed at a university central heating facility. The microcomputer system *directly* received the boiler variable signals necessary for efficiency calculations. This is a four boiler plant with an installed capacity of 160,000 kg/h producing an average yearly load of 300 million kg of steam. In addition to the reports already described in the previous example, this system identifies the correct combination of boilers that should be on-line for specific plant loads. If boiler performance deteriorates or the combination of boilers is incorrect, alarms are activated. The estimated fuel saving was 1.5 per cent, or $50,000 annually.

4. Design Fault Correction

Even in situations where considerable capital expenditure is required to correct a design fault the exercise can be cost effective. The steam output from a wood-fired boiler installation was considerably below the design expectations. The problem was identified as a lack of combustion air but the cause could have been several factors such as restrictions in boiler passes, an inadequate stack or undersized fans. Portable test measuring equipment was used to produce profiles of the combustion air and flue gas systems. Flow, temperature and pressure readings were taken at several points. A thorough analysis of the data proved that the dust collector pressure loss was excessive because the collector had been improperly sized. The dust collector was removed and replaced with a properly sized unit.

APPENDICES

Glossary

The Measuring, Metering and Monitoring, Module 15 and Automatic Control, Module 16 are closely related and will often be used together in analyzing energy management opportunities. Thus, the same glossary is used in each module.

Accuracy, measured — The difference between the ideal value and the measured value.

Accuracy, rating — A number or quantity that defines a limit that errors will not exceed when a device is used under specified operating conditions. Accuracy rating includes the combined effects of conformity, hysteresis, dead band and repeatability errors. It is typically expressed in terms of the measured variable, as per cent of span, per cent of upper range value, or per cent of actual output reading.

Air Consumption — The maximum rate at which air is consumed by a device within its operating range during steady-state signal conditions.

Alarm — An audible and/or visual signal that identifies a nonstandard condition.

Analysis, flue gas — The measurement of the constituents of the products of combustion. Normally expressed in % volume of Oxygen (O_2), Carbon Monoxide (CO) or Carbon Dioxide (CO_2)

Annunciator — A complement of hardware used to make operating personnel aware of a nonstandard condition through audible and visual signals.

Audit, diagnostic — Analysis of a potential opportunity to save energy which could involve the assessment of the current process operation, records, the calculation of savings, and estimates of capital and operating costs so that the financial viability could be established.

Audit, walk through — A visual inspection of a facility to observe how energy is used or wasted.

Automatic Controller — A device which operates automatically to regulate a controlled variable.

Automatic-Manual Station — A device which enables an operator to select an automatic or manual signal as the input to a final control element. The automatic signal is normally the output of a controller while the manual signal is the output of a manually operated device.

Calibrate — To establish outputs of a device corresponding to a series of values of the quantity which the device is to measure.

Cathode Ray Tube (CRT) — A display device that permits two way communication between a data logger or computer and a human.

Computer — An electronic device which receives inputs, processes them and produces outputs. It consists of a central processing unit, memory and input/output circuits.

Control Action — This relates to a controller and identifies how the output is affected by the input to the controller.

Control Action, rate (derivative) (D) — Control action in which the output is proportional to the rate of change of the input error signal. It is used to help offset measurement lag problems.

Control Action, reset (integral) (I) — Control action in which the output is proportional to the time integral of the input error signal. It is used to eliminate offset between the set point and the measured variable.

Control Action, proportional — Control action in which the change in controller output is proportional to the change in the input error signal.

Control Action, proportional-plus-rate (derivative) (PD) — Control action in which the output is proportional to a linear combination of the input error signal and the time rate of change of input.

Control Action, proportional-plus-reset (integral) (PI) — Control action in which the output is proportional to a linear combination of the input error signal and the time integral of the input.

Control Action, proportional-plus-reset (integral) plus-rate (derivative) (PID) — Control action in which the output is proportional to a linear combination of the input error signal, the time integral of input and the time rate of change of input.

Control, cascade — Control in which the output of one controller is the set point for another controller

Control Center — An equipment structure, or group of structures, from which the process is measured, controlled and/or monitored.

Control, differential gap — Control in which the output of a controller remains at a maximum or minimum value until the controlled variable crosses a band or gap, causing the output to reverse.

Control, direct digital — Control performed by a digital device which establishes the signal to the final controlling element.

Control, feedback — Control in which a measured variable is compared to its desired value to produce an error signal which is acted upon in such a way as to reduce the magnitude of the error.

Control, feedforward — Control in which information concerning one or more conditions that can disturb the controlled variable is converted, outside of any feedback loop, into corrective action to minimize deviations of the controlled variable.

Control, multielement — The use of more than one process variable to regulate the controlled variable.

Controller, direct connected — A controller which senses the controlled variable instead of receiving a signal from a transmitter.

Controller, direct acting — A controller in which the value of the output signal increases as the value of the input (measured variable) increases.

Controller, program — A controller which automatically holds or changes set point to follow a prescribed program for a process.

Controller, reverse acting — A controller in which the value of the output signal decreases as the value of the input(measured variable) increases.

Controller, self-operated (regulator) — A controller in which all the energy to operate the final controlling element is derived from the controlled system.

Control, optimizing — Control that automatically seeks and maintains the most advantageous value of a specified variable, rather than maintaining it at one set value.

Control, supervisory — Control in which the control loops operate independently subject to intermittent corrective action.

Control System, automatic — A control system which operates without human intervention.

Control Valve — A final control element, through which a fluid passes, which adjusts the flow as directed by a controller.

Data Logger — An electronic data recording device which has the ability to store and manipulate data.

Dead Band — The range through which an input signal may be varied, upon reversal of direction, without initiating an observable change in output signal.

Disturbance — A disturbance acts on a process to drive the controlled variable away from the set point.

Drift — An undesired change in output over a period of time.

Element, final control — A controlling element which directly changes the value of the manipulated variable.

Element, primary — The system element that converts the measured variable energy into a form suitable for measurement.

Element, sensing — The element directly responsive to the value of the measured variable.

Energy — The capacity for doing work; taking a number of forms that may be transformed from one into another, such as thermal (heat), mechanical (work), electrical, and chemical, in customary units, measured in kilowatt-hours (kWh) or megajoules (MJ).

Energy Accounting — The process of accurately gathering all pertinent information on production and energy usage and the subsequent analysis for reporting and control purposes.

Energy Management Opportunities, housekeeping — Activities which should be done on a regular basis and never less than once per year.

Energy Management Opportunities, low cost — Improvements that are implemented once and the cost is not great.

Energy Management Opportunities, retrofit — Improvements that are implemented once where the cost is considered to be significant.

Energy Performance — A measure of the effectiveness of utilizing energy expressed in energy per unit of production.

Energy, waste — Energy which is lost without being fully utilized.

Flowmeter — A device that measures the rate of flow or quantity of a moving fluid in an open or closed conduit.

Hardware — Physical equipment directly involved in performing process measuring and controlling functions.

Heating Value — The gross(Higher Heating Value) energy content of a fuel in MJ.

Indicator Travel — The length of the indicator scale.

Instrumentation — A collection of instruments or their application for the purpose of observation, measurement or control.

Instrument, indicating — A measuring instrument in which the present value of the measured variable is indicated.

Instrument, measuring — A device for ascertaining the magnitude of a quantity or condition.

Instrument, recording — A measuring instrument in which the values of the measured variable are recorded.

Intrinsically Safe Equipment and Wiring — Equipment and wiring which are incapable of releasing sufficient electrical or thermal energy under normal or abnormal conditions to cause ignition of a specific hazardous atmospheric mixture in its most easily ignited concentration.

Linearity — The closeness to which a curve approximates a straight line.

Loop, closed (feedback loop) — A signal path which includes a forward path, a feedback path and a summing point, and forms a closed circuit.

Microcomputer — A single circuit or component computer which uses a microprocessor as its central processing unit and has built-in memory and input/output circuits.

Microprocessor — A microelectric circuit or device which performs the processing function of a computer.

Modulating Control — Any form of control in which the manipulated variables can be set to any position within the control range to maintain the controlled variable at set point.

Monitoring — The act of observing facility conditions is called monitoring and the equipment that assists with this activity are called monitoring devices. In this module monitoring also means analyzing the data obtained through the monitoring process.

Offset — The steady-state deviation between the set point and the controlled variable.

Operating Conditions — Conditions to which a device is subjected, not including the variable measured by the device.

Operative Limits — The range of operating conditions to which a device may be subjected without permanent impairment of operating characteristics.

Overrange Limit — The maximum input that can be applied to a device without causing damage or permanent change in performance.

Pressure, absolute — Any pressure where the base for measurement is full vacuum expressed as kPa(absolute).

Pressure, differential — The difference in pressure between two points.

Pressure, gauge — Any pressure where the base for measurement is atmospheric pressure expressed as kPa(gauge). Note that kPa(gauge) + atmospheric pressure = kPa(absolute).

Pressure, maximum working (MWP) — The maximum total pressure permissible in a device under any circumstances during operation at a specified temperature.

Pressure, operating — The actual pressure at which a device operates under normal conditions.

Pressure, rupture — The pressure, determined by test, at which a device will burst.

Pressure, static — The pressure exerted in all directions by a fluid at rest. For a fluid in motion it is measured in a direction that is at right angle to the flow direction.

Pressure, velocity — The pressure measured in the direction of flow less the static pressure.

Process — Physical or chemical change of matter or conversion of energy.

Process Control — The regulation or manipulation of variables to obtain a product of desired quality in an efficient manner.

Process Measurement — The acquisition of information that establishes the magnitude of process quantities.

Programmable Controller — A solid state device that performs a control function by means of a stored program and feedback from input and output devices.

Proportional Band — The change in the input error signal required to produce a full range change in output due to proportional control action. It is reciprocally related to proportional gain.

Range — The region between the limits of lower and upper range-values.

Range-Value, lower — The lowest value of the measured variable that a device is adjusted to measure.

Range-Value, upper — The highest value of the measured variable that a device is adjusted to measure.

Reliability — The probability that a device will perform its objective adequately, for the period of time specified, under the operating conditions specified.

Repeatability — The closeness of agreement among a number of consecutive measurements of the output for the same value of the input under the same operating conditions, approaching from the same direction, for full range traverses.

Response, dynamic — The behavior of the output of a device as a function of the input with respect to time.

Sampling Period — The time interval between observations in a periodic sampling control system.

Self-regulation — The property of a process or machine which permits attainment of equilibrium, after a disturbance, without the intervention of a controller.

Set Point — An input variable which sets the desired value of the controlled variable.

Signal — The physical variable, which carries information about another variable (which the signal represents).

Signal, analog — A signal representing a variable which may be continuously observed and represented.

Signal, digital — Representation of information by a set of discrete values in accordance with a prescribed law. These values are represented by numbers.

Signal, error — The difference between the set point and the controlled variable.

Signal, output — A signal delivered by a device.

Span — The algebraic difference between the upper and lower range-values.

Span Adjustment — Means provided in an instrument to change the shape of the input-output curve

Standard — A unit of measure established to permit accurate comparisions to be made.

Steady State — The condition where a measured variable or instrument are not changing with time.

Temperature, ambient — The temperature of the medium surrounding a device.

Time, dead — The interval of time between initiation of an input change or stimulus and the start of the resulting observable response.

Transducer — An element or device which receives information in the form of one quantity and converts it to information in the form of the same or another quantity.

Transmitter — A transducer which responds to a measured variable by means of a sensing element, and converts it to a standardized transmission signal which is a function only of the measured variable.

Tune — An expression used to describe the exercise of adjusting controls and observing the process reaction until the operation responds acceptably to process disturbances.

Value, desired — The value of the controlled variable chosen.

Value, ideal — The exact quantity of a measured variable relative to a specific standard of measure.

Variable, controlled — In a control loop, the variable which is sensed to originate a feedback signal.

Variable, manipulated — The process variable which is regulated to maintain the controlled variable at or near set point.

Variable, measured — A quantity, property, or condition which is measured.

Zero Adjustment — Means provided in an instrument to provide a parallel shift of the input-output curve.

COMMON CONVERSIONS

1 barrel (35 Imp gal) (42 US gal)	= 159.1 litres
1 gallon (Imp)	= 1.20094 gallon (US)
1 horsepower (boiler)	= 9809.6 watts
1 horsepower	= 2545 Btu/hour
1 horsepower	= 0.746 kilowatts
1 joule	= 1 N-m
Kelvin	= (°C + 273.15)
1 kilowatt	= 3600 kilojoules
1 Newton	= 1 kg-m/s^2
1 therm	= 10^5 Btu
1 ton (refrigerant)	= 12002.84 Btu/hour
1 ton (refrigerant)	= 3516.8 watts
1 watt	= 1 joule/second
Rankine	= (°F + 459.67)

Cubes

1 yd^3	= 27 ft^3
1 ft^3	= 1728 in^3
1 cm^3	= 1000 mm^3
1 m^3	= 10^6 cm^3
1 m^3	= 1000 L

Squares

1 yd^2	= 9 ft^2
1 ft^2	= 144 in^2
1 cm^2	= 100 mm^2
1 m^2	= 10000 cm^2

SI PREFIXES

Prefix	Symbol	Magnitude	Factor
tera	T	1 000 000 000 000	10^{12}
giga	G	1 000 000 000	10^9
mega	M	1 000 000	10^6
kilo	k	1 000	10^3
hecto	h	100	10^2
deca	da	10	10^1
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}
micro	u	0.000 001	10^{-6}
nano	n	0.000 000 001	10^{-9}
pica	p	0.000 000 000 001	10^{-12}

UNIT CONVERSION TABLES
METRIC TO IMPERIAL

FROM	SYMBOL	TO	SYMBOL	MULTIPLY BY
amperes/square centimetre	A/cm^2	amperes/square inch	A/in^2	6.452
Celsius	°C	Fahrenheit	°F	(°C × 9/5) + 32
centimetres	cm	inches	in	0.3937
cubic centimetres	cm^3	cubic inches	in^3	0.06102
cubic metres	m^3	cubic foot	ft^3	35.314
grams	g	ounces	oz	0.03527
grams	g	pounds	lb	0.0022
grams/litre	g/L	pounds/cubic foot	lb/ft^3	0.06243
joules	J	Btu	Btu	9.480×10^{-4}
joules	J	foot-pounds	ft-lb	0.7376
joules	J	horsepower-hours	hp-h	3.73×10^{-7}
joules/metre, (Newtons)	J/m, N	pounds	lb	0.2248
kilograms	kg	pounds	lb	2.205
kilograms	kg	tons (long)	ton	9.842×10^{-4}
kilograms	kg	tons (short)	tn	1.102×10^{-3}
kilometres	km	miles (statute)	mi	0.6214
kilopascals	kPa	atmospheres	atm	9.87×10^{-3}
kilopascals	kPa	inches of mercury (@ 32°F)	in Hg	0.2953
kilopascals	kPa	inches of water (@ 4°C)	in H_2O	4.0147
kilopascals	kPa	pounds/square inch	psi	0.1450
kilowatts	kW	foot-pounds/second	ft-lb/s	737.6
kilowatts	kW	horsepower	hp	1.341
kilowatt-hours	kWh	Btu	Btu	3413
litres	L	cubic foot	ft^3	0.03531
litres	L	gallons (Imp)	gal (Imp)	0.21998
litres	L	gallons (US)	gal (US)	0.2642
litres/second	L/s	cubic foot/minute	cfm	2.1186
lumen/square metre	lm/m^2	lumen/square foot	lm/ft^2	0.09290
lux, lumen/square metre	lx, lm/m^2	footcandles	fc	0.09290
metres	m	foot	ft	3.281
metres	m	yard	yd	1.09361
parts per million	ppm	grains/gallon (Imp)	gr/gal (Imp)	0.07
parts per million	ppm	grains/gallon (US)	gr/gal (US)	0.05842
permeance (metric)	PERM	permeance (Imp)	perm	0.01748
square centimetres	cm^2	square inches	in^2	0.1550
square metres	m^2	square foot	ft^2	10.764
square metres	m^2	square yards	yd^2	1.196
tonne (metric)	t	pounds	lb	2204.6
watt	W	Btu/hour	Btu/h	3.413
watt	W	lumen	lm	668.45

4138T/T33(-4)

UNIT CONVERSION TABLES
IMPERIAL TO METRIC

FROM	SYMBOL	TO	SYMBOL	MULTIPLY BY
ampere/in^2	A/in^2	ampere/cm^2	A/cm^2	0.1550
atmospheres	atm	kilopascals	kPa	101.325
British Thermal Unit	Btu	joules	J	1054.8
Btu	Btu	kilogram-metre	kg-m	107.56
Btu	Btu	kilowatt-hour	kWh	2.928×10^{-4}
Btu/hour	Btu/h	watt	W	0.2931
calorie, gram	cal or g-cal	joules	J	4.186
chain	chain	metre	m	20.11684
cubic foot	ft^3	cubic metre	m^3	0.02832
cubic foot	ft^3	litre	L	28.32
cubic foot/minute	cfm	litre/second	L/s	0.47195
cycle/second	c/s	Hertz	Hz	1.00
Fahrenheit	°F	Celsius	°C	(°F-32)/1.8
foot	ft	metre	m	0.3048
footcandle	fc	lux, lumen/ square metre	lx, lm/m^2	10.764
footlambert	fL	candela/square metre	cd/m^2	3.42626
foot-pounds	ft-lb	joule	J	1.356
foot-pounds	ft-lb	kilogram-metres	kg-m	0.1383
foot-pounds/second	ft-lb/s	kilowatt	kW	1.356×10^{-3}
gallons (Imp)	gal (Imp)	litres	L	4.546
gallons (US)	gal (US)	litres	L	3.785
grains/gallon (Imp)	gr/gal (Imp)	parts per million	ppm	14.286
grains/gallon (US)	gr/gal (US)	parts per million	ppm	17.118
horsepower	hp	watts	W	745.7
horsepower-hours	hp-h	joules	J	2.684×10^6
inches	in	centimetres	cm	2.540
inches of Mercury (@ 32°F)	in Hg	kilopascals	kPa	3.386
inches of water (@ 4°C)	in H_2O	kilopascals	kPa	0.2491

UNIT CONVERSION TABLES
IMPERIAL TO METRIC (cont'd)

FROM	SYMBOL	TO	SYMBOL	MULTIPLY BY
lamberts	* L	candela/square metre	cd/m^2	3.183
lumen/square foot	lm/ft^2	lumen/square metre	lm/m^2	10.76
lumen	lm	watt	W	0.001496
miles (statute)	mi	kilometres	km	1.6093
ounces	oz	grams	g	28.35
perm (at 0°C)	perm	kilogram per pascal-second-square metre	$kg/Pa\text{-}s\text{-}m^2$ (PERM)	5.721×10^{-11}
perm (at 23°C)	perm	kilogram per pascal-second-square metre	$kg/Pa\text{-}s\text{-}m^2$ (PERM)	5.745×10^{-11}
perm-inch (at 0°C)	perm. in.	kilogram per pascal-second-metre	kg/Pa-s-m	1.4532×10^{-12}
perm-inch (at 23°C)	perm. in.	kilogram per pascal-second-metre	kg/Pa-s-m	1.4593×10^{-12}
pint (Imp)	pt	litre	L	0.56826
pounds	lb	grams	g	453.5924
pounds	lb	joules/metre, (Newtons)	J/m, N	4.448
pounds	lb	kilograms	kg	0.4536
pounds	lb	tonne (metric)	t	4.536×10^{-4}
pounds/cubic foot	lb/ft^3	grams/litre	g/L	16.02
pounds/square inch	psi	kilopascals	kPa	6.89476
quarts	qt	litres	L	1.1365
slug	slug	kilograms	kg	14.5939
square foot	ft^2	square metre	m^2	0.09290
square inches	in^2	square centimetres	cm^2	6.452
square yards	yd^2	square metres	m^2	0.83613
tons (long)	ton	kilograms	kg	1016
tons (short)	tn	kilograms	kg	907.185
yards	yd	metres	m	0.9144

* "L" as used in Lighting

4138T/T33(-2)

The following typical values for conversion factors may be used when actual data are unavailable. The MJ and Btu equivalencies are heats of combustion. Hydrocarbons are shown at the higher heating value, wet basis. Some items listed are typically feedstocks, but are included for completeness and as a reference source. The conversion factors for coal are approximate since the heating value of a specific coal is dependent on the particular mine from which it is obtained.

Consistent factors must be used when calculating Base Year and Current Year energy usage.

ENERGY TYPE	METRIC	IMPERIAL
COAL		
— metallurgical	29,000 megajoules/tonne	25.0 × 10^6 Btu/ton
— anthracite	30,000 megajoules/tonne	25.8 × 10^6 Btu/ton
— bituminous	32,100 megajoules/tonne	27.6 × 10^6 Btu/ton
— sub-bituminous	22,100 megajoules/tonne	19.0 × 10^6 Btu/ton
— lignite	16,700 megajoules/tonne	14.4 × 10^6 Btu/ton
COKE		
— metallurgical	30,200 megajoules/tonne	26.0 × 10^6 Btu/ton
— petroleum		
— raw	23,300 megajoules/tonne	20.0 × 10^6 Btu/ton
— calcined	32,600 megajoules/tonne	28.0 × 10^6 Btu/ton
PITCH	37,200 megajoules/tonne	32.0 × 10^6 Btu/ton
CRUDE OIL	38,5 megajoules/litre	5.8 × 10^6 Btu/bbl
No. 2 OIL	38.68 megajoules/litre	5.88 × 10^6 Btu/bbl .168 × 10^6 Btu/IG
No. 4 OIL	40.1 megajoules/litre	6.04 × 10^6 Btu/bbl .173 × 10^6 Btu/IG
No. 6 OIL (RESID. BUNKER C)		
@ 2.5% sulphur	42.3 megajoules/litre	6.38 × 10^6 Btu/bbl .182 × 10^6 Btu/IG
@ 1.0% sulphur	40.5 megajoules/litre	6.11 × 10^6 Btu/bbl .174 × 10^6 Btu/IG
@ .5% sulphur	40.2 megajoules/litre	6.05 × 10^6 Btu/bbl .173 × 10^6 Btu/IG
KEROSENE	37.68 megajoules/litre	.167 × 10^6 Btu/IG
DIESEL FUEL	38.68 megajoules/litre	.172 × 10^6 Btu/IG
GASOLINE	36.2 megajoules/litre	.156 × 10^6 Btu/IG
NATURAL GAS	37.2 megajoules/m^3	1.00 × 10^6 Btu/MCF
PROPANE	50.3 megajoules/kg 26.6 megajoules/litre	.02165 × 10^6 Btu/lb .1145 × 10^6 Btu/IG
ELECTRICITY	3.6 megajoules/kWh	.003413 × 10^6 Btu/kWh

Measuring, Metering and Monitoring

Checklist 15-1

Facility: ______________________ Date: ______________________

Location: ______________________ By: ______________________

Energy System	Metered Yes/No	Energy Consumed	Annual Cost	% Total	Metering Accuracy	Metering Confidence	Additional Metering
Total Heating							
Total Cooling							
Total Lighting							
Process Cost Centres							
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•							
Warehouse							
Boiler Plant							
Waste Treatment							
Maintenance Shop							
Refrigeration							
Kitchen							
Recreation							
Other							
•							
•							
•							
•							

Measuring, Metering and Monitoring

Checklist 15-1

Facility: ______________________ Date: ______________________

Location: ______________________ By: ______________________

Does the page 1 information allow an accurate determination of:

Energy users

Energy used

Energy use pattern

Energy use efficiency

What improvements could be made to existing measurements?

What equipment is required for improvements?

New measurements?

Equipment cost:

Total cost $. . . . .

Total Annual Savings $. . . . .

Potential for savings:

$$\text{Simple Payback} = \frac{\text{Total Cost}}{\text{Total Annual Savings}}$$

= $ ______________ per year

Does new or improved equipment appear to be justified? If yes what additional information is required:

Who to contact: Internally

Externally

Record of action to date