VECTOR™
VELOCITY CONTROL TECHNOLOGY

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# TURBINE BYPASS & PRDS SYSTEMS

KOSO

## Applications

- HP to cold reheat
- HRH (Hot Reheat) to condenser, also known as,
  - IP/ LP bypass to condenser
  - LP bypass to condenser
- HP to condenser

**Purpose:** Turbine bypass systems increase flexibility in operation of steam power plants. They assist in faster start-ups and shutdowns without incurring significant damage to critical and expensive components in the steam circuit due to thermal transients. In some boiler designs, turbine bypass systems are also used for safety function.

Major hardware components of turbine bypass systems are:

- Steam pressure-reducing valve
- Desuperheater
- Spraywater control valve
- Spraywater isolation valve
- Dump tube (sparger) (only for bypass to condenser)
- Actuator

Performance of the turbine bypass system has a strong influence on plant heat rate and capacity, effective forced outage rate (EFOR) and long-term health of critical components such as boiler tubes, headers and steam turbines. Therefore, correct sizing and selection of all components in turbine bypass systems is esential for the system to function correctly.

Front cover: *Custom engineered turbine bypass system for Mo Chin 600 MW supercritical unit. One of two HP bypass systems and four LP bypass systems supplied.*

**Figure 1. Locations of turbine bypass systems.**

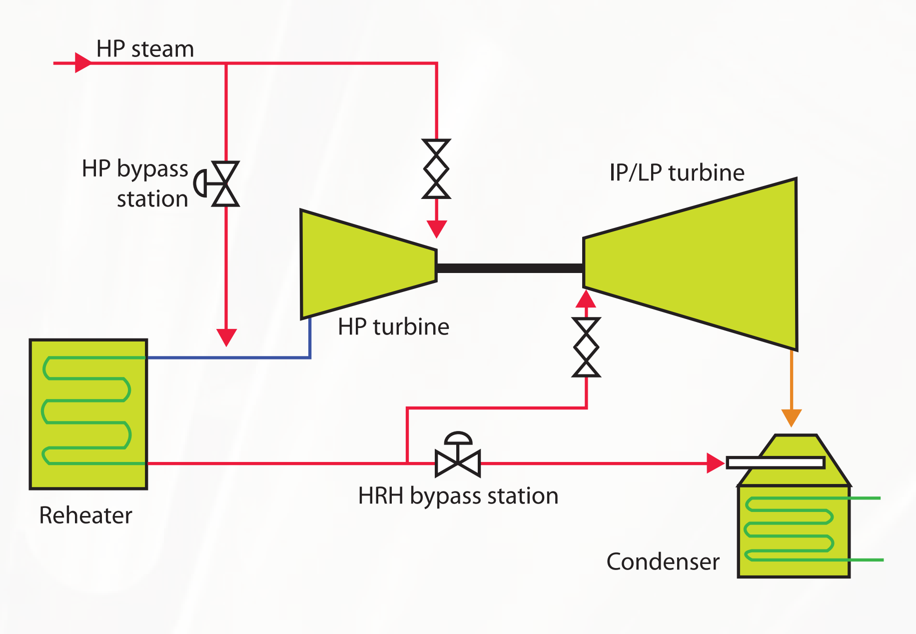
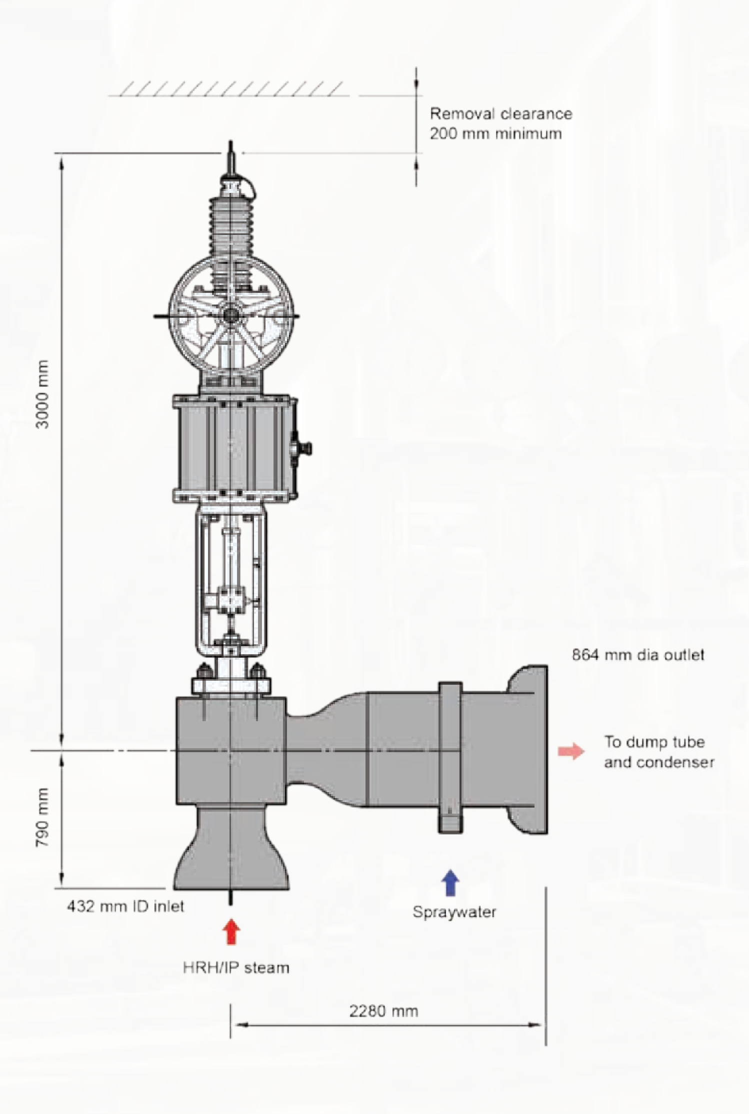


**Figure 2. Typical layout of an LP bypass system for a 500 MW supercritical unit**



## Table 1. Typical range of sizes and capacities of HP bypass to Cold Reheat systems for fossil plants

| Unit size (MW) x % bypass | Bypass flow | # of lines | Inlet/ outlet | Capacity (Cv) required |
|---|---|---|---|---|
| 1000 MW x 30% (supercritical) | 1000 MT/hr | 1 | 14” / 20” | 461 |
| 800 MW x 30% (supercritical) | 800 MT/hr | 1 | 12” / 18” | 367 |
| 800 MW x 60% (supercritical) | 1600 MT/hr | 2 | 12” / 18” | 367 |
| 600 MW x 30% (supercritical) | 600 MT/hr | 1 | 10” / 16” | 278 |
| 600 MW x 60% (sub-critical) | 1200 MT/hr | 1 | 14” / 22” | 845 |
| 500 MW x 60% (sub-critical) | 1000 MT/hr | 1 | 14”/ 20” | 740 |
| 250 MW x 60% (sub-critical) | 500 MT/hr | 1 | 12”/ 18” | 369 |
| 350 MW x 100% (sub-critical) | 1150 MT/hr | 1 | 14”/ 22” | 820 |

## Table 2. Typical range of sizes and capacities of HRH bypass to condenser systems for fossil plants

| Unit size (MW) x % bypass | Bypass flow | # of lines | Inlet/ outlet | Capacity (Cv) required |
|---|---|---|---|---|
| 1000 MW x 30% (supercritical) | 1160 MT/hr | 2 | 16” / 24” | 1894 |
| 800 MW x 30% (supercritical) | 930 MT/hr | 2 | 14” / 20” | 1517 |
| 800 MW x 60% (supercritical) | 1856 MT/hr | 4 | 14” / 20” | 1517 |
| 600 MW x 30% (supercritical) | 695 MT/hr | 2 | 14” / 18” | 1136 |
| 600 MW x 60% (sub-critical) | 1390 MT/hr | 2 | 16” / 24” | 2273 |
| 500 MW x 60% (sub-critical) | 1160 MT/hr | 2 | 16”/ 24” | 1894 |
| 250 MW x 60% (sub-critical) | 580 MT/hr | 2 | 12”/ 16” | 947 |
| 350 MW x 100% (sub-critical) | 1350 MT/hr | 1 | 24”/ 36” | 4419 |

## Table 3. Typical range of sizes and capacities of HP bypass to condenser systems combined cycle plants

| Unit size (MW) x % bypass | Bypass flow | # of valves | Inlet/ outlet | Capacity (Cv) required |
|---|---|---|---|---|
| 150 MW x 100% | 500 MT/hr | 1 | 14”/ 24” | 563 |
| 90 MW x 100% | 300 MT/hr | 1 | 12”/ 18” | 338 |
| 60 MW x 100% | 200 MT/hr | 1 | 10”/ 14” | 221 |

## Table 4. Typical range of sizes and capacities of HP bypass to condenser systems combined cycle plants

| Unit size (MW) x % bypass | Bypass flow | # of valves | Inlet/ outlet | Capacity (Cv) required |
|---|---|---|---|---|
| 150 MW x 100% | 290 MT/hr | 2 | 12”/ 16” | 1100 |
| 90 MW x 100% | 175 MT/hr | 2 | 8”/ 12” | 660 |
| 60 MW x 100% | 115 MT/hr | 2 | 8”/ 10” | 440 |

Notes:

(1) The tables above only for the purposes of illustration of typical configurations, sizes, flows, Cv’s etc. For those skilled in the art, it will be clear that there will be differences with specific installations.

(2) The bypass systems referenced in the tables above refer to the steam PRV and the downstream desuperheater combined. The inlet/ outlet sizes stated are the typical steam PRV inlet and DSH outlet sizes respectively.

Koso’s 530/540 bypass system provides a cost-effective solution in this severe duty application. It meets applicable codes in the power industry and is engineered taking a wealth of industry experience into account. The 530/540 design meets the critical functional requirements of turbine bypass systems which are:

- **High reliability** – necessary to achieve high availability of the plant
- **Low vibration and noise** – for personnel and equipment safety
- **Fine control** – for smoothness of start-ups and shutdowns, as well as for long-term life of critical high-pressure, high-temperature components
- **Tight shutoff** – this is necessary to avoid penalty in heat rate and/or reduction in plant output
- **Good, reliable desuperheating performance** – for long-term protection of the equipment downstream

Turbine bypass systems are generally sized for “X” percent bypass; the actual value of “X” depends on the end-users’ intent and desire for functionality. Common practices for bypass capacity are 30 – 35%, 60 – 70% and 100% of the design flow. Each of these reflects differing intent of how the plant will be operated and/or the functionality desired in operation.

Koso’s 530/540 bypass systems are configured with pneumatic actuators; electro-hydraulic actuation is available on demand. Electric actuators are generally unsuitable for this application.

### Steam pressure reducing valve (PRV):

The steam pressure-reducing valve in turbine bypass systems is the primary mechanism of controlling the upstream pressure. It is available in different configurations in the Koso system – (a) in-line globe body (530) or angle body (540), and (b) flow-to-open or flow-to-close. This results in four combinations. The final choice should be made based on the plant layout and users' preferences. Any of the combinations, when correctly designed, can meet the critical functional requirements for turbine bypass applications.

Angle-body, with flow-to-open configuration, generally results in the most compact and lower weight package. This configuration is advantageous in many other respects as well:

- Support requirements are less demanding
- Pre-warming requirements are simpler
- Valve and upstream pipe condensate drainage requirements are simpler
- Special treatment to eliminate noise at the outlet pipe is less likely

Typical flow conditions at full flow for modern turbine bypass systems are: HP bypass inlet - Pressure of 180 barA for subcritical Units, and 260 barA for supercritical Units; temperature of 550°C. IP/ HRH bypass inlet - Pressure of 40 barA and temperature of 560°C. Pressure at the outlet is determined by capacity of the dump tube or the device discharging into the condenser. Typical pressures at the outlet of the steam valve at full flow condition range from 5 - 15 barA. Trim in Koso steam PRV's is specially designed to keep noise and vibration within acceptable limits. Outlet cage dissipates the large high energy jet, which would otherwise issue from the seat ring region into the outlet piping. This outlet cage is part of the quick change trim and can be inspected during regular maintenance. This is a major advantage over designs where similar baffles are welded in the body outlet region. Such baffles have been known to break; when that happens, it requires cutting and replacing the whole valve.

**Figure 3. Cross-section of a steam pressure reducing valve with a VECTOR™ A trim.**

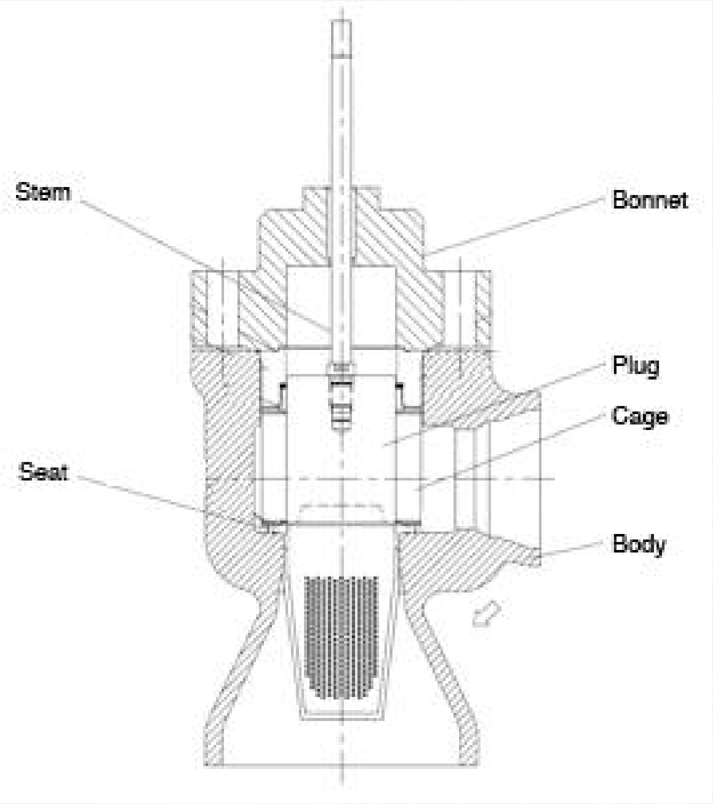


**Table 5. Typical materials of construction**

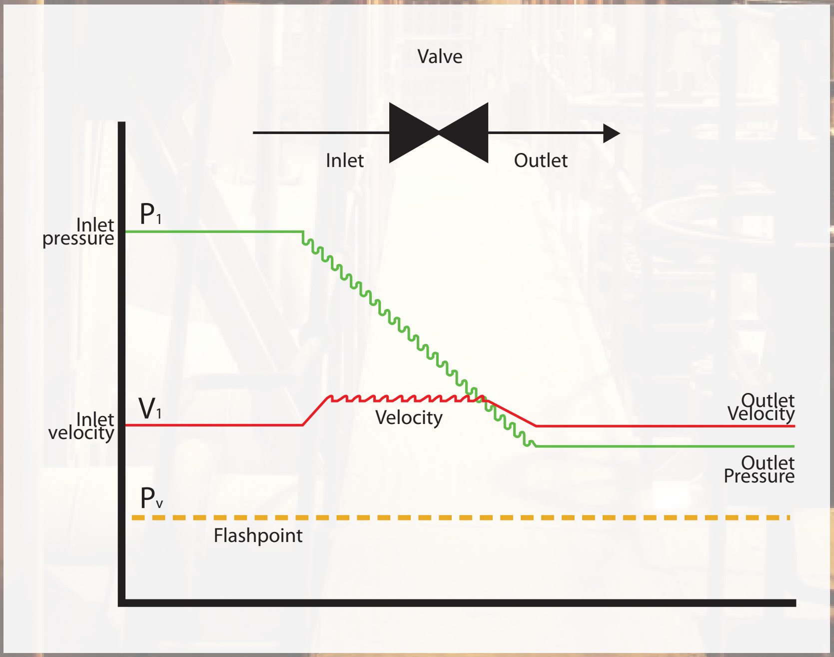
| | Design temperature | |
|---|---|---|
| | up to 540 °C (1005 °F) | above 540 °C (1005 °F) |
| Body | A182 F22/A 217 WC9 | A182 F91/ A217 C12A |
| Bonnet | A182 F22/A 217 WC9 | A182 F91/ A217 C12A |
| Inlet cage | 10CrMo910/A182 F22 | X20CrMoV121 |
| Plug | 10CrMo910/A182 F22 | X20CrMoV121 |
| Stem | Inconel 718 | Inconel 718 |
| Seat | 10CrMo910/A182 F22 | X20CrMoV121 |
| Outlet cage | 10CrMo910/A182 F22 | 10CrMo910/A182 F22 |

Alternate materials are available to met specific design requirements.

Example of a spraywater valve.

Koso's VECTOR trim delivers reliable control, long life and freedom from cavitation, erosion, vibrations and noise problems.

Figure 4. Velocity control valve eliminates cavitation.



**Spraywater control valve:** The function of the spray water valve is to regulate the correct amount of spraywater flow into the desuperheater. These are generally small valves, typically two to four inch size, and are available in angle-body or in-line globe body configurations. Direction of flow-to-close is preferred.

Critical functional requirements for the spraywater control valve are:

- High rangeability
- Quick response
- Good controllability
- Tight shutoff

Proper sizing of spraywater valves is critical to proper operation of turbine bypass systems. Excessive over-capacity in spraywater valves results in poor control at low flow rates.

Equal percentage or modified equal percentage characteristics is recommended to achieve good controllability. High thrust for seating is recommended to achieve repeatable tight shutoff in service.

**VECTOR™ velocity control trim:** The HP bypass spray application requires a velocity control trim like the type shown in Figure 4. Fluid kinetic energy along the flow path, within acceptable limits, which eliminates potential problems (cavitation, vibration, noise, premature erosion etc).

LP bypass spray and spraywater isolation usually are not severe services.

**Spraywater isolation valves** are recommended as a protection for the desuperheater. They are intended to prevent cold spraywater from dripping on to, or coming into direct contact, with hot metal in the desuperheater, in case that the spraywater control valve develops a leak.

**Actuation:** Pneumatic actuators are common in modern turbine bypass systems. Actuators are sized to provide fine control and the high thrust that is required to ensure tight shutoff.

Special pneumatic control circuit, which is local to the control valve, controls action of the actuator according to the DCS signals; this includes fast open/close action and trip modes.

KOSO also offers electrohydraulic (EH) actuators for this service where requested.

Actuator type is one of the key descriptors of turbine bypass systems. Choice of actuation system is typically made by the end-user based on their prior experience and the plant design. Until about 1980's, electro-hydraulic (EH) actuation was the most common type selected by turbine bypass systems. However, the problems with EH actuators were many: high maintenance requirement, potential for fires, unreliability, limited tolerance for extreme environment (dust, humidity, heat etc) etc.  However, there was little choice then because majority of the turbine bypass valves from the early generation of designs were "unbalanced trim" designs, which require very high actuator thrust. As a result, EH actuators seemed to be the only practical solution.

Double-acting pneumatic actuators have been around for a very long time. They are simple in construction – that means potential for high reliability. Also, the devices that control such actuators had been well-known, and readily available, in the industry. The evolution of modern turbine bypass designs with "balanced trim" designs resulted in thrust requirements that were within the capability of the pneumatic actuators. With that development, double-acting-pneumatic actuators found easy acceptance in the industry. End users were able to avoid the problems of the EH systems that were prevalent in the industry.

With the added benefits of easier maintenance and economy, pneumatic actuators have been accepted as a standard for turbine bypass systems in many power plant designs, although electro-hydraulic actuators continue to be used in some cases. A comparison of actuators options is shown in Table 4.

**Table 6. Comparison of actuator options**

| Attribute | Pneumatic | Electro-hydraulic | Electric |
|---|---|---|---|
| Stroke time | < 2 seconds | < 1 seconds | < 2 seconds |
| Positioning accuracy | <2% | <0.5% | <2% |
| Step change response | <1% overshoot | No overshoot | No overshoot |
| Reliability | Very high | High | High |
| Maintenance requirement | Low | High | Moderate |
| Cost | Low | High | Moderate |

**Electro Hydraulic actuator from Paladon to be retouched onto valve.**

**Figure 5.** Break-up of a water droplet by interaction with steam when Weber number (We) is greater than 14. We = $\rho U^2 d/\sigma$ where $\rho$ = steam density, U = relative velocity of steam, d = droplet diameter, $\sigma$ = surface tension of water.

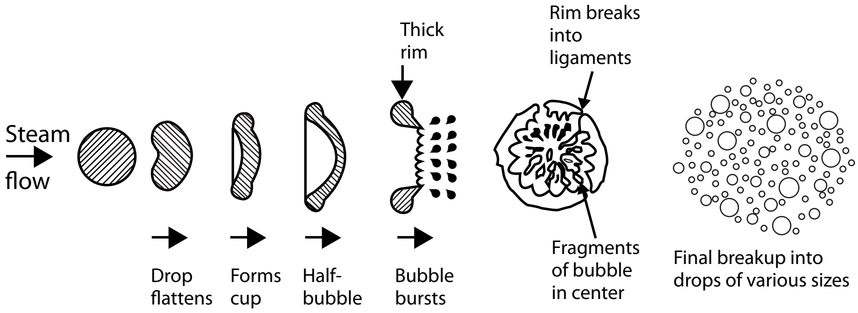
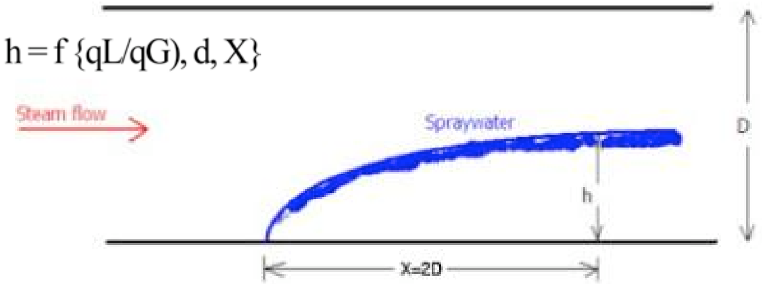


**Figure 6. Schematic of penetration of spraywater in a cross-flow of steam**



h = spray penetration, qL = momentum of spraywater jet, qG = momentum of steam
d = jet diameter.

**Desuperheater:** Desuperheating for turbine bypass applications is challenging because the amount of spraywater is huge. Typical requirement for LP turbine bypass service is 30 – 35% of the incoming steam flow. Even for a 30% bypass system in a 600 MW station, this means of spraywater flow rate of about 100 t/h, or equivalent of five fire-hydrants, spraying in the pipe downstream of the LP bypass steam valve. Within the envelope of the pipe, the desuperheater design has to ensure that:

- the cold spraywater does not impinge on the hot pipe wall – this is important for avoiding excessive thermal stresses and the resulting potential for cracking of pipes
- all the spraywater has to be evaporated within the short distance downstream that is available.

For HP bypass to cold reheat system, the situation is similar, even though the spraywater is about half that for the LP bypass system.

The performance goals described above require fine atomization and proper dispersion of the spraywater. Large drops are not good for the system. They tend to impinge on the side walls and/or fall out of the steam flow due to their high inertia; even when they don't drop out of the steam flow, they require a long time to evaporate. Generation of small drops depends on the inherent nozzle injection characteristics (or, primary atomization) as well as the energy of the steam flow into which the spray is injected (secondary atomization). Atomization of liquid in a steam is governed primarily by Weber Number (We), which is defined in Figure 5.

Droplets break up when We > 14. The relationship above shows the importance of the relative kinetic energy (1/2 $\rho$U2) of the steam in achieving fine atomization. This is the key principle used in the design of spray water nozzles as well as for the spray nozzle-steam system as a whole.

Droplet size rule - In practical terms, mean droplet diameter needs to be less than 250 microns under all operating conditions for good desuperheater performance.

Two other important considerations in desuperheater design is spray penetration and coverage. Spray penetration depends primarily on the momentum ratio of the injected spraywater and steam, initial size of the injection jet and downstream distance. See Figure 6.

Spray penetration rule: The spray penetration is controlled within 15 and 85% of the pipe diameter in a well-designed desupereheater.

Coverage is controlled by the number of spray nozzles used, their inherent characteristics as well as their placement in the steam flow. It is important for thorough mixing of spraywater in steam, which is essential for efficient evaporation.

Selected desuperheater must meet all operating conditions for a system – not just the full-load or sizing condition. This requires recognition of the differing characteristics of each system. Secondary atomization of large drops from spray nozzles requires steam flow has sufficient energy. From the Weber Number relationship described earlier, 250 micron droplet size to about 2 kPa (0.3 psi) of steam kinetic energy.This limits the performance capability of the desuperheater at low flow rates. This effect is severe for HP bypass to Cold Reheat (CRH) than for turbine bypass to condenser; the relationship between flow rate and steam kinetic energy is illustrated in Figure 7.

A spray ring type desuperheater is best-suited for steam bypass to condenser service. It offers both simplicity and economy, while meeting all performance requirements. Kinetic energy of the steam at the outlet of the steam valve is sufficiently high at all operating conditions in bypass-to-condenser systems; as a result, all the injected spraywater is broken up into fine drops. Spraywater injection from a large number of jets is especially beneficial in achieving proper coverage across the steam pipes, which tend to be large in low pressure turbine bypass applications. Typical ring-style desuperheater configuration is shown above right.

Multi-Nozzle Ring desuperheaters have discrete spraywater nozzles distributed around the steam pipe circumference. This design is well-suited especially for HP bypass to CRH. Spraywater is injected through the variable-area, spring-loaded spray nozzles in this design. These specially designed spray nozzles ensure that a pre-determined ΔP, which is sufficient for atomization, is available for spraywater injection- this ensures that the spraywater does not dribble at low spraywater flow requirements.

**Figure 7. Spray-ring desuperheater**

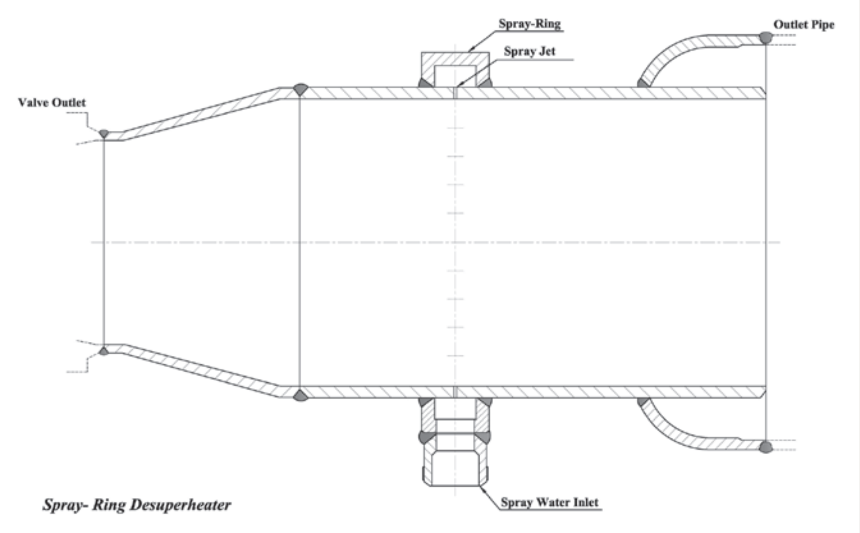


**Figure 8. Multi-Nozzle Ring Desuperheater schematic**

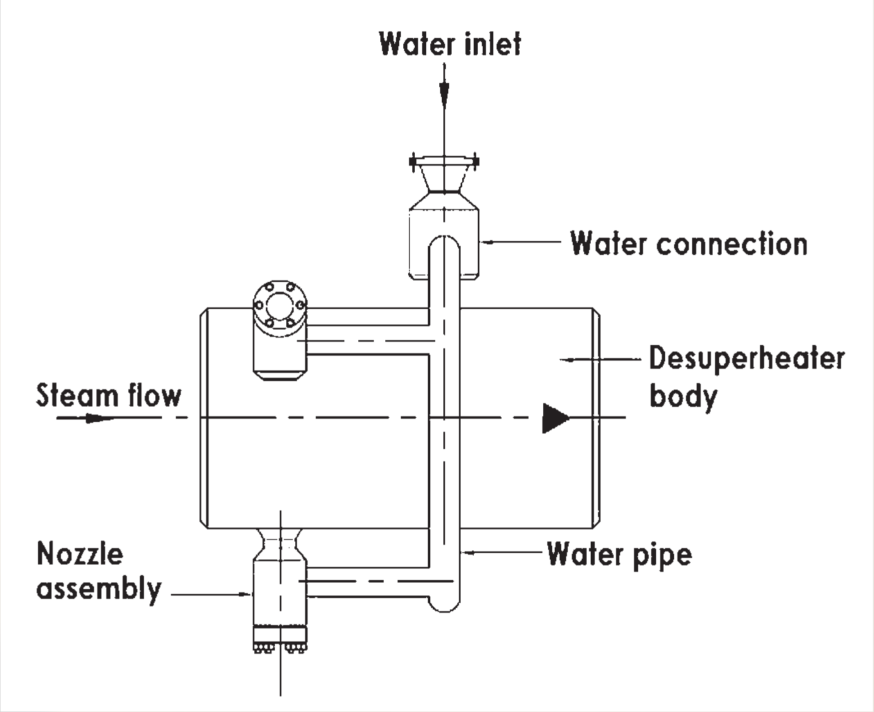


**Figure 9. Cross-section of a variable-area, spring-loaded spray nozzle**

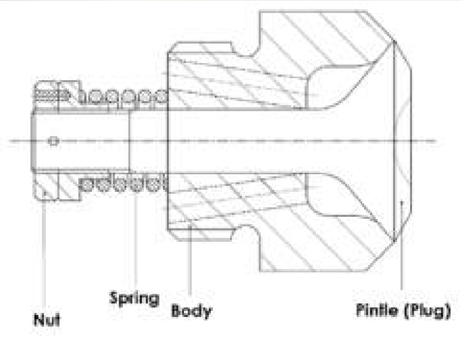


**Figure 10. Dump tube installation schematic**

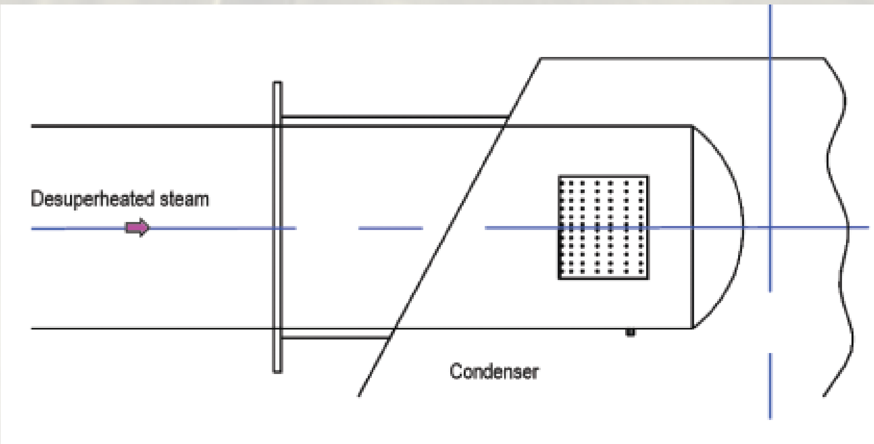
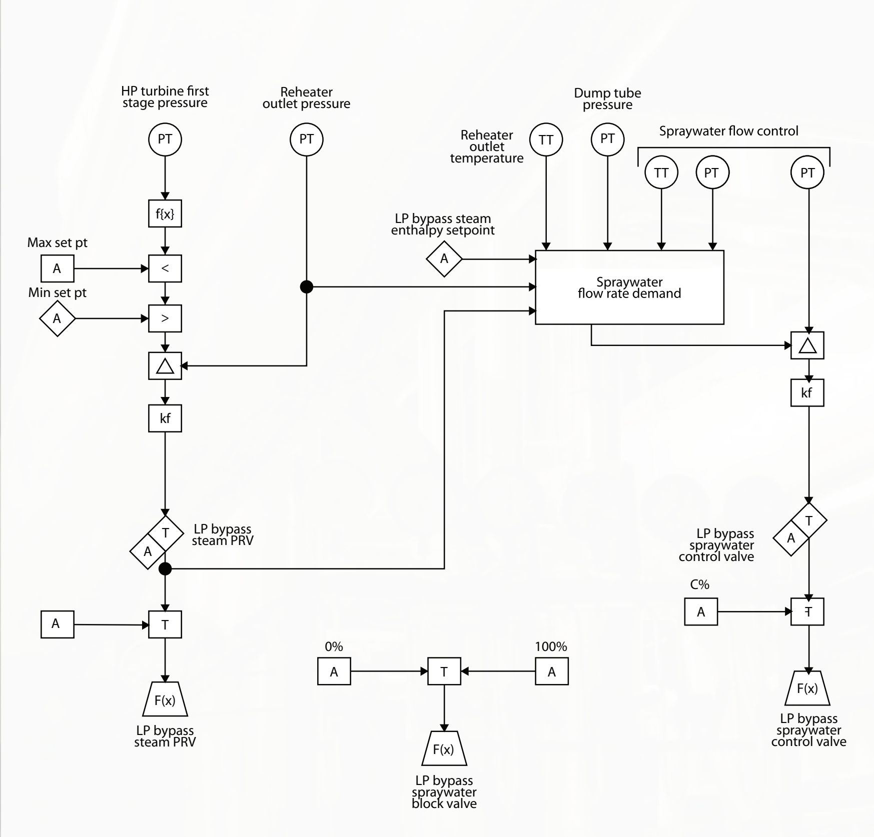


**Figure 11. Typical control logic for turbine bypass to condenser**



**Dump tube:** The function of the dump tube is to dump the bypass steam safely into the condenser. Proper sizing, selection and design of the dump tube is necessary to ensure that the potential for excessive noise and vibration is eliminated.

Typical maximum pressure at full flow condition used for sizing dump tubes ranges from five to 15 bar A. Selection of this pressure is an important part of turbine bypass sizing and has a major impact on the overall cost; it affects the size of the valve outlet, outlet pipe size, spraywater valve size, desuperheater design, size of the dump tube, etc.

Dump tubes should be sized for the highest pressure practical; this means smaller size pipe between the steam valve and the condenser, less demand on support structures etc., all of which leads to lower cost. Care has to be taken so that the selection of dump tube design pressure does not compromise the spraywater system.

Dump tube design must also consider the potential for erosion due to two-phase flow from the bypass systems. An optimal design avoids the failure risks associated with under-sized dump tube system as well as the unnecessary additional cost of an over-sized system.

Noise generated by the discharge from dump tubes is a major consideration in the design of turbine bypass systems. It can be controlled within acceptable limits with good designs. This is generally not a concern with water-cooled condensers. However, dump tubes for air-cooled condensers require special attention. Koso has low-noise technologies to meet such requirements.

**Control algorithm:** Good control of turbine bypass systems is essential both for smooth operation of power stations and to avoid premature failure of high-pressure, high temperature components in the system. Signal generation for the sprayflow flow control valve is a critical link from the stand-point of control of turbine bypass systems.

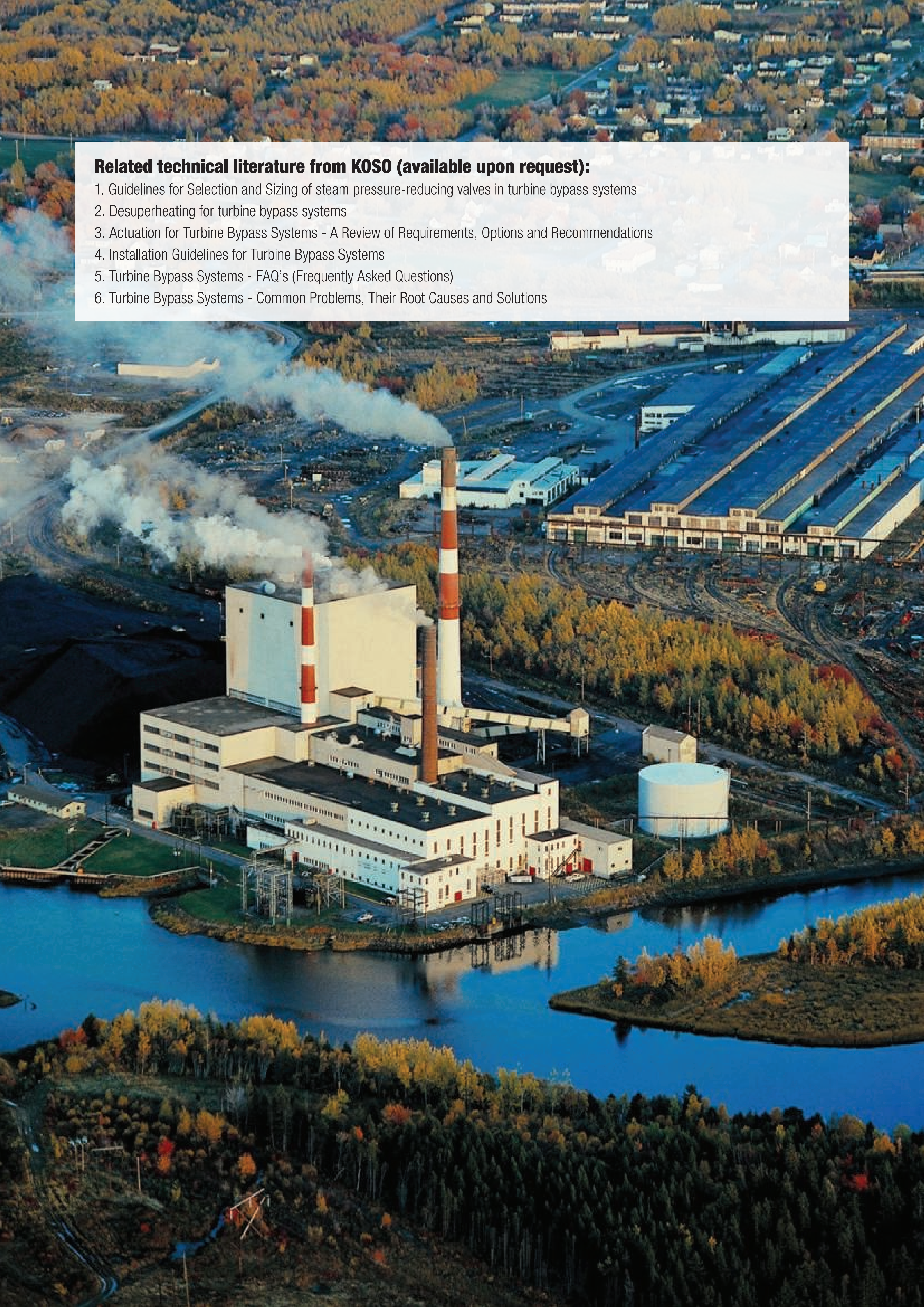
For turbine bypass steam valves, the plant control system provides the signal to maintain the respective upstream system pressure. However, control of spraywater flow is a critical link for desuperheating after steam pressure reduction. Signal for spraywater valve in the HP bypass system is based on a feedback control loop to maintain the downstream temperature set-point. A feed-forward control algorithm for spraywater flow is recommended for steam bypass to condenser. Koso technical experts are available to assist in the proper set-up of controls at the site.

### Customization of turbine bypass systems:

Customization is more of a rule than an exception in the power industry. Customization may be driven by the system operation or by special performance requirements. Common instances requiring such customizations are pre-defined piping layout, noise requirements, system operation, etc. Special attention may be required for transitions between the steam valve and the desuperheater, and from the desuperheater to the outlet pipe, to ensure that excessive noise will not be a problem. Similar materials of construction are preferred at the pipe joint to avoid welding of dissimilar materials in the field.

A collaborative effort between the plant designers and turbine bypass system providers is essential in practically all situations. It results in cost-effective solutions that meet all the requirements and achieve optimum performance. Most importantly, it reduces the risk during the commissioning and for the long-term operation.

A custom VECTOR™ velocity control HP turbine bypass steam pressure-reducing valve with desuperheater for a power station in Eastern Europe featuring: two inlets and fast-stroking electric actuator, both as requested by the customer.



**Related technical literature from KOSO (available upon request):**

1. Guidelines for Selection and Sizing of steam pressure-reducing valves in turbine bypass systems
2. Desuperheating for turbine bypass systems
3. Actuation for Turbine Bypass Systems - A Review of Requirements, Options and Recommendations
4. Installation Guidelines for Turbine Bypass Systems
5. Turbine Bypass Systems - FAQ’s (Frequently Asked Questions)
6. Turbine Bypass Systems - Common Problems, Their Root Causes and Solutions

KOSO

**Headquarters**
Nihon KOSO Co., LTD.
1-16-7, Nihombashi, Chuo-Ku
Tokyo, Japan, 103-0027
Tel: 81.3.5202.4100
Fax: 81.3.5202.1511
www.koso.co.jp/en/

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