THE LEE COMPANY

AN ENGINEER'S GUIDE TO

# SELECTING A PRESSURE RELIEF VALVE

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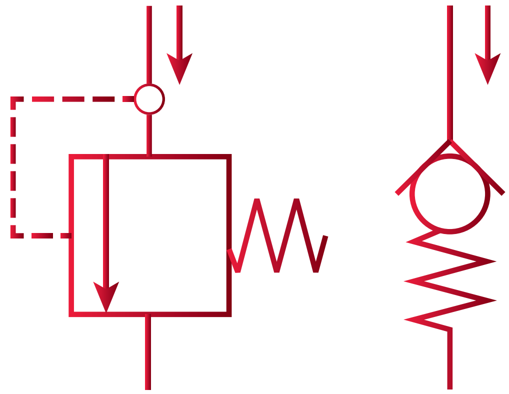
# WHAT IS A PRESSURE RELIEF VALVE?

A pressure relief valve is a mechanical device which allows a gas or liquid to escape from a section of a fluidic system when the pressure exceeds a predetermined limit.

Pressure relief valves originally became popular for use in the boiler systems used to heat buildings. A boiler creates hot water or steam which is distributed throughout a building via radiators. If the pressure created by the steam got too high, pipes or tanks could burst, causing extensive damage and potentially injuring people. A pressure relief valve would vent the steam to a safe location prior to the pressure rising to a dangerous level. More recently, pressure relief valves are used for protection in a wide variety of applications, such as hot water heaters, storage systems used to transport liquids or gases, chemical treatment plants, nuclear reactors, engine fuel systems, and hydraulic systems used to operate automobiles, construction equipment, or aircraft.

COMMONLY USED GRAPHIC SYMBOLS REPRESENTING PRESSURE RELIEF VALVES IN HYDRAULIC AND PNEUMATIC SYSTEMS



# PRESSURE RELIEF VALVE FUNCTIONS

Pressure relief valves can serve several different functions within a system. The performance requirements of a pressure relief valve will be influenced by its intended use. Selecting a valve appropriate for your application is critical to ensure the system operates properly. The function of a pressure relief valve can generally fall into one of three categories:

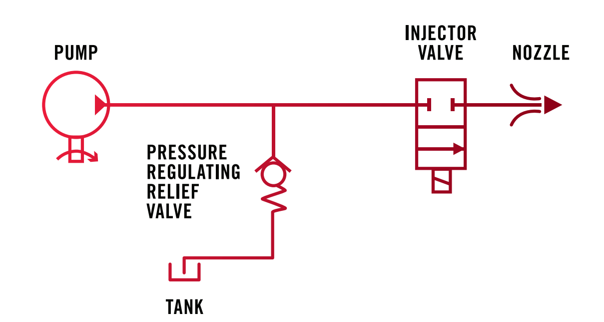
## SAFETY RELIEF VALVES

These types of relief valves are “pop-off”, fast-acting valves ideal for applications with the potential for sudden pressure spikes within a system. While necessary for system safety, these valves typically do not open frequently. For example, when using a pump to fill a storage tank with a gas, the pressure in the tank rises quickly as it becomes full. If the tank becomes too full, it can burst like a balloon. To avoid this, the line between the pump and tank will include a safety relief valve. If the pressure increases to a point above the preferred tank pressure, the relief valve will pop open quickly and relieve the flow. Flow can either be relieved to the atmosphere or to a line that returns the gas to its original source upstream of the pump. When the pump is turned off, disconnected from the tank, or the pressure returns to a safe level, the relief valves closes.

## PRESSURE REGULATING RELIEF VALVES

Pressure regulating relief valves are intended to operate more continuously within a system. The valve will often be in a varying state between closed and fully open. Therefore, valve stability is critical because pressures and flows will vary while the valve is open. This type of valve is commonly found in an engine fuel system. Fuel is delivered into the combustion chamber of an engine through injection nozzles that operate most efficiently within a specified pressure range. The fuel is typically supplied by a fixed volume pump while the injection nozzles open and close at varying rates depending on engine demand. A pressure relief valve is located between the pump and fuel injection nozzles. As the pump delivers fuel, the pressure regulating valve opens varying amounts and relieves excess fuel back to the tank. This maintains a constant pressure to the injectors for improved fuel efficiency.

FUEL INJECTION SCHEMATIC




## THERMAL RELIEF VALVES

Thermal relief valves are intended to relieve a very small amount of fluid due to thermal expansion within a trapped volume. In this case, it is important that the valve is optimized for very low flow rates. One application example for this type of valve is the parking brake system of an aircraft. External temperatures during flight can get very low, while ground temperatures are potentially much higher. While the aircraft is parked the fluid in the parking brake system will expand due to the temperature increase. A thermal relief valve can be used to relieve the fluid when it expands, decreasing pressure to avoid the potential failure of the parking brake system and the dangerous situation of the aircraft rolling unexpectedly.

# HOW PRESSURE RELIEF VALVES WORK

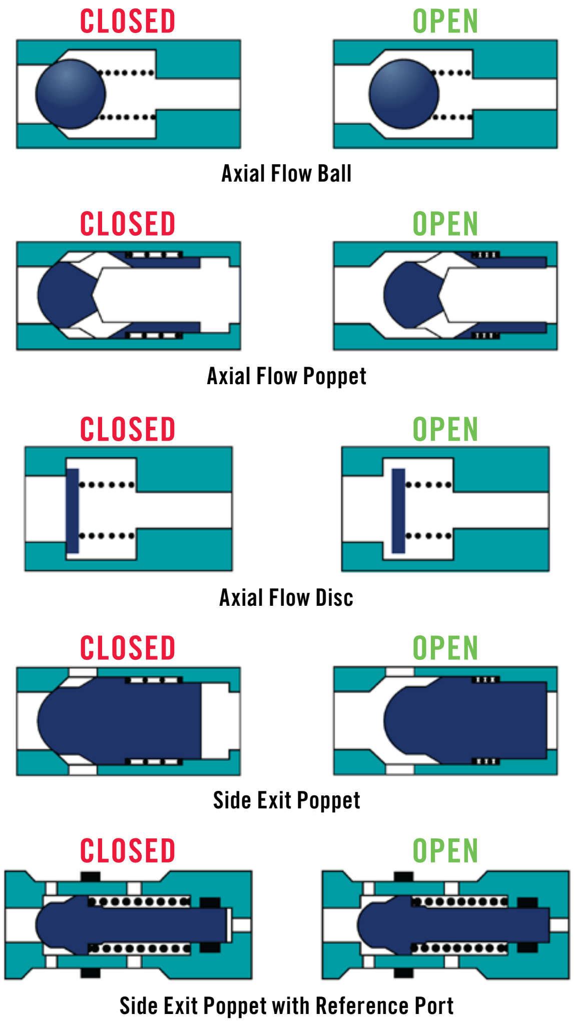
A pressure relief valve is a direct-acting device, which means pressure acts directly upon the internal components of the valve. Pressure relief valves are normally closed, with internal components held in a position that creates a seal to prevent flow. When pressure increases beyond the valve's specified limit, the valve is forced open, allowing fluid to vent out of the pressurized area to another section of the system or into the surrounding environment. By allowing fluid to vent, the pressure relief valve prevents pressure from increasing further and/or reduces the pressure within the system. After the pressure reduces to an acceptable level, the valve will return to its normally closed position and will shut off flow.

## PRESSURE RELIEF VALVE CONFIGURATIONS

Pressure relief valves are available in a variety of configurations. A common configuration features a loaded, compressed spring that holds a ball bearing, poppet, or disc against a valve seat. The combination of these components provides the internal seal used for preventing flow. While in the open position, fluid flows axially between the seal and valve envelope or through passages within a poppet. Alternatively, some valve configurations allow flow to exit at 90 degrees relative to the valve inlet. In some designs, a diaphragm or bellows may be used to control the opening of the valve rather than a spring.

Most relief valves operate based on the differential pressure between the inlet and outlet ports. However, there are cases where the main concern is the inlet pressure relative to a third, or reference, pressure. This pressure can be ambient pressure, or another pressure generated by the system. In such a case, a separate third port within the relief valve is left open to that reference pressure. This can be important when a system requires a certain inlet pressure, regardless of the outlet pressure, to function properly.

REPRESENTATIONS OF VARIOUS PRESSURE RELIEF VALVE CONFIGURATIONS



# WHAT ARE THE CRITICAL PERFORMANCE CHARACTERISTICS OF A PRESSURE RELIEF VALVE?

There are several factors that must be considered to ensure proper operation of a pressure relief valve within a system or pressure vessel. Neglecting to consider these factors can lead to reduced valve or system performance, damage to other components within the system, or a total system failure. The following performance characteristics should be defined when selecting a pressure relief valve:

## SYSTEM PRESSURES

There are four pressure ratings that should be considered for any pressure relief valve: operating pressure, system pressure, proof pressure, and burst pressure. *Operating pressures* are the pressures the valve will be subject to during normal operation throughout its life, both in the relief flow direction and the checked, or opposite, direction. *System pressure* is the maximum nominal pressure that the system the valve is installed into will achieve. *Proof pressure* is the pressure the valve should be able to withstand without permanent deformation or degradation of performance when the system returns to operating pressure. *Burst pressure* is the pressure at which the valve should survive without rupturing or bursting. All four pressure ratings must be considered during design to ensure the valve and its components are durable enough for the application.

## CRACKING PRESSURES

A pressure relief valve's set pressure, or cracking pressure, is the pressure at which the valve opens and begins to allow fluid to pass. The cracking pressure is based on the pressure vessel or system's design criteria and is typically defined as a nominal pressure with a tolerance or as a minimum. The minimum cracking pressure is the lowest pressure that the valve may open and implies the actual crack will occur at a pressure between the minimum and the relief flow pressure as pressure increases.

If the valve opens at a pressure that is too low, there is a risk of improper valve operation or a decrease in system efficiency. Alternately, if it does not crack open and pressure increases too much, there is a risk of experiencing the issues which the valve is supposed to prevent such as deformation to the system or its subcomponents.

## FLOW RATE

To ensure that the system pressure does not reach a critical point, the relief valve must allow a certain volume of fluid to exit within a limited period of time. This flow rate is based on the potential rate of a pressure increase (also called a pressure rise rate), the volume of fluid in the system, and the volume of fluid that needs to be displaced to alleviate the pressure increase. For example, a pressure relief valve protecting a large pressure vessel from damage due to a powerful pump malfunction requires more flow capacity than a pressure relief valve protecting a small pressure vessel from the pressure increase created by thermal expansion on a cold day.

# WHAT ARE THE CRITICAL PERFORMANCE CHARACTERISTICS OF A PRESSURE RELIEF VALVE? (cont.)

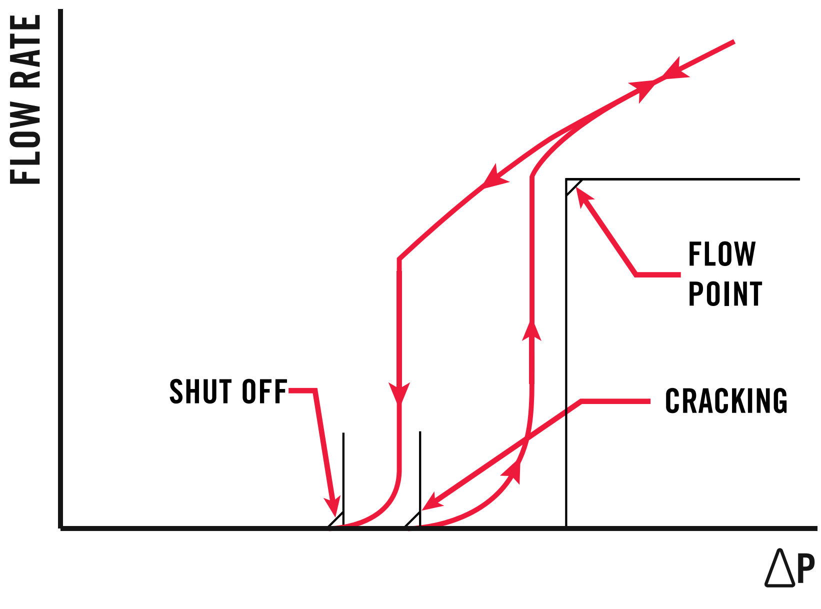
## FLOW RATE (cont.)

The flow rate the valve is designed to achieve is typically defined at a specific pressure known as the flow point pressure, overpressure point, or relief flow pressure. The flow point pressure is always higher than the cracking pressure and may signify when the valve is in its fully open state, at which point it will perform as a fixed restriction. This performance criteria ensures the pressure relief valve will relieve enough fluid at a low enough pressure to prevent further increases in pressure or to reduce system pressure back to safe levels.

## RESEAT OR SHUT OFF PRESSURE

A pressure relief valve's reseat pressure is the pressure at which the valve closes when decreasing from the open state. The shut off pressure is the pressure at which the valve completely shuts off and no longer allows excessive internal leakage past the valve's seal. These pressures are typically defined as minimum pressures. These are the lowest pressures that the valve is allowed to close or stop leaking and implies the actual reseat or shut off will occur at a pressure between the relief flow pressure and the minimum as pressure decreases. The crack or overpressure points protect the vessel or system, while correctly specifying the reseat or shut off pressure ensures continued normal operation of the system. Like the cracking pressure, if a reseat or shut off pressure is too low, there is a risk of improper valve operation or a decrease in system efficiency.

FLOW VS. PRESSURE CURVE HIGHLIGHTING CRITICAL PERFORMANCE POINTS



# WHAT ARE THE CRITICAL PERFORMANCE CHARACTERISTICS OF A PRESSURE RELIEF VALVE? (cont.)

## LEAKAGE

Valve leakage can be broken down into two categories: external and internal. External leakage refers to fluid flowing around the exterior of the valve body, which may include threads, O-ring seals, or other external features. Internal leakage is any fluid flow through the valve's body while the valve is in its closed position. Leakage allowances can be influenced by variables such as whether it is an open or closed system, total system volume, fluid transfer capability, and desired system efficiency.

## MATERIALS

A pressure relief valve is comprised of several sub-components. The materials of each component must be able to withstand the various forces that will be applied to them during the valve's operating life. This includes the pressures applied internally and externally to the valve, along with the associated pressure rise rates.

Materials must also be compatible with their environment, including external fluids, temperatures, and the system fluid that will relieve through the relief valve. It is possible that a valve may be subject to extreme humidity or be incorporated in a system submerged in other liquids or gases. The valve's materials should be considered when determining how the valve will be installed into the system. Failure to consider material compatibility may create issues related to thermal expansion and corrosion.

## ENVELOPE

The envelope is an important factor to consider when selecting a relief valve. The first consideration is the location of the valve within the system and the desired flow path for the relieved fluid. The system may require the relief valve to be located within a specific area, limiting external dimensions or overall size. The location may also dictate the flow path of the relieved fluid based on existing lines. The envelope must also account for installation, retention, and maintenance requirements. For example, some valves incorporate threaded fitting ends, while others are installed directly into manifold housings. Next, determine whether the installation must be permanent or removable. Finally, evaluate if the valve may be used in a system in which weight is a factor, such as a portable system or when fuel efficiency is paramount.

VARIETY OF PRESSURE RELIEF VALVES

# WHAT ENVIRONMENTAL FACTORS IMPACT THE DESIGN OF A PRESSURE RELIEF VALVE?

After determining the required performance characteristics of a relief valve, it is critical to identify other variables that will influence the pressure relief valve's design. The internal and external environment of the system will affect the valve's design in a variety of ways, impacting every aspect of its functionality and limiting options for the valve's construction. When designing a valve, the following aspects of the system and environment must be considered:

## OPERATING FLUID

The performance of a pressure relief valve is greatly affected by the operating fluid's viscosity and specific gravity. Liquids and gases have different fluid properties that impact flow rate, leakage, and the movement of the valve's internal components. The operating fluid also introduces other variables that must be considered, such as material compatibility. A fluid that is incompatible with the valve's materials could cause damage to the valve, including corrosion or other harmful effects. This damage will negatively affect the performance of the valve, and subsequently the system. It is also possible that the valve's materials may alter the fluid's properties, negatively affecting system performance. For example, a system analyzing blood or chemicals must use components that are inert to the fluid being analyzed. Similarly, a system flowing a flammable gas may need to avoid metals that may ignite when making contact.

## OPERATING LIFE

It is important to consider how long the valve must withstand the conditions it will be exposed to during operation. This includes both the maximum length of time the valve shall be in service and the number of cycles the valve performs. A pressure relief valve may experience wear due to exposure to its environment or by forces caused by contact of internal components, particularly the sealing surfaces. Excessive wear of the valve's components over an extended operating life could lead to performance issues.

## TEMPERATURE

Both the temperature of the fluid and the ambient temperature can impact the performance of a pressure relief valve. Changes to the temperature of the fluid will alter the fluid's properties, including viscosity and specific gravity. Liquids will thicken and increase in density with decreases in temperature, making it harder for the fluid to flow. Conversely, increasing temperatures will cause the fluid to thin, lowering its viscosity and density. Maximum leakage rates may be higher as temperatures increase because leakage is more likely to occur when working with a thinner fluid. Temperatures also impact decisions about the materials used in the pressure relief valve. At cold temperatures, some materials become hard or brittle. At elevated temperatures, materials may become soft or melt. These changes can reduce a valve's operating life. The minimum and maximum temperature rating should be specified for valve performance, normal operation, and survivability.

# WHAT ENVIRONMENTAL FACTORS IMPACT THE DESIGN OF A PRESSURE RELIEF VALVE? (cont.)

## EXTERNAL PRESSURES

Relief valve performance is typically based on changes in pressure within the system or pressure vessel. However, the pressure relief valve envelope may be subject to other environmental pressures, such as those found deep underwater, underground, or even the absence of pressure found in outer space.

## VIBRATION, SHOCK, AND G-FORCES

Pressure relief valves can be subject to forces external to the system in which it is installed, as well as the forces generated by operation of the system. These forces are typically vibration, shock, and G-forces. For example, some systems or vehicles which use pressure relief valves generate levels of vibration during normal operation. A shock may occur if the system or vehicle in which the valve is installed suddenly encounters another object. Lastly, the system or vehicle may generate G-forces during operation due to sudden or rotational movement. The magnitude, frequency, and direction of the potential forces must be considered. The internal components of the valve move differently based on the direction of the force. The frequency of the vibration may be detrimental to the valve if it corresponds to the natural frequencies of the design. In most cases, a relief valve is required to withstand and even remain closed during these events.

## CLEANLINESS

A pressure relief valve may have trace amounts of fluids, debris, or dust on or within the valve. This contamination may be caused by the processes used to manufacture the valve or the environment it is subjected to during manufacturing, transportation, or storage. In most cases, the trace amount of contamination that is present on the valve at the completion of production is acceptable. If the end user cannot tolerate the presence of this level of contamination, the valve may need to go through special cleaning and packaging processes. Examples of these types of applications include a pressure relief valve used in a chemistry analyzer or in an oxygen system which provides breathable air to a person. Some industries, such as the space, automotive, and medical industries, have defined cleanliness levels that dicate these requirements for any component or system.

## PUMP AND SYSTEM FLOW CAPACITY

Safety relief valves are designed to achieve a specific flow rate when open at the flow point pressure. The system's source of pressure, such as a pump, must be able to supply that minimum flow rate to the pressure relief valve while it is open, or else it may become unstable. It is also important that the flow path between the pressure source and the pressure relief valve does not include any restrictions or other components that will prevent the necessary flow from being supplied to the relief valve.

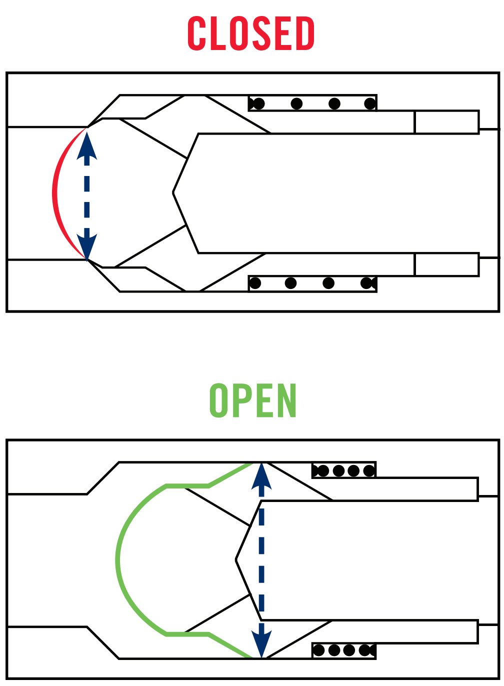
# PRESSURE RELIEF VALVE PERFORMANCE TRADE-OFFS AND DESIGN CHALLENGES

After determining the optimal performance requirements and the environmental factors that will impact performance, the next step is to select or design an appropriate pressure relief valve for the application. Unfortunately, it may be challenging to find a solution that meets every requirement. As with most decisions, there are trade-offs that must be considered. Some of these trade-offs are common sense. For example, decreasing the valve's envelope size may result in a lower flow capacity. Changing a valve component's material from plastic to metal will increase operating or burst pressure capability but will impact the valve's weight. There are other performance aspects specific to pressure relief valves that may require more careful consideration during the selection process. These include:

## HYSTERESIS

Valve hysteresis is the difference in flow performance based on whether pressure is increasing or decreasing. As can be seen in the graph on page 12, the flow curve generated with increasing pressure from the closed position to the flow point pressure will be offset from the flow curve generated with decreasing pressure from the flow point pressure back to the closed position. As a valve opens, there may be an increase in the affected area the pressure acts upon. See the Affected Area figure to the right for an example of this. It is this change, along with other forces, that can cause a difference in increasing and decreasing pressure flow performance. Therefore, when a valve is open and pressure is decreasing, the pressure may need to decrease further for it to close as compared to the same pressure when it's increasing from the closed position.

AFFECTED AREA

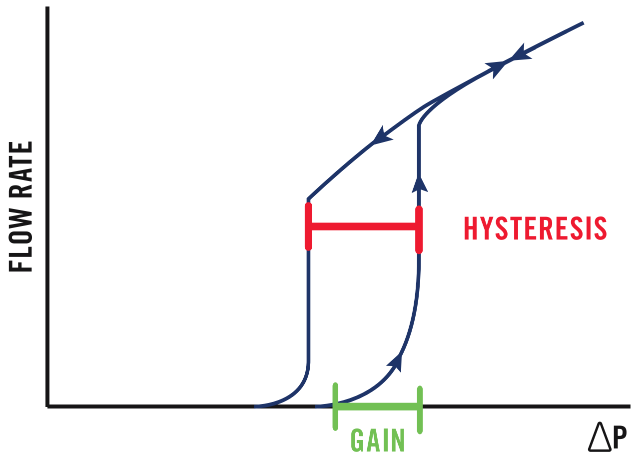


# PRESSURE RELIEF VALVE PERFORMANCE TRADE-OFFS AND DESIGN CHALLENGES (cont.)

## GAIN

Valve gain is defined as the rate of increase in flow rate per increase in pressure. This is a measure of how efficiently a valve moves from a closed position to the flow point pressure. A high-gain valve is one that can fully open with minimal increase in pressure, which is desired in pop-off applications. A low-gain valve requires a more significant increase in pressure to achieve a fully open condition.

VALVE HYSTERESIS AND GAIN




If a valve is designed such that the force balance results in a significant, instantaneous movement of the poppet from the mostly closed to the fully open position, the flow rate through the valve will experience a sudden, simultaneous increase in flow rate. This sudden increase in flow may be accompanied by a decrease in pressure differential across the valve. This instantaneous event is sometimes referred to as an "open break." A valve with an open break will have very high gain, and may even achieve a "negative" gain, if the differential pressure decreases as the valve opens. A low-gain valve opens with a more significant increase in pressure but can potentially offer greater stability which is required for regulation applications. This greater stability generally comes from the lack of an open break.

## HYSTERESIS VS. GAIN

Designing a pressure relief valve usually requires a trade-off between the valve's gain and hysteresis. Typically, higher gain results in a larger hysteresis, and vice versa. These dynamic characteristics will affect the valve's critical performance criteria, including its cracking pressure, flow point pressure, and reseat pressure. A design engineer may have to determine if it is more critical that a valve achieves its flow point at a pressure near the cracking pressure and reseats at a lower point, or that the valve requires more pressure to fully open, but can reseat closer to the cracking pressure. Some compromise between the two options is often required.

## RESPONSE TIME

For pressure relief valves, response time is how long the valve takes to sense the increase in pressure and react by opening. This can be important in situations when the upstream pressure spike has an extremely high pressure rise rate. A valve with a slow response time with respect to a high pressure rise rate will allow the upstream pressure to momentarily exceed desired limits, even if the valve has sufficient flow capacity and is specified to the correct crack, flow point, and reseat pressures. This is likely to cause damage to the system or other components. Therefore, it is important to ensure the relief valve's response time is designed to cope with the system's expected pressure rise rates.

# POTENTIAL FAILURE MODES

Even when a valve is designed with the previously discussed performance criteria and environmental factors considered, pressure relief valves may get damaged and fail to perform properly in service. It is important to be aware of certain failure modes to ensure a relief valve is designed appropriately and the proper measures are in place within the system to mitigate the risk of failure. Below are some examples of potential failure modes. This is not a complete list, so all potential failure modes for a specific application must be evaluated.

## CONTAMINATION / FOREIGN OBJECT DAMAGE (FOD)

The most common failure mode for a pressure relief valve is damage due to ingestion of foreign material, or simply, contamination. Unfortunately, fluids can contain contaminants of various sizes and materials. This contamination can damage the valve's internal components or sealing surfaces, or may become lodged inside the valve, which can negatively impact the valve's performance. In a worst-case scenario, contamination can become trapped in a place that prohibits the valve from closing, such as between the sealing surfaces, causing the complete loss of system pressure and functionality as fluid drains through the valve. Adequate protection against contamination should be incorporated upstream of the relief valve.

## PRESSURE RISE AND DECAY RATE

As noted in the performance criteria, pressure requirements are important for valve selection. However, the minimum and maximum pressure differentials are not the only concern. The rates at which pressure increases and decreases generate additional forces on the valve due to the rate of acceleration of the moving parts. Unforeseen, extremely high rates of increasing or decreasing pressure may cause these moving parts to impact other components with forces high enough to cause damage. This may affect decisions regarding the valve's damping characteristics, spring rate, and material selection.

## INSTABILITY DUE TO INTERMEDIATE PRESSURE

A high-gain safety relief valve that is designed to have an open break may not be stable if the valve is forced to operate at an intermediate pressure between the closed and fully open positions. The instability is due to an imbalance of forces acting on the spring and moving mass. This instability results in unpredictable relief flow and system pressure as well as the potential for audible chattering while the valve repeatedly transitions between the open and closed positions. This instability may dramatically increase the number of cycles the valve is subjected to as well as generate very high pressure rise and decay rates within the valve, which may cause damage.

## POTENTIAL FAILURE MODES (cont.)

### INSTABILITY DUE TO INSUFFICIENT FLOW

A pressure relief valve opens due to the overall differential pressure between its inlet and outlet ports, and this overall pressure differential is created by a series of pressure differentials across the valve's internal components. The valve is designed to achieve a flow rate at or before a certain differential pressure across the moving components to move them to a fully open position. If the pressure at the inlet port exceeds the valve's cracking pressure, but the valve is not supplied with sufficient flow to generate the pressure differential across the moving components to fully open the valve, the valve will be compelled to close after it has cracked open. Once closed, the pressure will again build until the cracking pressure is exceeded and the process repeats. This repeated opening and closing results in an unstable condition for the valve. This may be a problem for safety relief valves that could result in excessive wear and damage. Thermal relief valves are intentionally designed for low flow rates. Pressure regulating valves are designed to operate properly when the valve is not fully open.

### IMPROPER INSTALLATION

Improper installation of a relief valve can result in degradation of the valve's performance. For example, if the valve is not installed correctly its envelope could become damaged during the installation process, which may result in an external leakage path. It's also possible that damage to the valve could interfere with its internal components. To avoid these issues, it is critical that the installation instructions for a relief valve are followed closely.

# ARE THERE UNIQUE INDUSTRY REQUIREMENTS FOR PRESSURE RELIEF VALVES?

Many industry associations have documented recommendations or requirements for the validation and verification of pressure relief valve performance to ensure safety within a specific system. Compliance to these specifications is usually required by governing bodies and passed down to suppliers of systems and components. When selecting a pressure relief valve, it is important to ensure it meets the industry standards required for the application. Some examples of industry associations with pressure relief valve guidelines include:

## ISO

International Organization for Standardization

## ASME

American Society of Mechanical Engineers

## ANSI

American National Standards Institute

## PED

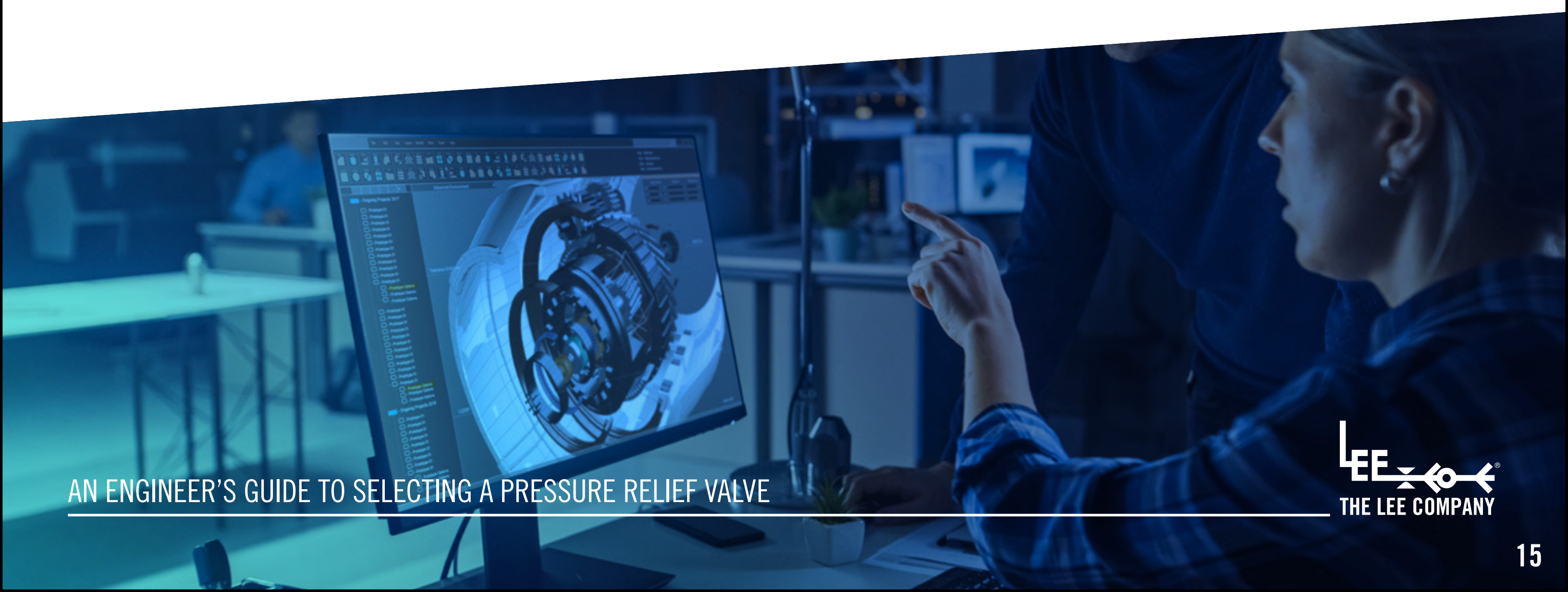
Pressure Equipment Directive

## SAE

SAE International

## API

American Petroleum Institute



## HOW CAN THE LEE COMPANY HELP?

For more than 70 years, The Lee Company has been a leading supplier of miniature, precision fluid control products to a wide range of industries including aerospace, oil & gas, automotive, off-highway equipment, medical device, and scientific instruments. Lee products are recognized worldwide for superior quality, reliability, and performance.

The Lee Company offers a wide range of pressure relief valves designed to be the smallest and most reliable relief valves available. Lee pressure relief valves are currently operating miles beneath the Earth's surface in tools used to explore for oil and thousands of miles above it for rocket and satellite propulsion. They are also found in the cars and airplanes used every day for transportation, in industrial hydraulic equipment for construction and farming, and in medical diagnostic and scientific instruments.

LEARN MORE >

The Lee Company has a team of Technical Sales Engineers available around the world to work one-on-one with our clients to solve their unique fluid control problems. Contact The Lee Company today to learn more about pressure relief valves and how The Lee Company can customize a solution for your unique needs.

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