Line Break Detection System Analysis is Critical to Safer, More Economic Gas Pipeline Operations

1 Introduction

There are a number of factors driving the growing need for a fail-safe method of detecting and isolating pipeline ruptures or major leaks. The key considerations are:

• Safety
• Throughput security for a line break
• Economics
• Public Relations

These considerations help define the operational requirements of a line break detection system, which are:

• Fast identification and isolation of the ruptured section pending additional accident control measures
• Indication of the rupture location
• Information regarding the viability of the remaining system

A line rupture detection device does not improve the reliability and integrity of a pipeline transmission system. The device is not preventive or remedial, but used in conjunction with other devices and systems can mitigate a rupture.

Since break identification depends very much upon transmission system configurations, operating transients and operating criteria, the selection of any detection system must be based on a comprehensive analysis of the pipeline system.

Rate of pressure drop and rate of flow are common industry sensing parameters. However, for rupture systems they present an exposure to false closure. This exposure typically increases with the distance between mainline valves since the rate of pressure drop increases with time and distance.

The systems based on the rate of pressure drop experience difficulty distinguishing between pressure drops due to pipeline rupture and those due to
unexpected start/shutdown of major consumers (processing plants, power plants). This can be fixed by modifying the response time ahead of an event or by using powerful computational devices.

Natural gas pipelines employ automatic safety devices to close valves and prevent the release of gas in the event of a pipeline break. These systems are critical to safe, economic operation of the pipelines. This paper examines the application of two primary break detection systems and their interaction with other pipeline protection systems.

A pipeline break causes a pressure drop. But the nature of this drop is complicated by multiple factors, including: diameter and length of the pipeline, dimension of the break, temperature and pressure of the gas, and flow rate.

In addition, detection and response is difficult because the valve actuators and line break devices are dependent on their distance from the break point and the resulting pressure drop.

The complexity is also increased by normal pipeline operations that result in pressure drops unrelated to a break. These fluctuations can be caused by changes in the operation of compression stations or by increased gas consumption by branches and users.

A very reliable way to identify a pipeline break is to detect the "abnormal" value of the rate of pressure drop (DP/DT) relative to values established during the normal operation of the pipeline.

The paper addresses the two main types of line break detection systems: gas- and electric-operated.

Gas-operated systems (without electronic transducers) sense the pressure drop rate or level mechanically with pneumatic components logic. All the energy is supplied by the transmitted flow and can be stored in tanks.

Electronic devices employ a pressure transducer to continuously sense the line. A microcontroller records the data and triggers a solenoid valve to move the isolation valve. The small amount of energy required can be provided by lithium battery packs or alternative power supply such as a solar panel, thermoelectric generator, or fuel cells.

These leakage detection systems can work standalone or combined as a part of a supervisory control and data acquisition (SCADA) system that may also include wire, pressure profile and optical fiber systems. Understanding the operation of these systems, the factors affecting their measurements, and interaction with
other aspects of the system is critical to safer, more economic pipeline operations.

1.1 Rupture analysis

Statistically one of the main causes of a major pipeline rupture is action by a third party. The incidence is dramatic even in well-maintained pipelines with integrity programs using predictive devices.

Fire caused by an opening in the pipe can spread to involve major areas of damage and can be propagated “open seam” for kilometers. As a result, the main block valves and their local control systems are a vital part of the pipeline’s safety

Figure 1

This type of accident could also damage communication links, such as fiber optic cables, and power supply lines. As a result, it is critical that several levels of safety devices are used to enhance pipeline safety, reliability and economics. The line break detection devices are the last barrier to quickly stopping the gas leakage and the potential fire.

2 Devices based on Rate of Pressure Drop or Rate of Flow
2.12.1 Pneumatic Linebreak detection

On natural gas pipelines, automatic safety devices are necessary to close the valves and stop the gas losses, which could threaten people, infrastructure, and economics.

A pipeline break causes a rate of pressure drop that depends on multiple factors, including:
- Diameter and length of the pipeline
- Dimension of the break
- Temperature and pressure of the gas
- Flow rate
- Distance from the breaking point to the valve on which the actuator, complete with the line break device is assembled. (The longer the distance, the less the pressure drop rate acting on the line break device.)

During the normal operation of the natural gas pipeline, there are also pressure drop rates caused by operating changes at compression stations or by increased gas quantities required by branches and users.

A reliable way to identify pipeline breaks is to detect an "abnormal" value of the rate of pressure drop (DP/DT) that exceeds the values verified during normal pipeline operation.

The line break device for automatic valve closure in the event of a natural gas pipeline break is based on detecting the pressure drop rate (DP/DT) by measuring the pressure difference between the reference tank (connected to the line through a calibrated orifice) and the pipeline. The device is easily set to meet the dimensional and operating features of pipeline.

The system is powered by pipeline gas and does not require any external power source, which is an advantage for standalone devices in remote areas.

Set up for the device must consider the minimum rate of pressure drop caused by a pipeline break that ensures operation of the line break device, and the maximum rate of pressure drop occurring during normal operation that will not cause the line break device operation.
2.1.1 Working principle
A break in the pipeline causes an increase in gas speed and consequently, an increase in pressure drop across the valve. But it is not possible to use this as the signal for the central device operation because with the valve fully open, the pressure drop is very low.

If a reference tank is connected to the pipeline through a calibrated orifice with a check valve, an increase in pipeline pressure is immediately equalized by pressure in the tank. However, when line pressure decreases, tank pressure remains higher than the pressure into the pipeline.

The higher the pressure drop rate in the pipeline, the smaller the orifice diameter; the larger the volume of the reference tank, the higher the pressure difference between the reference tank and the pipeline.

A diaphragm device measures this differential pressure. When the differential pressure exceeds the set point, the valve closes and is prevented from opening.
2.1.2 Line break device operation

The line break device is connected to the pipeline downstream from the valve to avoid undesired valve closure when it opening is actuated under differential pressure. (It is assumed in fact, that the upstream pressure is always higher or equal to the downstream pressure).

When the pipeline pressure rises, the check valve opens and the reference tank pressure immediately equalizes the pipeline pressure. Conversely, when pipeline pressure drops, the check valve remains closed and the only connection between the pipeline and the reference tank is through the orifice. In this way, the pressure in the reference tank remains higher than the pressure in the pipeline.

The pipeline and the reference tank are connected to the two chambers of the diaphragm valve such that the differential pressure acts on its diaphragm. A higher pressure drop rate, results in a higher differential pressure. When the differential pressure exceeds the set value of the diaphragm valve, a pressure signal is tripped. The differential pressure value is adjusted by setting the valve’s return spring.

The pressure signal coming from the diaphragm valve controls the actuator operation in closing and prevents the opening operation.
After the emergency closing operation controlled by the line break device, the system must be manually reset to enable the opening operation.

2.1.3 Curves for line break device operation

When pipeline pressure drops, the pressure into the reference tank also decreases. But this occurs with a certain delay as the connection is made through the calibrated orifice. The difference between the two pressures increases with time up to a maximum value (dP MAX) and then decreases. The value of the differential pressure is a function of the pipeline pressure drop rate, the orifice diameter and the pipeline pressure value.

2.1.4 Change of differential pressure with time for two different pipeline pressure drop rates, using the same orifice diameter and same initial pipeline pressure.

The curves in Figure 4 show that the differential pressure between the reference tank and the pipeline is higher if the pressure drop rate is higher. They also show that with the same orifice diameter, the time (t0) required to reach the maximum dP value is the same for all the pressure drop rates and it is dependent only on the orifice diameter.

![Figure 4](image-url)
2.1.4 Change of differential pressure with time for two different orifice diameters, by same pipeline pressure drop rate and same initial pressure

The curves in Figure 5 show that with the same pressure drop rate, the pressure difference between the reference tank and the pipeline is higher if the orifice diameter is smaller. The values of differential pressures \( dP_2 \) are higher than \( dP_1 \), with the diameter of orifice 2 smaller than the diameter of orifice 1. The curves also show that more time is required to reach the \( dP_{\text{max}} \) value of the differential pressure if the orifice diameter is smaller.

![Graph showing differential pressure over time for two orifice diameters](image.png)

The orifice diameter 2 is smaller than the orifice diameter 1

Figure 5

2.1.5 Change of differential pressure with time, for two different initial pipeline pressures, by same pressure drop rate and same orifice diameter

The curves in Figure 6 show that with the same pressure drop rate, the pressure difference between the reference tank and the pipeline is higher if the initial
pressure is lower. The values of the pressure difference 
$dP_2$ are higher than $dP_1$, because the initial pressure of the curve 1 is higher than the initial pressure of curve 2.

The curves also show also that the time required to reach the differential pressure maximum values $dP_{1 \text{ max}}$ and $dP_{2 \text{ max}}$ are the same and depend solely on orifice diameter.

Figure 6

2.1.6 Maximum differential pressure values generated by different pressure drop rates, by different pipeline initial pressures and different orifice diameters

The curves in Figure 7 show the values of the maximum differential pressure between the reference tank and the pipeline as a function of the pressure drop rate. There are three different values of initial pipeline pressure (35, 55, 75 bar), which are in the normal working pressure range of the pipelines.
The curves are drawn for 4 different orifice diameters: 0.5, 0.7, 0.9, and 1.25 mm. The pressure drop rates are calculated as the average value over one minute.

The curves allow identification of the orifice diameter, which is used to assure the line break device is set to the actual working conditions of the pipeline (pressure and pressure drop rate) in case of line break.

![Figure 7](image-url)

**2.1.7 Setting the pneumatic line break device**

To set the line break device it is necessary to know the working conditions of the pipeline. These conditions include:

- Range of the gas pressure
- Value of the minimum pressure drop rate (measured in the portion of pipeline where the valve is installed) for minimum, normal and maximum working pressures of the pipeline
- Value of the maximum pressure drop rate (measured in the portion of pipeline where the valve is installed) during the normal operation for minimum, normal and maximum working pressures of the pipeline

The device setting must avoid
the intervention of the line break device for all pressure drop rates occurring during normal pipeline operation but still assure intervention for all the pressure drop rates caused by a pipeline break.

It is necessary that the pressure drop rate in the normal working conditions is always lower than the pressure drop rate caused by the line breaking, at the same working pressure.

To set the device, a pressure drop rate value must be identified that will cause device intervention. This value must be higher than all the pressure drop rates that may occur during the normal working conditions, but lower than all the pressure drop rates caused by the line breaking. When the pressure drop rate and the corresponding working pressure have been defined, the orifice diameter can be identified by means of the curves drawn in Figure 5. On the abscissas axis (BAR/MIN) a point is fixed corresponding to the value of the pressure drop rate selected for the setting. A vertical line is drawn to the intersection, with the curve of the maximum differential pressure values related to the selected working pressure. From the intersection point a horizontal line is drawn, which crosses the ordinates axis at the point of maximum differential pressure value that can be used to set the diaphragm valve. The value of the differential pressure must be in the range of 0.2 to 1 bar.

For the diaphragm valve setting, it is recommended that the differential pressure value is not higher than 90% of the value defined by the above-described procedure, to be sure of the device intervention.

The time required for the device intervention is dependent on the diameter of the orifice used.

### 2.1.7.1 Example of the device setting

Suppose that the gas pressure into the pipeline is 55 bar, the maximum pressure drop rate during the normal operation is 0.5 bar/min, and the minimum pressure drop rate caused by a line breaking is 1.5 bar/min.

The device is set to operate with a pressure drop rate of 1 bar/minute. By using the curves in Figure 8, we can see that the appropriate orifice is 0.5 mm. diameter. This will yield a differential pressure in the range between 0.2 and 1 bar.

On the abscissas axis (BAR/MIN) a point is fixed corresponding the pressure drop rate value = 1 bar/min.

A vertical line is drawn to the intersection with the curve of the maximum differential pressure values related to the working pressure 55 bar.
From the intersection point a horizontal line is drawn, which crosses the ordinates axis at the point of 0.7 bar differential pressure.

In order to ensure device intervention, the diaphragm valve is set at the differential pressure of 0.6 bar.

To set the device it is necessary to install the orifice with a 0.5 mm hole diameter and adjust the diaphragm valve to 0.6 bar differential pressure.

Figure 8

Pneumatic LB detection systems work without any external power source or control system. The systems are commonly fitted with solenoid valves for remote valve operation in standalone applications or integrated as part of a total pipeline
safety system that includes supervisory control sending ESD signals based on other parameters.

2.2 Electronic line break detection

An electronic line break detection system continuously monitors pressure in the line and in case of rupture sends a command to the actuator to stroke the line valve to the fail safe position. The electrical power necessary for working is minimal and can be supplied by:

- Long-lasting batteries such as small lithium packs that allow the device to work for at least one year
- Small solar panels with a rechargeable battery pack
- Other alternate sources can supply the small amount of energy, including thermal generators, fuels cells, and other energy harvesting methods

The electronic line break device has a local operator interface, usually LCD displays type and push-buttons, that allow entry of configuration data and visualization of variables values or the status of the device. Moreover, serial communication ports and wireless link provide connectivity for notebooks and other intelligent devices for parameter configuration, variables visualization or downloading recorded event data for further analysis of pipeline behavior.

The electronic line break device cyclically samples the line pressure value measured by the pressure transducer (PT) and memorizes the sampled values in a temporary rolling memory. The pressure magnitude and drop rate are continuously compared to the reference values set by the user in the configuration memory.
An event is defined as the condition that occurs when the measured pressure magnitude or pressure drop rate exceeds the customer set point for a configured time. In case of an event, the pressure magnitude values in the memory, a packet preceding the event and another packet after the event, are transferred to the data memory.

2.2.1 Example of pressure drop rate control

Figure 11 shows electronic line break device behavior in the presence of a continuous pressure drop rate.
Figure 11

Figure 12 shows electronic line break device behavior in the presence of a temporary pressure drop rate.

Figure 12

A next step in local electronic line break detection devices is the use of new technologies, powerful microcontrollers and digital signal processors (DSP). The problem of misunderstanding erratic pressure drops can be overcome by devices
that recognize “shapes” in the curves, an advancement over Dp/Dt using computational algorithms.

3. The complete safety system

The line break detection systems are only a part of the complete pipeline safety programs. The two types analyzed in this paper are the last barrier to mitigating the effects of pipeline rupture.

Today´s complete systems include central monitoring of the pressure profile, leakage detection systems to prevent early-stage pipeline breaks due to material failure or corrosion.

4. Conclusions and recommendations

• Use high reliability equipment – SIL certified; Safety certified equipment will reduce the failure on demand

• Gas operated systems don’t require additional energy or energy conversion, they are recommended to be used where electric power supply is not available or the risk of third party malicious attack is high

• The electronic device is easily configured and is independent of the seasonal fluctuations, Adding more processing capabilities it will solve in the future the problem of operational transient identification

• Ensure the next emergency operation by implementing PST and diagnostics

• Add capabilities to local control systems with line break, seismic sensors, intrusion, and surveillance
• Use communication redundancy--OF links plus wireless (radio, satellite, GPRS)