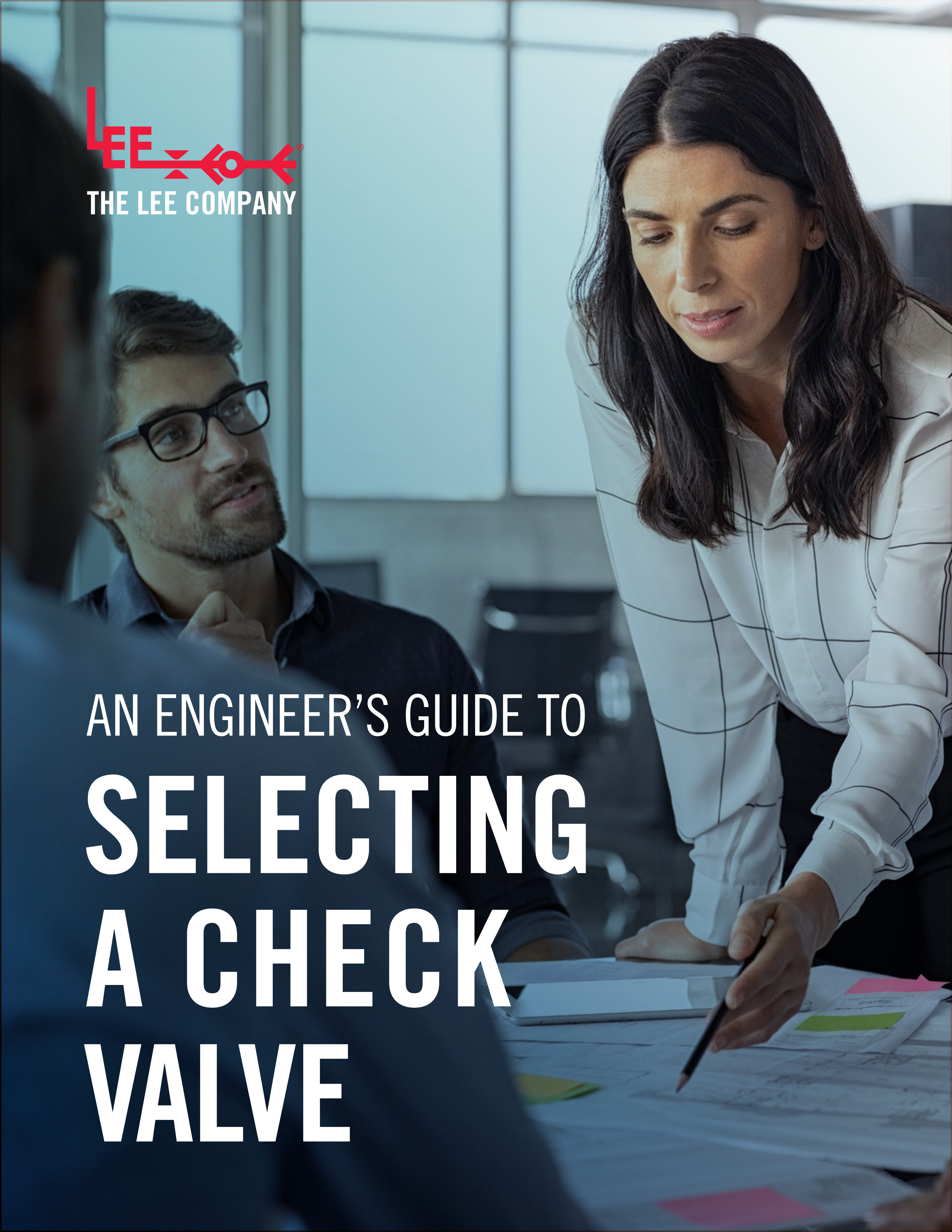

THE LEE COMPANY

AN ENGINEER'S GUIDE TO

SELECTING A CHECK VALVE

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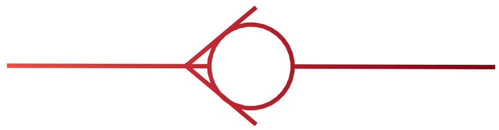
WHAT IS A CHECK VALVE?

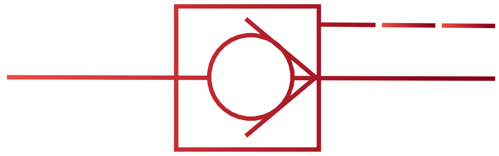
A check valve, also known as a non-return or one-way valve, is a mechanical device that allows a gas or liquid to flow freely in one direction while preventing reverse flow in the opposite direction. The direction in which the fluid or gas can flow is called the free flow direction; the direction in which fluid is prevented from flowing is called the checked or non-return direction.

Check valves are found in common household items. For example, when a raft or air mattress is inflated, the check valve allows air in and prevents its escape until a release is activated. Irrigation systems also use check valves; they allow water to spray out of the sprinkler head and prevent mud and rainwater from flowing back into pipes leading to the water supply.

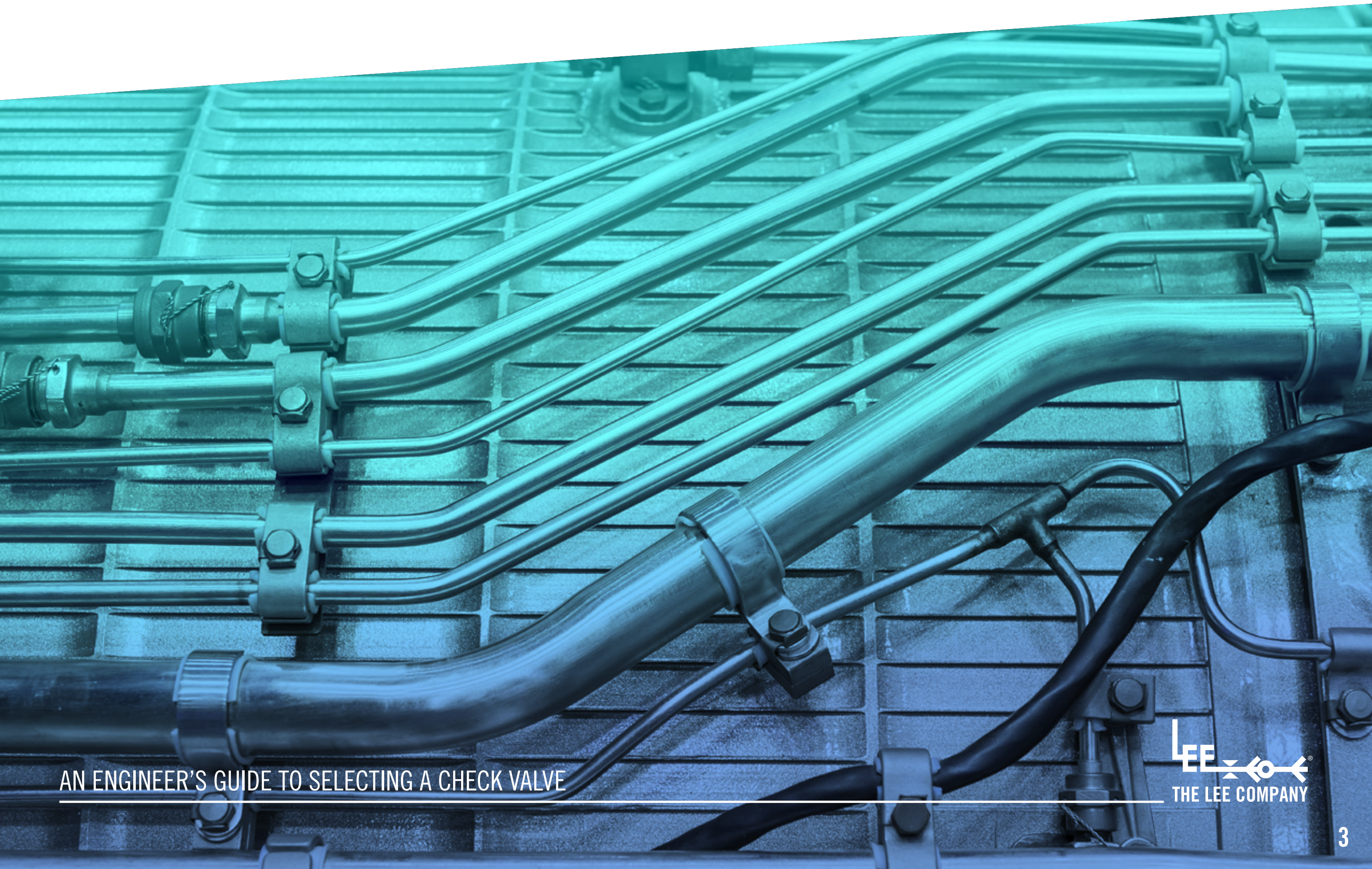
COMMONLY USED GRAPHIC SYMBOLS REPRESENTING CHECK VALVES IN HYDRAULIC AND PNEUMATIC SYSTEMS



Check Valve



Pilot-Operated to Open Check Valve



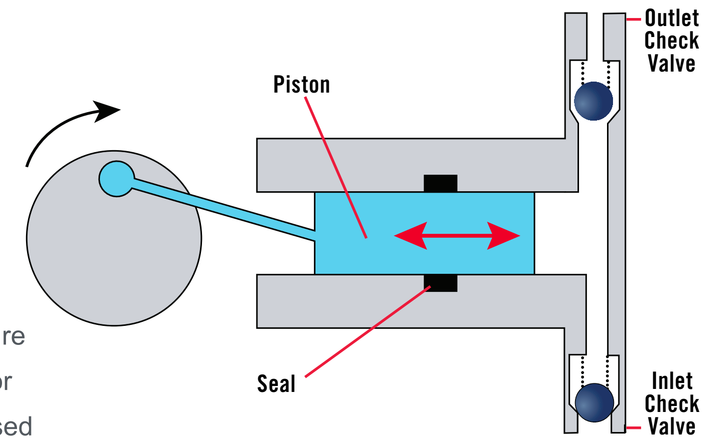
CHECK VALVE FUNCTIONS

The purpose of a check valve in an application will determine some design parameters. Generally, check valve functions can be divided into three categories: non-return, vent, and fill and drain. It is important to select the correct check valve to ensure proper functionality during system operation.

NON-RETURN CHECK VALVE

These types of check valves allow flow in one direction with minimal pressure loss and prevent flow in the opposite direction. A common application for a non-return check valve is in pump inlet and outlet ports. One check valve placed at the pump inlet allows fluid to flow from the desired source. A second check valve located at the outlet allows the pump to dispense fluid.

EXAMPLE OF INLET AND OUTLET CHECK VALVES USED AS PART OF A RECIPROCATING PUMP



VENT CHECK VALVE

Vent check valves are designed to open and prevent pressure build-up in a system, while preventing flow in the checked, or non-return, direction. For example, vent check valves are used to protect a vehicle's fuel tank. Gasoline volume expands as it warms and contracts as it cools; the volume of gas in the tank fluctuates even when a car is parked. As the volume of gasoline increases, air must exit the tank to alleviate the change in pressure. The tank uses a check valve to vent air when pressure increases; this prevents damage within the tank and to connected components. The check valve also prevents debris and moisture from getting into the tank.

FILL AND DRAIN VALVE

These check valves permit fluid to flow into a system and prevent the fluid from escaping once it is filled. Fill and drain valves are commonly found near the tank of any hydraulic or pneumatic system. If the system needs maintenance or will be retired, safety precautions may require depressurization of the charged system. The check valves used to fill the system may be piloted open, mechanically or manually, to drain the system fluid.

HOW CHECK VALVES WORK

A check valve is a direct-acting device; that means pressure acts directly upon the internal components of the valve. Check valves are typically normally closed components. They are often held closed by a force-producing mechanism within the valve. This force is minimal and returns the valve to a closed position when there is no longer a pressure differential acting on the valve in the flow direction. Some configurations have no force-producing mechanism; they require a pressure differential in both directions to move internal components.

With a pressure differential in the flow direction, the valve opens and allows fluid to flow freely from one location to another within the fluidic system. When pressure is removed, the valve will return to its normally closed position.

When there is an increase in pressure differential in the checked, or non-return, direction, fluid flow is prevented due to the seal created by the internal components when closed. As pressure increases in the checked direction, the force to keep it closed increases. This generally improves the sealing capability of the check valve. Thus, the rate of checked direction leakage may improve with increased pressure in that direction.

CHECK VALVE CONFIGURATIONS

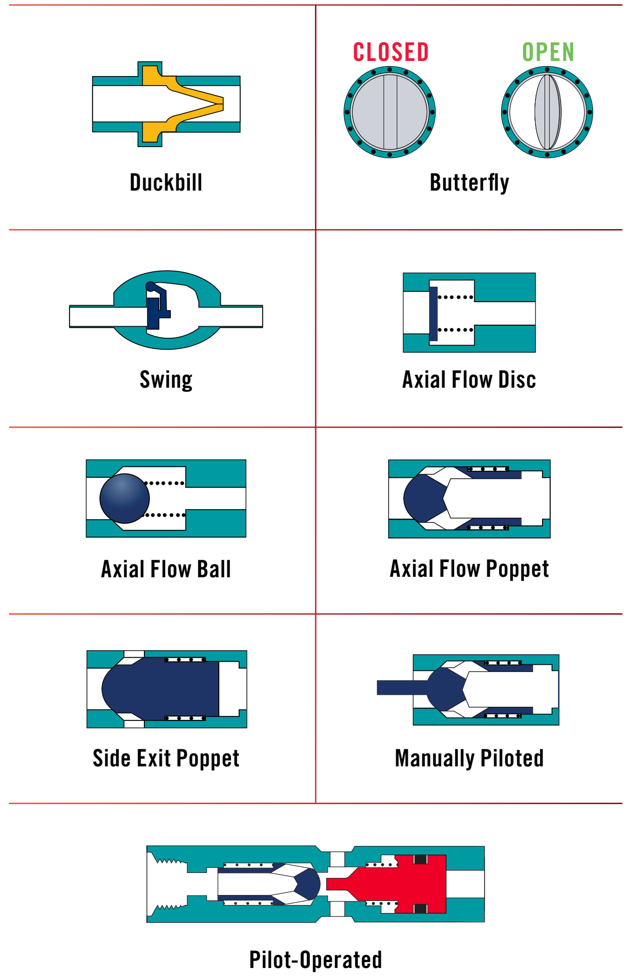
Check valves are available in a variety of configurations. Common configurations feature a ball bearing, poppet, disc, or other seal held against a seat when pressure is in the checked direction. In many cases the seal will be biased into the position against the valve seat by a lightly loaded, compressed spring. The combination of these components creates the internal seal used to prevent flow in the checked direction.

There are many configurations for the internal flow path of spring-loaded check valves. For example, the fluid may flow axially between the ball or poppet and the interior of the valve housing; or it may flow through passages within a poppet down through the center of the valve. Alternatively, some valve configurations allow flow to exit at 90 degrees relative to the valve inlet.

In low-pressure applications, a check valve may utilize a flexible material to control flow based on pressure conditions. The material may act as a basic diaphragm or in a duckbill configuration.

In high-flow hydraulic applications, butterfly and swing check valves are common. These valves use large, flat metal doors attached to a housing that causes them to open with flow in one direction and shut in the checked direction.

CHECK VALVE CONFIGURATIONS*



*Configurations are shown in the normally closed position unless otherwise noted.

PILOT-OPERATED CHECK VALVE CONFIGURATIONS

If the application requires flow in the checked direction under certain conditions, the check valve may include additional features to force it open against pressure. Some check valves may include a feature that allows them to be manually piloted. Alternatively, one common configuration for hydraulic systems is a pilot-operated check valve. This is generally a three-port design in which the third port is connected to a pilot piston within the valve. Pressure is applied to this pilot port, and the pilot piston presses against the poppet to allow flow in the checked direction. When pressure is removed from the pilot port, the check valve will reseat and return to preventing flow in the checked direction. Additional performance characteristics and failure modes associated with various piloting technologies require a separate discussion and are not covered further within this document.

WHAT ARE THE CRITICAL PERFORMANCE CHARACTERISTICS OF A CHECK VALVE?

There are several factors that must be considered to ensure the proper operation of a check valve within a system. Failure to consider these factors may 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 check valve:

SYSTEM PRESSURES

There are four pressure ratings that should be considered for any check valve: operating pressure, system pressure, proof pressure, and burst pressure. *Operating pressure* is the pressure applied to the valve during normal operation throughout its life, both in the free flow direction and the checked direction. *System pressure* is the maximum nominal pressure achieved at the valve's location within the system. *Proof pressure* is the pressure the valve can withstand without permanent deformation or degradation of performance when the system returns to operating pressure. *Burst pressure* is the pressure at which the valve can survive without rupturing or bursting. All four pressure ratings must be considered during design to ensure the valve and its components are sufficiently durable for the application.

FLOW RATE

In order to perform its function in an efficient manner, a hydraulic system requires a precise volume of fluid within a specific period of time. For example, an engine requires a specified amount of fuel, and an actuator must extend and retract at a certain rate. A check valve will create an added restriction within the system, so the system designer must specify the necessary flow rate through the valve. The flow rate is typically specified at a point above the cracking pressure when the valve is in its fully open state—also known as the *flow point pressure* or *free flow point*. Defining the performance criteria ensures the check valve will have enough capacity to meet system requirements.

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, specifically in the checked direction for a check valve. Leakage allowances can be influenced by variables such as an open or closed system, fluid supply and volume, and desired system efficiency.

WHAT ARE THE CRITICAL PERFORMANCE CHARACTERISTICS OF A CHECK VALVE? (CONT.)

CRACKING PRESSURE

A check valve's opening 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; it is typically defined as a nominal pressure with a tolerance or as a maximum. The pressure may be controlled by the spring force used to bias the valve closed or by the material properties and configuration of a diaphragm. Some check valves include free-floating seals and have zero cracking pressure. Increased cracking pressure is desirable to avoid potential damage caused by fluid flow in the checked direction should external forces, such as a shock or vibration, cause the valve to open despite fluid pressure in the checked direction.

MATERIALS

A check 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 flow through the check 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 check valve. The first consideration is the location of the valve within the system and the desired flow path for the free flow fluid. The system may require the check valve to be located within a specific area, limiting external dimensions or overall size. The location may also dictate the flow path of the free flow fluid based on existing lines. The envelope must also account for installation, retention, and maintenance requirements. For example, some valves incorporate threaded tubing ends, while others are installed 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.

VARIETY OF CHECK VALVES

WHAT ENVIRONMENTAL FACTORS IMPACT THE DESIGN OF A CHECK VALVE?

After determining the required performance characteristics of a check valve, it is critical to identify other variables that will influence the valve's performance. The internal and external environment of the system will affect the valve's performance 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 check 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 spark 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 number of cycles the valve performs. A check valve may experience wear due to exposure to its environment or by forces caused by contact of internal components, particularly between the sealing components. Excessive wear on the valve's components over an extended operating life could lead to performance or installation and retention issues.

TEMPERATURE

Both the temperature of the fluid and the ambient temperature can impact the performance of a check 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. Leakage rates may be higher as temperatures increase because it is more difficult to seal against a thinner fluid. Temperatures also impact decisions about the materials used in the check valve. At cold temperatures, some materials become 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 CHECK VALVE? (CONT.)

EXTERNAL PRESSURES

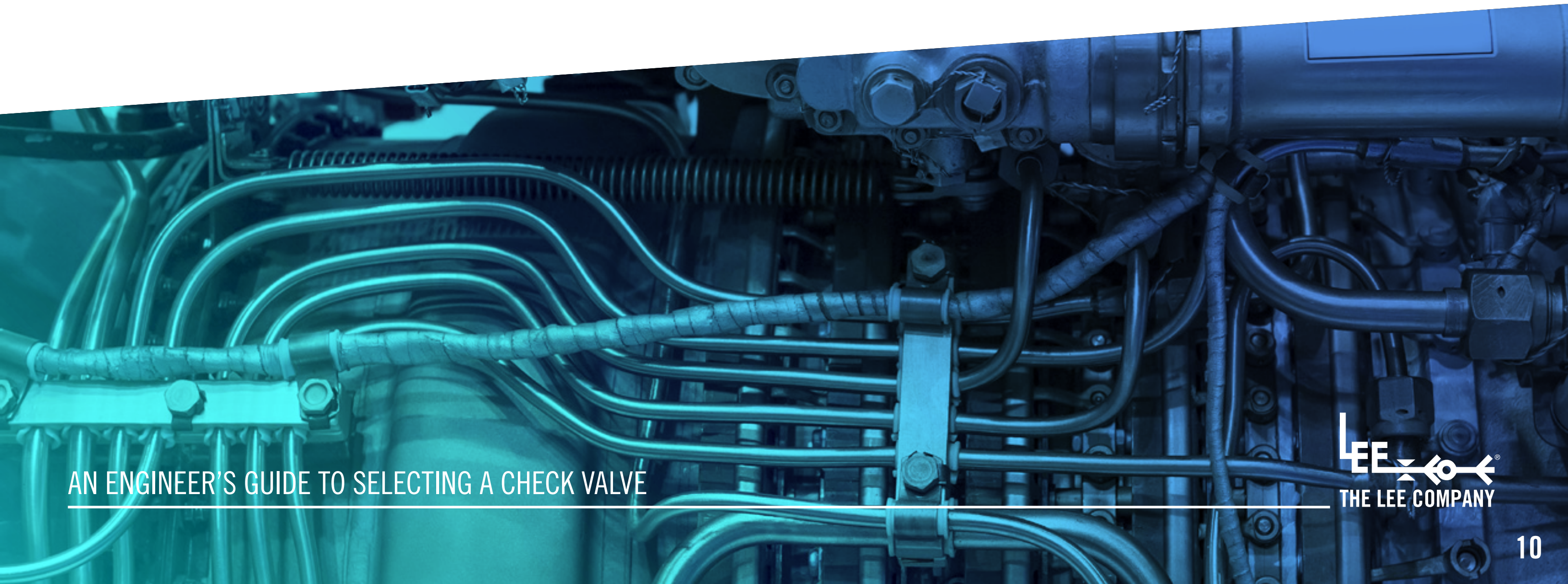
Check valve performance is typically based around pressures within the system. However, the check valve envelope may be subject to other environmental pressures, such as those found deep underwater, underground, or even the absence of pressure found in outer space.

VIBRATION, SHOCK, AND G-FORCES

Check 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 check 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 forceful 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 may have a different impact based on the spring rate in the valve. In all cases, a check valve is usually required to withstand and sometimes remain closed during these events.

CLEANLINESS

A check 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 check 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 dictate these requirements for any component or system.



CHECK 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 check 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 the valve'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 check valves that may require more careful consideration during the selection process. These include:

GAIN

Valve gain is defined as the rate of increase in flow rate per increase in pressure; it 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. A low-gain valve requires a more significant increase in pressure to achieve the fully open condition. However, a lower gain valve may offer greater stability when the system's flow rate is too low to fully open the check valve.

RESPONSE TIME

The response time indicates how quickly a check valve goes from a state of free flow to fully closed; this occurs when pressure reverses and generates a pressure differential in the checked direction. Response time may be important when the direction of pressure changes quickly and increases at an extremely high rate. A valve with a slow response time to a rapid pressure reversal and high rise rate may briefly allow flow and pressure in the checked direction until the valve closes. This may negatively affect system performance or may even cause damage to upstream components the check valve is intended to protect.

SEAL MATERIALS

Valve materials were previously discussed in relation to their ability to withstand the required environment. There are also significant performance trade-offs related to the choice of materials for sealing components. Seals made of harder material, such as metal, are often able to withstand higher pressure and wider temperature ranges than seals made of softer materials, such as plastic or rubber. However, the softer materials are often capable of providing tighter leakage control. Leakage will also vary based on the force applied to the seals. Selecting materials that offer the necessary balance between leakage rate, pressure range, temperature range, and durability is critical to system performance.

POTENTIAL FAILURE MODES

Even when a valve is designed with the previously discussed performance criteria and environmental factors considered, check valves may get damaged and fail to perform properly in service. It is important to be aware of certain failure modes to ensure a check 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 check valve is damage due to ingestion of foreign material, or simply contamination. Unfortunately, fluids can contain contaminants of various sizes and materials or those contaminants can be introduced by the system itself. This contamination can damage the valve's internal components, or may become lodged inside the valve. This may cause the valve to leak or even become stuck in either the open or closed position. In a worst-case scenario, contamination can become trapped in a place that prohibits the valve from closing, such as between the sealing surfaces, allowing fluid to unexpectedly flow in the checked direction. Adequate protection against contamination should be incorporated upstream of the check 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 can cause these moving parts to impact other components with forces high enough to potentially cause damage unexpectedly. This may affect decisions regarding the valve's material selection and internal design.

INSUFFICIENT FLOW

A check 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 check valves that could result in excessive wear and damage.

INSUFFICIENT FLOW (CONT.)

Insufficient flow through a check valve can also result in a problem commonly called *silting*: the collection of contamination and debris between the valve's seat and seal. It may occur when the capacity of a valve is significantly higher than the system's flow rate, causing the valve to only partially open. This renders the valve more susceptible to trapping small pieces of dust or debris within fluid that would normally flow through a fully open valve without adverse effect.

IMPROPER INSTALLATION

Improper installation of a check 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 check are followed closely.

ARE THERE UNIQUE INDUSTRY REQUIREMENTS FOR CHECK VALVES?

Many industry associations have documented recommendations or requirements for the validation and verification of check 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 check valve, it is important to ensure it meets the industry standards required for the application. Some examples of industry associations with check valve guidelines include:

ISO

International Organization for Standardization

ASME

American Society of Mechanical Engineers

ANSI

American National Standards Institute

ARP

Aerospace Recommended Practices

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 devices, and scientific instruments. Lee products are recognized worldwide for superior quality, reliability, and performance.

The Lee Company offers a wide range of check valves designed to be the smallest and most reliable check valves available. Lee check 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.

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