# PRESSURE RELIEF VALVE SELECTION AND APPLICATIONS FOR HYDRAULIC SYSTEMS

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***Abstract:*** *The flow-pressure relationship is an important external characteristic of the pressure relief valve and the hydraulic circuit. So, many engineers have been put an effort on this topic for its significant impact on the overall hydraulic system. Most of them are focused on the influences of the pressure relief valves, their selections and applications. It is very important to select, size, locate properly and maintain the pressure relief systems to prevent or minimize the losses from major incidents. Detail of selection and sizing of pressure relief valve is shown the following sections of this study. In order to help the circuit operators, a few flow charts are also included. Pressure relief system is used to protect piping and equipment against excessive overpressure for equipment and personnel safety.*

**Keywords**: RELIEF VALVE, PRESSURE SENSITIVE VALVE, VALVE SELECTION, HYDRAULIC SYSTEM.

## 1. Introduction

The pressure relief valve is used in almost every hydraulic system. The function of the relief valve is to limit the maximum pressure that can exist in a system. Under ideal conditions, the relief valve should provide alternative flow path to tank for the fluid while keeping the system pressure constant [1]. Pressure relief valves are spring-loaded valves designed to open and relieve the excess pressure, then immediately close, preventing any loss of fluid flow after normal conditions have been reinstated. Pressure relief valves are designed to act as a safety measure in hydraulic system. It is a device designed for the automatic release of a substance from hydraulic system when the pressure preset limits to protect system [2]. In spite of the high development status of the conventional pressure relief valves, there is an important research demand on the investigation of them, since they are the most used devices for protections of human life, environment and equipment.

Several types of pressure-control valves are encountered in hydraulic systems. Some keep the whole system from excess pressure while other equipments only protect a portion of the system. They allow fluid flow to a circuit after reaching a preset pressure. Bypass fluid at low or no pressure when activated.

All fixed-volume pumps in hydraulic systems require a relief valve to protect the system from excess pressure. Fixed-volume pumps must move fluid when they run. Pressure compensated pump circuits could operate successfully without relief valves because they only pass fluid when pressure drops below their compensator setting. In either cases, a relief valve is similar to a fuse in an electrical system. When circuit amperage stays below the fuse amperage, all is well. When circuit amperage tries to exceed fuse amperage, the fuse blows and disables the circuit. Both devices protect the system from excess value by keeping it below a preset level. The difference is that when an electrical fuse blows it must be reset or replaced by maintenance personnel before the machine can cycle again. This requirement alerts the electricians to a possible problem and usually causes them to look for the reason before restarting the machine. Without the protection of a fuse, the electrical circuit would finally overheat and starts a fire.

## 2. Description of Relief Valve Design

In a hydraulic circuit, a relief valve opens and bypasses fluid when pressure exceeds its set value. The valve then closes again when pressure falls down. This means a relief valve can bypass fluid anytime or all the time without intervention by operator. Many fixed-volume pump circuits depend on this bypassing capability during the cycle, and some even by-pass fluid during idle time. A well-designed circuit never bypasses fluid unless there is a malfunction, such as a limit switch not closing or an operator overriding the controls. This eliminates most overheating problems and saves energy too.

Ray [3] formulated a non-linear dynamic model of a relief valve in the stage form. It is developed from fundamental principles of rigid-body motion and fluid dynamics in 1978. According to the results, opening time of the valve is linearly related to the dimensionless parameter given by the ratio of orifice length to radius. Sethi and Lai [3] developed dynamic models of a spring-loaded pressure relief valve with computational fluid dynamics and valve dynamic modelling. In 2002, Dasgupta and Karmakar [4] studied the dynamics of a pilot operated pressure relief valve through Bondgraph simulation technique. The governing equations of the system were derived from the model. Prescott and Ulanicki [5] developed a relatively simple and accurate model to solve the dynamical behaviour of a pressure reducing valve. In 2005, Suzuki and Urata [6] investigated the dynamic characteristics of a direct-pressure sensing water hydraulic relief valve with Matlab–Simulink.

Sizing is the most important component in selecting the right presssure relief valve for the circuit assuring reliable safety of the system. Nowadays, sizing is achieved entirely with software some available on the market and some provided by manufacturers. It is very important to know what is behind the software and to look into the formulas on which these calculations are based. It is also important that, relief valves be selected by the operators who do have a detailed knowledge of all the pressure-relieving requirements of the system to be protected [7]. Circuit designer must be aware of what is available on the market in order to select the right valve for the correct application, assuring a safe hydraulic system.

### 2.1. Operation of Relief Valves in Hydraulic Systems

Some manufacturers generally assist the end user in sizing the valve based on his input of the relevant technical data. But, it is responsibility of the end user to select the right valve based not only on the system data but also on all other effective factors. Many manufacturers hand over offer dependable programs for valve sizing. Since, most are based exclusively on their own specific products, it will be difficult to compare valve brands [8].

There are two different designs of relief valves in common use such as, direct acting and pilot operated. Both types have advantages and work better in certain applications in the hydraulic circuits. Some terms relating to relief valves and their functions are explained in (a), (b), (c), (d) and (e) such as overshoot, hysteresis, stability, reset pressure and pressure overrides respectively.

(a) The actual pressure reading when a relief valve first opens to bypass fluid. (It can be up to twice the actual pressure setting.)
(b) The difference in pressure between when a relief valve starts letting fluid flow and when fluid flow is passing.
(c) The fluctuation of pressure as a relief valve is bypassing at set pressure.
(d) The pressure at which valve closes after it has been bypassing.
(e) The difference in the pressure reading, a relief valve first opens (cracking pressure) until pump flow pass to tank.

### *2.2. The Fundamentals of Sizing Rules in Selection of Relief Valves*

In general, presssure relief valve sizes are decided by only coordinating the size of an existing nozzle or the pipeline. This method is very dangerous and does not comply with the codes. Correct and extensive sizing and selection is complex. That's why multistep process should be followed by step-by-step method. Therefore, following items in four separate section must be taken in account for right sizing [9].

1**.** Each piece of equipment in the system must be calculated for present overpressure master plan.
2. Establish a suitable design foundation must be prepared for each item of the system which needs protection based on overpressure cases.
3. The size of the relief valve based on the design necessity must be determined.
4. By the establishment of the system, the ideal size for the relief valve, selection of the type are to be achieved. Then, design can be controlled by analysis with piping engineering basic standards.

In sizing the relief valve the other requirement is to determine the correct orifice of a valve type for relieving capacity. That's why the following methodology is advised.

- A set pressure at which the relief valve is to operate based upon operational limits of the system must be determined.
- Relieving capacity of the valve has to be assigned.
- For particular application size and the type of the valve with suitable capacity within the limits can be selected.

Sizing of relief valves is calculated but, selection is from a capacity chart in a manufacturer's operation manual. This method is also preferable by the end users [10]. If the reliability of that chart can be demonstrated by the manufacturer then, the last method is used. In selection and properly sizing the relief valves following list of servicing conditions can be advised in Tablo 1.

***Table 1***. The advised parameters of selection and properly sizing the relief valves in servicing conditions

| ***Fluid properties*** |
|---|
| ➢ Fluid and state<br>➢ Molecular weight<br>➢ Viscosity<br>➢ Specific gravity<br>➢ Liquid<br>➢ Compressibility factor |
| ***Opening conditions*** |
| ➢ Operating pressure<br>➢ Operating temperature<br>➢ Maximum allowable working pressure |
| ***Relieving conditions*** |
| ➢ Required relieving capacity<br>➢ Set pressure<br>➢ Allowable overpressure<br>➢ Superimposed backpressure<br>➢ Built-up backpressure<br>➢ Relieving temperature<br>➢ Liquid discharge |

In the pressure relief systems, the first step is to decide the location where the pressure relief can be mounted. So it will be easy to name the type for each location in the second step. After the selection of the type of device, the specific type of safety valve and/or bursting disc should be chosen [11]. In selection of the pressure relief valve, there are few subjects which must be taken in account. These subjects are such as, seat tightness, blowdown, operation temperature, orifice and sizing, liquid and materials [12-14] respectively.

### *2.3. The Characteristics of Relief Valves in Hydraulic System*

#### *2.3.1. Seat Tightness*

Operating pressures between 90% and 95% of set pressure, pilot-operated safety relief valves and spring-operated are used. Since metal-seated spring valves will get damaged in a short time so, they don't stay tight for long durations. The soft-seated valves are limited in temperature and often in pressure. If operation pressure above 95%, soft-seated valves are prefable.

#### *2.3.2. Blowndown*

Some soft-seated, spring-operated valves have large alterable blowdown ranges. Present blowdown can usually be set shorter than 5 % on conventional spring valves. Long blowdown required due to inlet pressure losses above 3 %: In case of losses, pilot-operated valves with a remote sensor must be used.

#### *2.3.3. Operation Temperature*

At 197°C and below temperatures, it is recommended to use soft-seated and for high-performance soft-seated snap action spring valves are used at 200$^{o}$C and below temperatures [12]. Valves with following specifications such as bubble tightness close to set pressure, opening faster than 10% overpressure and short adjustable blowdown are prefered. For operation at 70°C and below values and backpressures needing a balanced valve pilot-operated, soft seated valves are preferable.

#### *2.3.4. Orifice and Sizing*

Some of the spring valves can be equipped with customized nozzles. One may have the option of installing multiple spring valves or using a pilot-operated valve with full bore orifice. Pressure/size limits are generally higher for pilot-operated valves than for spring-loaded valves [13]. The valve should modulate from 0 up to full lift and then will not chatter, even if oversized.

#### *2.3.5. Liquid*

Spring-operated valves can be used but need to be equipped with a trim suitable for liquid service so, they can obtain nominal flow at 10 % overpressure. When quick opening or closing is necessary, the operation will be unstable and possibly causes water hammer. Alternatively, a modulating pilot valve can be used, preferably equipped with a filter. The volume of the filter slows the pilot, which reacts too fast, creating instability and water hammer.

#### *2.3.6. Materials*

An important factor in selecting the correct relief valve is choosing the correct materials for the application. Since it is quite difficult to show all the materials for relief valve body in this study, we can give some more important ones. These are named [12,14] as:

■ ASTM A890 CE3MN UNS J93404
■ ASME SA 351 CD3MWCuN UNS J93380
■ ASME SA 351 CE8MN UNS J93380
■ Z 6 CNDU 28.08 M, NF A 320-355 at 17 HRC MAX
■ ASTM A351 CK3MCUN (6Mo)

**For high temperature operations we can prefer following ones:**

■ ASME SA 351 CF8 SAME (with same chemical restrictions as CF8M)
■ ASME SA 217 WC6 (up to maximum 593°C)
■ ASME SA 217 WC9 (up to maximum 593°C)

**For high temperature operations up to 815$^{o}$C, we can prefer following ones:**

■ ASME SA 479 Grade 304H (same chemical restrictions as 316H)

■ ASME SA 479 Grade 347H (same chemical restrictions as 316H)

### *2.4.Selection Parameters of Pressure Relief Valves*

#### *2.4.1.The Selection on Location of Pressure Relief Valves*

If the systems have two or more separate branches, the engineer has to decide whether a pressure relief device is required for every branch or not. For this decision tree (see Fig. 1) can be used in deciding the valve. In this tree, there are six questions for every chamber.

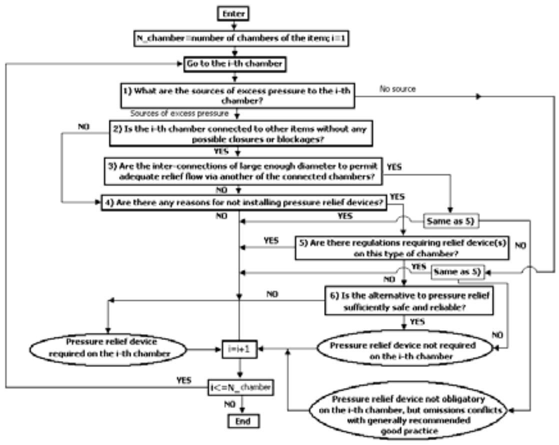


***Fig. 1.*** *Decision tree for pressure relief device [15]*

Besides these, uncomprimising are following as;
(1) What are the sources of over pressure to the compartment?
(2) Are the connections of large enough diameters to allow required relief flow via another of the compartment?
(3) Do you really have any reasons for not installing pressure relief connected?
(4) Is one other device alternate to valve sufficiently safe?

#### *2.4.2. The Selection of Type of Pressure Relief Devices*

After establishing the pressure relief valve for adviced point, the engineer has to to select a suitable type of valve. The decision tree (see Fig. 2) for selecting between safety valves and bursting discs are shown.

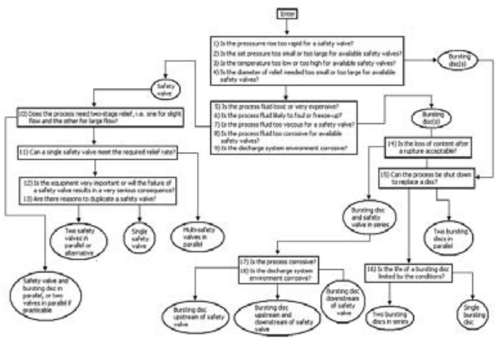

***Fig 2.*** *Decision tree for selection of relief devices [15]*

Besides these one can also discuss the following questions;
(1) What is the pressure rise for a safety valve, is it rapid or slow?
(2) What is the value of the set pressure? Is it small or large for the selected valve?
(3) What is the value of the temperature? Is it low or too high for the selected valve?
(4) What is the value of the diameter of relief valve? Is it too small or too large for safety valve?
The answer might be yes or no, if it is yes, this means any leakge will not be accepted in this unit.
(5) Is hydraulic fluid toxic or expensive?
(6) Is hydraulic fluid probably to freeze-up?
(7) Is the fluid too viscous for a valve?
(8) Is the fluid too corrosive for a selected valve?
(9) Does the process need two-stage relief, one for small and the other for large flows?
Once more the answer might be yes or no, If it is yes, valve and a bursting disc must be used in parallel.
(10) Can a single safety valve meet the required relief rate?
If the answer is no, multi-safety valves in parallel must be used.
(11) Are there reasons to copy a safety valve?
(12) Is the process corrosive?

#### *2.4.3.The Selection of Special Features for Safety Valves*

The decision tree prepared for the selection of typical safety valves is shown in Fig. 3.

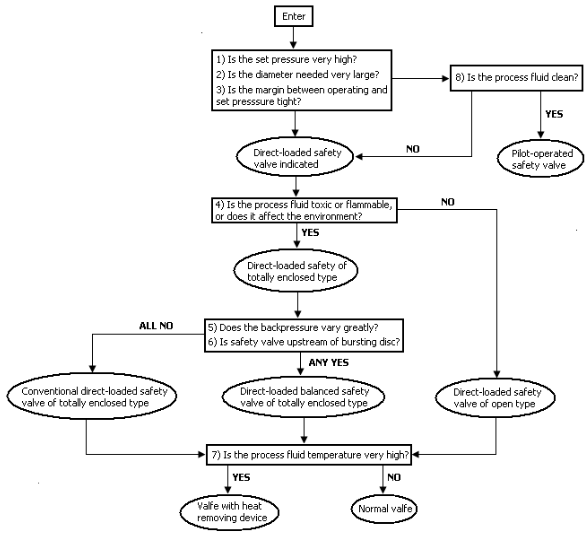


***Fig. 3.*** *Decision tree for safety valves selection [15]*

Questions are useful in following to explain the details of the tree.
(1) What is the set pressure, is it high or low?
(2) What is the diameter, is it large or small?
(3) What is margin between operating and set up pressure, is it tight or wide?
(4) Is the process fluid toxic or flammable?
(5)What is the fluid temperature? Is it high or low?

## *3. Conclusion*

In the design of pressure relief systems regulations, codes and standards must be taken into account seriously. Otherwise, design assignment might be complex and time consuming. In order to execute the design efficiently, decision trees are used. Figure 1 is for the selection of the location of pressure relief valves. After the identification of the valves, Figure 2 is used for the selection of the type of pressure relief valves. For the selection of the special features of safety valves and bursting discs, Figure 3 is used. Besides all these studies, evaluations are also advisable to reverse the decision trees into practical design tools.

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