1. Introduction

Thanks to its outstanding heat transfer properties, steam is widely used as an energy medium in power stations, plant engineering applications, the chemical and petrochemical industries as well as the processing industry. Various methods and processes are used for the purpose of generating steam with the properties required by individual consumers to suit their specific systems. The most intricate and therefore the most cost-intensive variant is to set up a separate steam generator for final consumers requiring steam with the same properties. A more favourable method is the use of flash steam from individual extraction points in the medium pressure range of steam turbines. The disadvantages of this method, however, include the disruption in the overall thermodynamics of the power station caused by large extraction quantities and the fact that the steam characteristics defined by the turbine circuit do not always agree with those required by the final consumer. For these reasons, pressure reducing by means of a corresponding system of control valves and fittings is the most commonly used method of supplying consumers steam with the required properties. This control system is normally based on a control valve that operates either with auxiliary energy (electric, pneumatic) or without auxiliary energy (self-actuating). In the following presentation the second variant is described in detail and its concept explained.

2. Design

Self-actuating pressure control takes place by means of a special control valve, i.e. the pressure reducing valve, also known as a pressure reducer. This valve is classified in the group of regulators without auxiliary energy, i.e. self-actuating. A series of further auxiliary and monitoring valves and fittings is necessary in a steam installation for the purpose of operating a pressure reducer. The term “steam pressure reducing station” incorporates all these necessary components as well as the piping systems. Fig. 1 shows the design and the interfaces to the remaining parts of the system.

![Fig. 1: Steam Pressure Reducing Station](image-url)
Two pipe strands can be clearly seen, i.e. the main line, divided into the upstream pressure and downstream pressure line as well as the bypass line. Initially, the steam flows through the stop valve and strainer in the upstream pressure line before it reaches the main component, the pressure reducer. Following pressure reducing in the pressure reducer, it flows through a further stop valve in the downstream pressure line to the station outlet with the safety valve connected directly to this section. The size of the main line depends on the maximum permissible flow rate. Due to the low steam density, the nominal diameter downstream of the pressure reducer must be larger than upstream. For the purpose of achieving effective control performance, the pressure reducer itself is often designed with an even smaller nominal diameter than that of the upstream pressure line. The exact dimensioning is described under the points "Design Layout" and "Practical System Examples". The control line must be connected at a point in the downstream pressure line where the flow has steadied, i.e. there must be no valves or elbows within a minimum distance of 10x DN or at least 1 m from this take-off point. In addition, the control line and the water seal pot must be filled with water. In this way, the diaphragm of the pressure reducer, which is installed hanging downward together with the actuator, is protected against the high steam temperatures. The bypass line is required to facilitate continued manual operation of the subsequent parts of the system while carrying out maintenance on the strainer and pressure reducer. For this purpose, the stop valves upstream and downstream of the pressure reducer are closed and the control valve located in the bypass valve opened. With an eye on the pressure gauge, in this way operation can be maintained temporarily with the safety valve still effectively fulfilling its pressure safeguard function in this case.

During steam operation condensate constantly forms in the lines requiring it to be drained off via the steam trap. The drain in the upstream pressure line in the form of the ball float type steam trap can be clearly seen in Fig. 1. The upper stop valve is normally open and is closed only for the purpose of carrying out maintenance on the steam trap. The lower stop valve is provided for de-sludging purposes and is normally closed. The flow of condensate can be observed through the inspection glass thus making it possible to monitor operation of the steam trap. A condensate drain facility is also necessary in the downstream pressure line. This facility has not been illustrated in Fig. 1 as this drain is normally located at the collectors or heat exchangers in the adjacent downstream pressure section of the system.

Pressure gauges upstream and downstream of the pressure reducer are appropriate for the purpose of monitoring the pressure reducing station. In particular the upstream pressure between the strainer and pressure reducer should be measured so that it is possible to determine the occurrence of more extensive soiling. The downstream pressure should be measured close to the pressure take-off point for the control line as this greatly simplifies the setting procedure and possible disturbances can be detected more effectively.

3. Valves and Fittings

The function and selection of valves and fittings for a steam pressure reducing station are described in the following. The layout (size definition) is described under Point 4.

ARI-FABA:
This designation refers to stop valves with a stainless steel bellow spindle seal. The valve in the bypass line should be equipped with a regulating plug whereas a flat plug is sufficient for all other stop valves. In order to prevent misuse, the hand wheel of the bypass valve should be secured with a lead-sealed cap.

ARI strainer:
It is necessary to install a strainer upstream in order to protect the valve seat and plug of the pressure reducer. To avoid condensate collecting, the plug should be installed with the sieve on the side.
ARI-PREDU:
This valve represents the heart of the pressure reducing station. Its function is explained in the following based on a simplified representation (Fig. 2) without the water seal pot required for steam operation. The downstream pressure is applied through the control line against the actuator diaphragm where it is converted into a force acting against the spring force. By way of adjustment, the pretension of the spring can be varied such that both forces are in equilibrium at the required downstream pressure. A change in the steam take-off quantity results in corresponding displacement of the valve plug until a state of equilibrium is re-established. The two stainless steel bellows of the pressure reducer can be seen in Fig. 2. One serves the purpose of sealing off the spindle from the outside and the other bellow is the pressure relief element that serves to ensure equalisation of forces at the valve plug. For this purpose, the upstream pressure is applied through a hole in the valve plug in the interior against the outside of the bellow. The inner side of the bellow is connected via orifices to the downstream pressure side. Since the effective area of the bellow is the same size as the seat area the differential forces are compensated so that the pressure reducer is essentially unaffected by fluctuations in the upstream pressure. In automatic control engineering applications the pressure reducer is classified as a proportional controller. Such controllers are characterized by a permanent control deviation with respect to the setpoint dependent on the following factors: Spring pretension, nominal diameter and the p2/p1 ratio.

Fig. 2: Pressure reducer - design and function
ARI-SAFE:
The downstream pressure section of the system downstream of the pressure reducer must be equipped with a safety valve to avoid impermissibly high overpressure corresponding to the load bearing capacity of the associated components and piping system [1,2]. When defining its arrangement, particular attention must be paid to the fact that, as illustrated in Fig. 1, the pressure reducer actuator and the bypass line are directly connected to the safety valve. This renders necessary a blow-off line after the safety valve which, however, is not shown in Fig. 1 for the sake of clarity. As is the case with all steam pipes, this line also needs to be drained and must be routed safely into the open. Further details concerning safety valves are also provided in [3].

AWH ball float steam trap:
This type of steam trap requires no supercooling facility and immediately carries off the collected condensate without a time delay. An integrated thermal control element ensures automatic venting of the system during the start-up procedure.

AWH flow indicator:
The function of the steam trap can be simply monitored with the aid of the inspection glass in the flow indicator.

4. Design Layout
The following steam data are required for the layout of a steam pressure reducing station as illustrated in Fig. 1: upstream pressure, downstream pressure, temperature (superheated steam) and steam volume. Initially, the necessary kvs value of the pressure reducer must be determined using the formulae as stipulated by the standards DIN EN 60534-2-2 (also DIN IEC 60534). Diagram 1 can be used to obtain a rough estimate of the layout. The design layout program ARI-VASI® facilitates exact calculation and valve selection (Fig. 3). In addition to the size, it is also necessary to select the correct setpoint range. Since the control deviation at the end of a section (max. spring pretension) is smaller than at the beginning, the lower range should be selected in the event of range overlaps. At a required downstream pressure of 2.4 bar for instance, the range 0.8 – 2.5 bar should therefore be selected although the range 2 – 5 bar would also be possible. Since the rangeability (ratio of the maximum possible to minimum permissible mass flow) of the pressure reducer is smaller than that for control valves with auxiliary energy, more favourable operating characteristics can be achieved by parallel connection of different sized pressure reducers. The one is set to a slightly lower downstream pressure and therefore is responsible for the peaks and the other then covers the basic load.
Diagram 1: Pressure reducer - for saturated steam

With safety valves the first step is to define the set pressure. Initially, this pressure depends on the nominal pressure of the section of the system downstream of the pressure reducing station and on the pressure reducer actuator. A sufficiently large interval between the set pressure and the downstream pressure is to be targeted otherwise the slight pressure peak connected with zero take-off can lead to constant actuation of the safety valve. The size of the safety valve depends on the maximum possible steam volume (mass flow) which the pressure reducer can carry off in the case of fault at the set pressure of the safety valve and specified upstream pressure. This volume can also be determined with ARI-VAS® in addition to subsequent size rating and selection of the safety valve. In this case, particular care must be taken to ensure that a safety valve with open bonnet is selected as the set pressure is decreased in the event of insufficient spring cooling resulting in the valve responding at a considerably more frequent rate.

The size of the steam trap depends on the amount of condensate that collects in the section to be dewatered (drained). The quantity depends to a great extent on the specific system. It corresponds to the length and diameter of the piping system and the insulation thickness upstream of the pressure reducing station. The method of determining the amount of condensate will not be described in further detail at this point. Once this quantity has been defined, the nominal diameter can be determined with the aid of flow diagrams (diagram 2)
Diagram 2: Flow AWH-ball float steam trap

The nominal diameters of the piping systems in the pressure reducing station depend on the maximum permissible flow rates and the incoming and outgoing lines. The following values are considered a rough reference:
Saturated steam approx. 25 m/s; superheated steam approx. 50 m/s

5. Practical System Example

The layout described under Point 4 is to be illustrated by way of example of superheated steam with following data:

- Upstream pressure \( p_1 \) = 16 bar (\( ü \))
- Downstream pressure \( p_2 \) = 8 bar (\( ü \))
- Temperature \( \vartheta \) = 300 °C
- Mass flow rate \( Q \) = 4000 kg/h

a) After entering the above data and selecting the piping systems, corresponding to the max. velocity of 50 m/s (D1: DN 65; D2: DN 100) calculation of the pressure reducer with the ARI-VASI\textsuperscript{®} results in a kv value of 22.9. Taking into consideration an allowance factor of 1.25, the program selects a pressure reducer DN 50 with kvs 32. In compliance with the catalogue [4], the setpoint ranges 4.5 – 10 bar and 8 – 16 bar can be selected for this pressure reducer. In this case, the range 4.5 – 10 bar is to be selected as this means the control deviation will then be smaller.

b) To facilitate taking the pressure reducer out of operation, the stop valve in the bypass line must allow the necessary volume to pass through, i.e. it must at least have the kv value of 22.9 as calculated under a). In this case, this means, according to the catalogue [4], a nominal diameter DN 40 at kvs 27 (control plug). In this case, the pipes upstream and downstream of the valve can have a nominal diameter of DN 40 as they are only used for manual control in exceptional cases.
c) The set pressure of the safety valve is selected at \( p_e = 10 \text{ bar} \). The maximum blow-off volume to be carried off is derived from the flow volume of the pressure reducer calculated with ARI-VASI\textsuperscript{®} from a) \((p_1 = 16 \text{ bar (g)} / p_2 = 10 \text{ bar (g)} \text{ and } D_1 = DN \text{ 65}/D_2 = DN \text{ 100})\) and equals \( Q = 5188 \text{ kg/h} \). At \( Q = 5188 \text{ kg/h} \), the safety valve can also be determined with ARI-VASI\textsuperscript{®} to be: 902 DN 50.

**Important:** If it is possible that the bypass valve can operate a higher output rating than the pressure reducer or they are opened simultaneously this additional flow rate must be taken into consideration in the sizing of the safety valve!

d) The valves in the upstream pressure and downstream pressure line (stop valves and dirt strainer) depend on the nominal diameters of the respective piping systems. The blow-off line of the safety valve can be dimensioned using ARI-VASI\textsuperscript{®}, this procedure will not be detailed at this point. The valves and fittings in the condensate drain depend on the steam trap. The procedure described under Point 4 applies in this case.

6. **Summary**

Steam pressure reducing stations are often used to supply steam pressure required by various final consumers. Pressure control by means of self-actuating pressure reducers necessitates a series of further auxiliary valves and fittings. This presentation illustrates by way of a practical design layout example the station design, the function and flow-related design layout of all valves, fittings and piping systems necessary for this purpose. With the design layout program ARI-VASI\textsuperscript{®} the system designer has available an intelligent tool to facilitate selection of corresponding valves and fittings as well as effective project management.

**Bibliography**


