Distribution System Pressure Monitoring

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Introduction

The natural gas industry operates an extensive system of 2.4 million miles of distribution and transmission pipelines across the country to supply natural gas to more than 117 million customers. The design, construction, operation, inspection and maintenance of all operating pipelines are subjected to state and federal regulations. The Pipeline and Hazardous Material Safety Administration (PHMSA) is the primary Federal Administration responsible for ensuring that the pipelines are safe, reliable, and environmentally sound. The Code of Federal Regulations (CFR) 49, Parts 190-199 includes the rules to govern pipeline safety. Individual states may have additional pipeline safety regulations. In particular, Part 192 prescribes a wide variety of minimum safety requirements for gas pipelines. This regulation contains sections applicable to gas gathering, transmission and distribution.

This paper does not cover any regulations and requirements by state or federal government. This paper does not include any operating procedures and practices to operate the pipeline. It is essential to understand the regulations; however, this paper intends to provide an overview of devices used in monitoring pressure in a natural gas distribution system with an emphasis on current methods of electronic measurement. This overview is for those who are new to the industry or for those who are looking for a refresher.

Throughout the country, pipelines carry natural gas to residential, commercial and industrial customers for cooking, heating, manufacturing, power generation, etc. The pressure within the pipeline must be regulated and monitored to provide a reliable and safe gas flow throughout the pipeline.

Gas utilities also known as Local Distribution Companies (LDC) receive natural gas from transmission companies at very high pressure compared to the actual delivery pressure they provide to their customers. The high pressure allows the gas to flow in the pipeline throughout the country. Once the utility has taken custody of the gas, the pressure is step down (reduce) at different stages using regulators and control valves in the system until it reaches proper pressure for the customer. The regulator responds to gas demand to maintain the constant pressure. The actual delivery pressure varies by customer type; for example, a residential home would typically be provided a 0.25 PSI (i.e., Pounds per Square Inch), (7” WC, i.e., Water Column) connection while a commercial/industrial customer in some cases could be provided a 5 PSI connection.

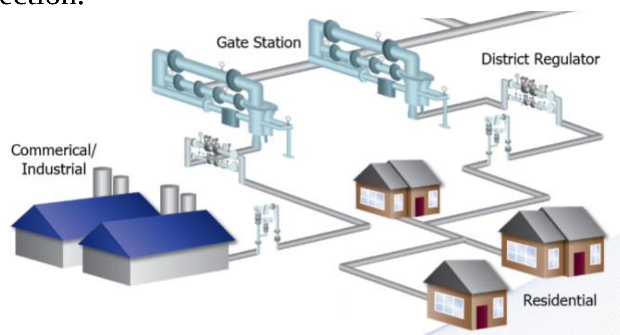

Fig. 1. Distribution Flow Chart

Throughout this transport and step-down process, the pressure will be monitored at every stage using mechanical or electronic devices. These devices include mechanical chart recorders and electronic chart recorders amongst other pressure sensing devices like gauges. The main difference between these devices is what it does with the pressure reading that it obtains.

Distribution system can have analog pressure gauges, digital pressure gauges, mechanical pressure recorders, electronic pressure recorders, pressure transmitters, or pressure transducers. In most cases, there will be a combination of the devices listed.

Local Distribution Companies have an Engineering Department or hire an Engineering Company that handles the design and equipment specifications of stations within a system. The distribution systems are designed to provide safe, reliable and efficient supply to the customer. This includes City Gate Stations, District Regulator Stations (DSR), and any other pressure reducing station or monitoring station. Pressure monitoring equipment will be chosen and placed on the pipeline based on what the engineers have determined to be strategic and appropriate. A site that continually needs to be monitored would likely have an electronic pressure monitor with communications while a site that doesn't require much attention would get a standalone electronic pressure monitor or chart recorder.

Once Engineering designed the station and supplied the equipment, the Operations department implements and maintains the station; in some cases, they will only maintain equipment. Typical maintenance task for the pressure monitoring devices includes changing batteries, performing calibrations, checking for leaks, or changing chart paper.

If the LDC is equipped with Supervisory Control And Data Acquisition (SCADA) System, the electronic pressure monitors can be configured to report the alarms when system pressure falls outside acceptable limits. Remote pressure monitoring at critical and strategic location in the pipeline assist in operating pipeline under maximum allowable operating pressure (MAOP).

Measurement of Pressure

The measurement of pressure in a natural gas distribution system is to quantify the force applied by a gas upon a surface and provide that in numerical representation.

Pressure measurement requires a unit of measure to represent the values being obtained and also needs a high level of accuracy to have confidence in the reading obtained.

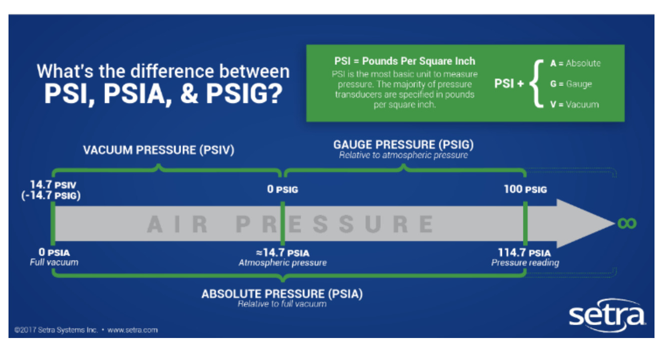

Fig. 2. Difference Between PSI,PSIA, and PSIG (Source: Setra Systems, Inc. website)

The typical unit of measurement for pressure in the United States is Pounds Per Square Inch (PSI). As pressures get extremely low, the units used are typically displayed in inches of water column ("WC) to provide a better resolution to the reading.

When reading pressure in PSI, a reference must be added such as Absolute or Gauge. Absolute pressure is measured relative to a vacuum that is void of air molecules and therefore results in a PSIA reading having the average atmospheric surface pressure added onto it. Gauge Pressure is measured relative to average atmospheric surface pressure; consequently, it does not require adding anything to the final reading. The surface pressure at sea level is 14.7 PSIA. To compare the two as noted in figure 2. 100 PSIG is the same reading as 114.7 PSIA.

Low-pressure systems like ones used to feed appliances in a residential home have inches of water column ("WC) as the typical unit of measure. Inches of the water column is defined as the pressure exerted by a column of water that has one inch of height. In other words 1 "WC is equal to the pressure that a 1-inch tall column of water would put on the media it rests. 1 PSIG equals to 27.679"WC.

Pressure sensing devices vary in accuracy and have two main methods of referencing that accuracy. The device's accuracy can be stated in percent of reading (% Reading), percent of full scale (%FS), or as a combination of both. An accuracy stated in %Reading would have a smaller amount of error throughout its range at a different pressure than a device that had the same accuracy stated in %FS. For example a 1000 PSI transducer with an accuracy of 0.25 %FS sitting at 500 PSI could be +/- 2.5 PSI of that reading and still be within its stated accuracy, while a 1000 PSI transducer with an accuracy of 0.25 %Reading sitting at 500 PSI could be +/- 1.25 PSI of that reading and still be within its stated accuracy.

Gauges

Pressure gauges vary in design and construction materials; however, they are typically mechanical and electronic.

Mechanical gauges commonly used in the natural gas industry utilize bourdon tubes. Other common gauges have pressure sensing elements that are diaphragms or bellows. Permanent installations of gauges on stations will commonly be mechanical and oil filled.

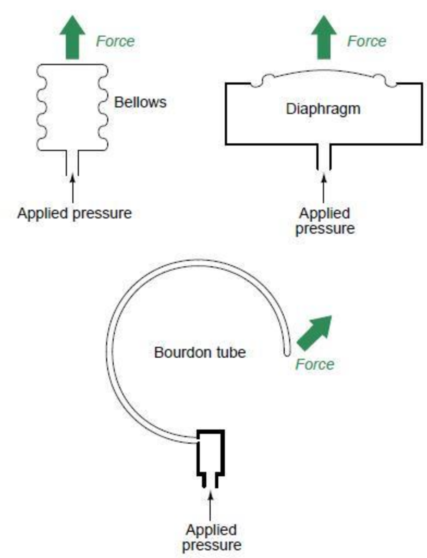

Fig. 3. Examples of different gauge sensing elements (Source: http://3.bp.blogspot.com)

Bourdon tubes have a C shaped hollow metallic tube that expands as pressure increases, see figure 3. The movement at the end of the tube rotates a geared linkage which in turn moves an indicator on a visual readout. The bourdon tube is encased in a housing to keep out debris and bugs and may be filled with oil to reduce mechanical wear.

Electronic gauges have varying types of sensing elements, accuracy, and beneficial features. Common electronic gauges utilize piezoresistive strain gauge technology. The electrical resistance in the strain gauge changes as pressure causes mechanical stress and deforms the material. Semiconductors like silicon have much larger piezoresistive effects than metal which make them ideal for measuring the electrical resistivity. Electronic gauges have accuracies that vary; distribution companies could have gauges ranging from 0.05 %FS to 0.25 %FS and have multiple gauges of different pressure ranges. Features included in electronic gauges may consist of zero, min, max, temperature, or lighted displays. Distribution companies would use these to calibrate pressure recorder transducers.

Mechanical Chart Recorder

Fig. 4. Example of a chart recorder

Chart recorders were the standard for recording pressure over time remotely before electronic pressure recorders. A pen logs single or multiple pressures onto a circular or linear paper chart. Paper charts can represent periods as short as a day to over many months, seven days and single month charts are the most common.

A mechanical clock or electromechanical clock perform timing. When the clock moves, a paper chart rotates, and a pen resting upon the chart logs the pressure.

Electronic Pressure Recorder

Electronic pressure recorders are used to store instantaneous samples, samples averaged over time or a combination of instantaneous and averaged values into digital timestamped records. These records are archived and stored in a memory buffer to be retrieved through local or remote communications.

Fig. 5. Example of an Electronic Pressure Recorder.

The main benefit of an electronic pressure recorder in a distribution system is the ability to have communications to remotely gather data and provide device initiated alarming to a host system for pressure events.

An electronic pressure recorder typically consists of the following main components:

- Enclosure

- Processor Board (motherboard)
- Display
- Keypad
- Pressure Transducer
- Local Communication Port
- Remote Communications Options
- Operating Software/Firmware
- Power Supply

While the above are typical components, each application requires its combination of necessary components and could include more or less of the items listed.

Fig. 6. Example of an electronic pressure recorder.

Enclosure is weatherproof and suitable for outdoor use. Most enclosures also allow for a security seal, door lock and entry/exit connections.

Processor Board (motherboard) is the “brains” of an electronic pressure recorder, see Fig. 7. The processor board is a printed circuit board assembly (PCBA) with all the electronic parts necessary for the pressure recorder. The PCBA has the appropriate connectors and terminals for interfacing to accessories, such as pressure transducers, temperature sensors, displays, communications equipment, etc.

The processor board also has power supply circuitry, at least one microprocessor, multiple memory types, analog/digital converters, analog inputs/outputs, digital inputs/outputs, signal conditioning, as well as several other supporting circuitries.

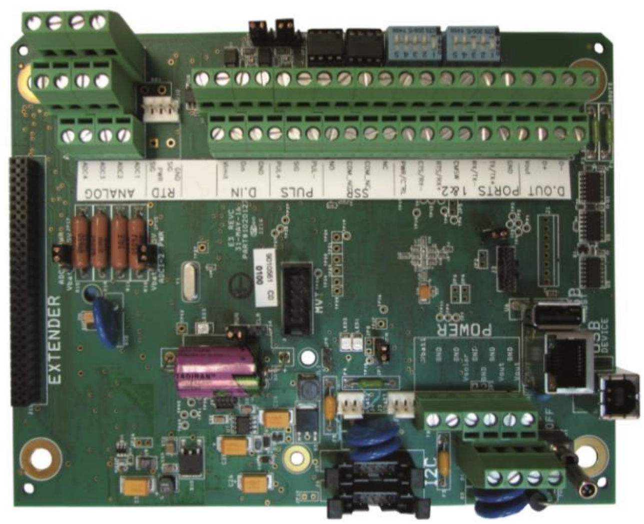

Fig. 7. Example of a microprocessor based processor board (PCBA).

The processor board's internal circuits are usually powered by 5 VDC or 3.3 VDC depending on the technology used on the board and who the manufacturer is. The onboard power supply regulator allows the pressure recorder to be powered externally by 12VDC or 24VDC. External power requirements vary by manufacturer and could require for example an exact 7.2VDC or have a range of 7-30VDC.

Display provides a way to view designated parameters locally. The most common display type is a Liquid Crystal Display (LCD). The LCD may be a part of the processor board or a separate PCBA connected to the processor board.

Most single line LCD's are designed to display a limited number of characters. Multi-line displays can display the value along with descriptive labels.

Manufacturers enable different parameters to be scrolled through by pressing a button or waving a magnet on a designated area.

If a magnet is used to control scrolling, the display PCBA uses magnetically activated reed switch.

Keypad is used for local data entry. A Keypad allows for configuration or quick access to parameters. Not all pressure recorders may be equipped with a keypad as they are not a requirement.

Pressure transducer is a sensor used in measuring gas pressure, see Fig 8. The pressure transducer generates proportional electrical signals as a function of the pressure imposed on its pressure sensor element. The electrical side of

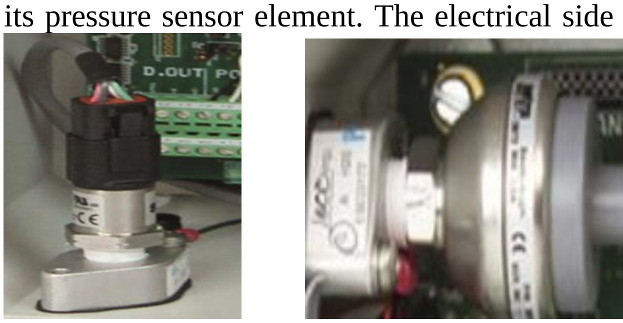

Fig. 8. Example of a pressure transducer inside the enclosure.

the pressure transducer is connected to the analog inputs signal, power, and ground connections on the processor board. The other side of the pressure transducer is threaded to accept tubing from a pressure tap.

Proper valves and tubing are installed to allow maintenance and calibration of the transducer. A quick connect for a mechanical/electronic gauge should be considered for quick verification of the electronic readings.

Local communication port is typically a serial port with a mechanical or InfraRed (IR) connector on the side of the electronic pressure recorder enclosure. This communication port allows direct communication to the user's laptop or tablet. A unique data cable may be required between the electronic pressure recorder and the user's computer. The local communication port is used for initial setup, calibration, maintenance, and data collection.

Remote communication options allow users to interrogate the pressure recorder without being physically present. Remote communications are often achieved by, but not limited to, the use of cellular modems, satellite transceivers, or radio transceivers. This allows the user to communicate with the unit in the field from another location, such as a field office. Often, a Supervisory Control and Data Acquisition (SCADA) software or a measurement collection software are used to collect data remotely on a scheduled basis.

Operating software is software that is loaded onto the user's laptop or tablet to use for communication with the electronic pressure recorder. This software, provided by the manufacturer, allows for system setup, configuration, data collection, maintenance, and troubleshooting of the electronic pressure recorder.

Power supply is the primary source of DC voltage for the pressure recorder and is available in many options, such as uninterruptable power supplies (UPS), solar power supplies (SPS), multi-cell battery packs, thermo-electric generators, etc. The type of power supply is based on the power available at the site and the hardware requirements.

Battery pack is a widely used power source for electronic pressure recorders in the field, see Fig 9. The most popular types of battery packs include alkaline and lithium thionyl chloride (Li-SOCI2).

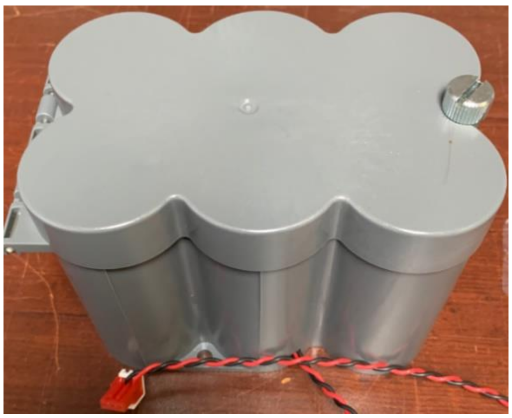

Fig. 2. Example of the battery pack

Alkaline and Li-SOCI2 battery cells are not rechargeable. The battery must be replaced before it reaches the low voltage limit required to operate the device and avoid loss of measurement. A low voltage alarm can be configured to alert a user when a battery pack is near its end of life.

The battery pack should be sized to handle both operations of the pressure recorder and the communication requirements, Many electronic pressure recorders can be configured to wake up at periodic intervals to perform sampling, record creation, and communications tasks; to preserve the battery life.

Uninterruptible Power Supply (UPS) consists of a rechargeable battery and AC to DC converter, see Fig 10. The UPS is powered by AC voltage, 110VAC or 240VAC. Upon AC power failure, the pressure recorder can continue to run on a rechargeable backup battery until AC power is restored. Backup battery sizing is determined by how long the device is required to run in case of AC power loss.

Fig. 3. Example of an Uninterruptible Power Supply (UPS)

Solar Power Supply consists of a solar panel, mounting bracket, solar charger, and a rechargeable battery. The solar panel is typically mounted onto a pole with the mounting bracket and adjusted to face South to get the most sunlight exposure possible.

The size of the solar panel depends on how much average sunlight is available per day and how much charging current is required. The size of the rechargeable battery is determined by how long the electronic pressure recorder should continue to operate without sunlight and how many amp hours (Ah) the system draws while in operation.

Solar panels can be as small as 1 watt and directly mounted to the enclosure of the electronic pressure recorder. They can also be as large as 130 watts or more and require a sizeable supporting structure/mounting bracket.

Remote Communications

There are many options available for remote communications.

These may include:

- Analog Phone Line (POTS)
- Wireless Licensed Radio
- Wireless Unlicensed Radio
- Cellular Modem
- Ethernet Drop
- LEO Satellite

For each of the above options, the appropriate hardware needs to be connected to the processor. Additionally, for each communication type, the proper baud rate (the *setting for the speed of communication*) when appropriate and any related communication parameters need to be configured.

The electronic pressure recorder is identified in the field by its unique Site Identification (ID), or identification address. This is important for the remote measurement system or SCADA system to identify the pressure recorder while communicating. The unique ID could be manufacturer specific or just a Modbus address.

Dial-Up Phone Line uses a traditional analog telephone line to communicate with the electronic pressure recorder. The pressure recorder requires being equipped with a dial-up modem. At present, in many areas, analog dial-up lines are going away. Users are commonly switching to cellular technology for remote communication.

Wireless Radio communications require a radio transceiver, coax cable, and antenna. The radio network could communicate to an individual pressure recorder or hundreds of them on a broadcast network.

There are two types of radios: licensed and unlicensed. Licensed radios require a dedicated frequency license from the Federal Communications Commission (FCC). The most popular unlicensed radios are frequency hopping spread spectrum (FHSS) type radios.

Fig. 11. Example of a Cellular Modem.

Cellular has become one of the most popular methods for communicating with electronic pressure recorders in the field. Cellular modems use internet protocol (IP) technology, see Fig 11. Instead of having only a phone number like an analog line, the cellular modem also has an IP address (e.g., 166.56.73.128). This allows for the remote computer connected to the internet to connect to the device in the field via cellular towers or for the pressure recorder to establish a connection outbound if an event occurs. The use of cellular modems requires signing up with a cellular service provider. IP addresses can be dynamic or static; dynamic IP addresses can change when the power of the device is cycled as where a static IP will always stay the same. Users can latch to the carriers generic access point name (APN) for standard static IP addresses or can get custom APN’s from the carrier to have a private network for their cellular devices providing enhanced security.

Satellite communication technology uses a satellite modem installed in an electronic pressure recorder along with an antenna that provides communication to a satellite in the sky, typically a low earth orbit (LEO) satellite though other technologies are used as well, see Fig 12.

Fig. 12. Example of a Satellite Transceiver

Satellite communication supports two-way data communication. The data service is provided by a satellite service provider. Another alternate satellite technology is in use is Geosynchronous Earth Orbit (GEO).

Maintenance

The electronic pressure recorder has minimal moving parts; therefore it requires minimal maintenance. Following certain maintenance guidelines will minimize failure and increase the effective life.

Enclosure maintenance is a program of routine inspections to ensure the integrity of the door seal and other sealing gaskets. Excess moisture can cause problems with electronics if allowed to accumulate within the enclosure, even though most circuit boards are coated to protect against humidity usually up to 95% RH. The wiring connections and various exposed metal surfaces are susceptible to corrosion in extreme cases of interior humidity.

Ensure that the mounting arrangement for the unit is secure, level, and provides a stable platform for termination of the pressure tubing, conduits, etc. Check the lid gasket for deterioration, chemical damage, tears, or compression. Check for damaged or not fully tightened compression fittings.

Battery Packs will need to be replaced or new cells installed at regular intervals. Any non-rechargeable battery pack, under normal operating conditions, will eventually drop below the voltage level required to maintain power for the pressure recorder. Its lifespan is determined by multiple variables specific to each device and type of battery construction, and therefore tricky to generically predict a replacement interval.

The rechargeable battery pack, under normal operating conditions, should provide many years of productive service before needing to be replaced. When it becomes apparent that the rechargeable pack cannot maintain its charge or its voltage has dropped below 10.8VDC, the battery should be changed.

Calibration is a crucial element of any scheduled maintenance program. Today, most of the electronic pressure recorders use software calibration. The software calibration does away with the need for difficult adjustments, thereby simplifying field calibration. Calibrations can be a simple two-point Zero and Span or an elaborate 11-point calibration.

Other Electronic Pressure Recorder Features and Options

The electronic pressure recorder does more than just sample pressure and records it.

Historical data can be stored in the pressure recorders memory on a secondly, minutely, hourly, and/or daily basis. Typical historical data could be pressure, gas temperature, battery voltage, ambient temperature, etc.

Alarm limits can be set with parameters to alert on a local display and store a local historical record if parameters fall outside the alarm limits.

It can also be configured to report to the remote computer system via a communication link.

Audit Trail is an important feature to record any changes made to the corrector. Typical audit trail records include the date and time a change was made along with the old value, and new value of a parameter. An audit trail is usually serialized to track the changes over time.

Power Management features allow the pressure recorder to minimize power usage, thus extending the battery life. Today, pressure recorders can be configured to power up periodically to perform specific tasks along with sampling or to power the communication devices only at predetermined times. Most communication devices consume large amounts of power when compared to the power required to operate the pressure recorder. For example, the pressure recorder could use 100 micro-amps as it samples inputs and a cellular modem can easily use 100 milli-amps while connected to a network and not communicating.

External Transmitters for pressure or temperature may be used with some pressure recorders. The external transmitter may output a signal of 4-20 mA, output a voltage from 1-5 VDC, or other less common output ranges. These transmitters generally require a 24 VDC supply.

Data Availability

Data availability requirements are intended to ensure that the minimum necessary data is collected and retained to allow proper oversight of the station.

Remote collection of this data, such as through a SCADA system or polling engine, is acceptable unless prohibited by statute, regulation, tariff, or contract.

Onsite data is typically stored in the pressure recorder. Local storage could be in months or years for total records however the minimum requirement for total records is defined below. Local distribution companies may collect the archive data retained in the electronic pressure recorder, or they may poll the device at frequent intervals and build their trends in the SCADA system being utilized.

Security and Data Integrity

Security is required to prevent unauthorized alterations of configurations and data which affect measurement integrity.

The electronic pressure recorder in the distribution system shall be configured to deny unauthorized access to configuration profiles and measurement data via unique access codes and/or username and password. A hardware lockout jumper can also be used.

All data records shall be stored in such a way they cannot be altered. There must not be any changes to the original data. Both original and edited data must be retained.

Summary

Electronic pressure recorders and the other pressure measurement devices referenced above are only a single part of a distribution system but are essential to monitoring pressure across a local distribution company’s pipeline infrastructure for reliable and safe natural gas supply. With advances in cellular and satellite communication technologies more and more companies are monitoring pressures in real time twenty-four hours a day. Real-time monitoring allows changes in pressure report immediately and take timely action to avoid undesirable event.

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