BONETTI's Technical notes

Using drain valves to save energy and money in a combined cycle power plant

Drain valves are important items in all steam-handling installations, since they enable the operation and economy of the process to be handled properly. In combined cycle power plants, however, their role is fundamental; they have to undergo severe partialization sequences during start up and commissioning, and then they are required to ensure a line tight shut off under full plant operating pressure.

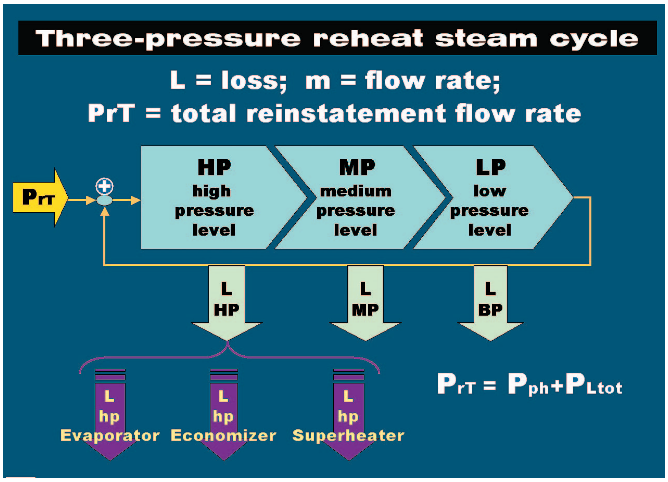

Fig. 1

Here we consider the case of a typical installation with three pressure levels (hereinafter referred to briefly as high, medium and low pressure), and we shall describe the operating conditions, evaluate the problems that have arisen, and give details of the fully satisfactory solution adopted.

The partialization sequences required for drain valves during start up and commissioning after maintenance stops, are intended to set the drum level and reach the appropriate cleanliness and pH value of the process fluid, which during normal operation will flow in a closed loop, with the addition only of low pH water (and the corresponding drainage of high pH water) necessary to maintain the physical-chemical characteristics of steam.

The tightness of the loop is then achieved by the same valves operating the drainage, facing a differential pressure equal to the operating pressure of the vessel to which they are connected, and it is here that problems can arise.

In fact, in the installation we have monitored, standard stop valves were mounted as drain valves, and a large chimney plume was noticed, produced by the steam lost in the atmosphere. The reason for such steam loss will be clear after we have given consideration to the conditions undergone by the drain valves during the start up and commissioning stages.

First, however, having noticed the typical trim damage produced by this occurrence, we should describe the phenomenon of cavitation, as it is very likely that the operating conditions of the valves under evaluation are such as to produce a systematic cavitation effect.

Cavitation has been thoroughly investigated and complete and accurate literature already exists on the subject; here a rough description, based on survey and experience, is quite sufficient for the facts to be understood and to explain the reason why the new valves installed have been so successful.

Cavitation occurs in vessels acting as vehicles for liquids flowing at high velocity, with sudden variations in the progress of the pressure.

As is well known, in almost all valves, especially when operating under partialization conditions, all or some of the fluid jets, while crossing the trim, are forced to follow an 's' shaped path.

The double bend in this kind of path alone provides a certain degree of recovery, i.e. a "*vena contracta*" pressure lower than the outlet pressure, and, above all, due to centrifugal acceleration, a non constant pressure on all the points of the vena contracta section.
In other words, referring to the average pressure on the vena contracta section, the jets travelling nearer to the deflection radius (internal jets) are at lower pressure, whilst the external jets are at higher pressure, and this span can be a very large one.

Moving forward along the 's' path, the situation becomes its opposite: those jets that underwent lower pressure, since their paths, once in the internal area of the vena contracta section, are now in the external zone of the outlet section, pass from lower to higher pressure (due to the turbulence, of course, the change does not affect each jet in precisely the same way).

When the fluid is liquid or low quality vapour and the pressure in the internal side of the vena contracta is sufficiently low, the liquid will evaporate, through dynamic behaviour known as flashing.
The flashing produced in the 'internal' jets is caused by evaporation under low pressure and high velocity, with a relevant increase in the specific volume. The mix of low pressure, high velocity, and specific volume increase implies its typical noise and vibrations.

In the subsequent part of the path, the same flashing jets reach a higher pressure due to centrifugal acceleration and possibly condensate, thus reducing their specific volume; the velocity cannot be reduced, and these jets slide forward (fluid continuity interrupted), with the velocity, therefore, locally controlled almost exclusively by the trim surfaces. This situation can be described as several very small drops hitting the trim surfaces at high velocity. Thereby producing a typical form of erosion, similar to the grooves left by a comb.

This means that normally cavitation occurs with a differential pressure that is much lower than the critical differential pressure characteristic of the given liquid, where only flashing and choked flow would arise. (It should be noted that if dissolved gases are in the flow, the phenomenon starts even earlier.) Valve manufacturers indicate both the recovery factor and the

Fig. 2

incipient cavitation factor for each type of valve, the latter being quite a lot lower (more stringent versus the maximum allowable differential pressure).

Continuing the case in point, we wish to discuss sequence details of some drain valves (referring to the P&I tags of Fig. 3), then evaluate the steam loss by measuring the flow rate of water supplied to replenish the process flow, and finally evaluate the energy and money loss, according to the share of the total loss actually occurring for each vessel involved.

Since, obviously, the most severe operating conditions are

Fig. 3

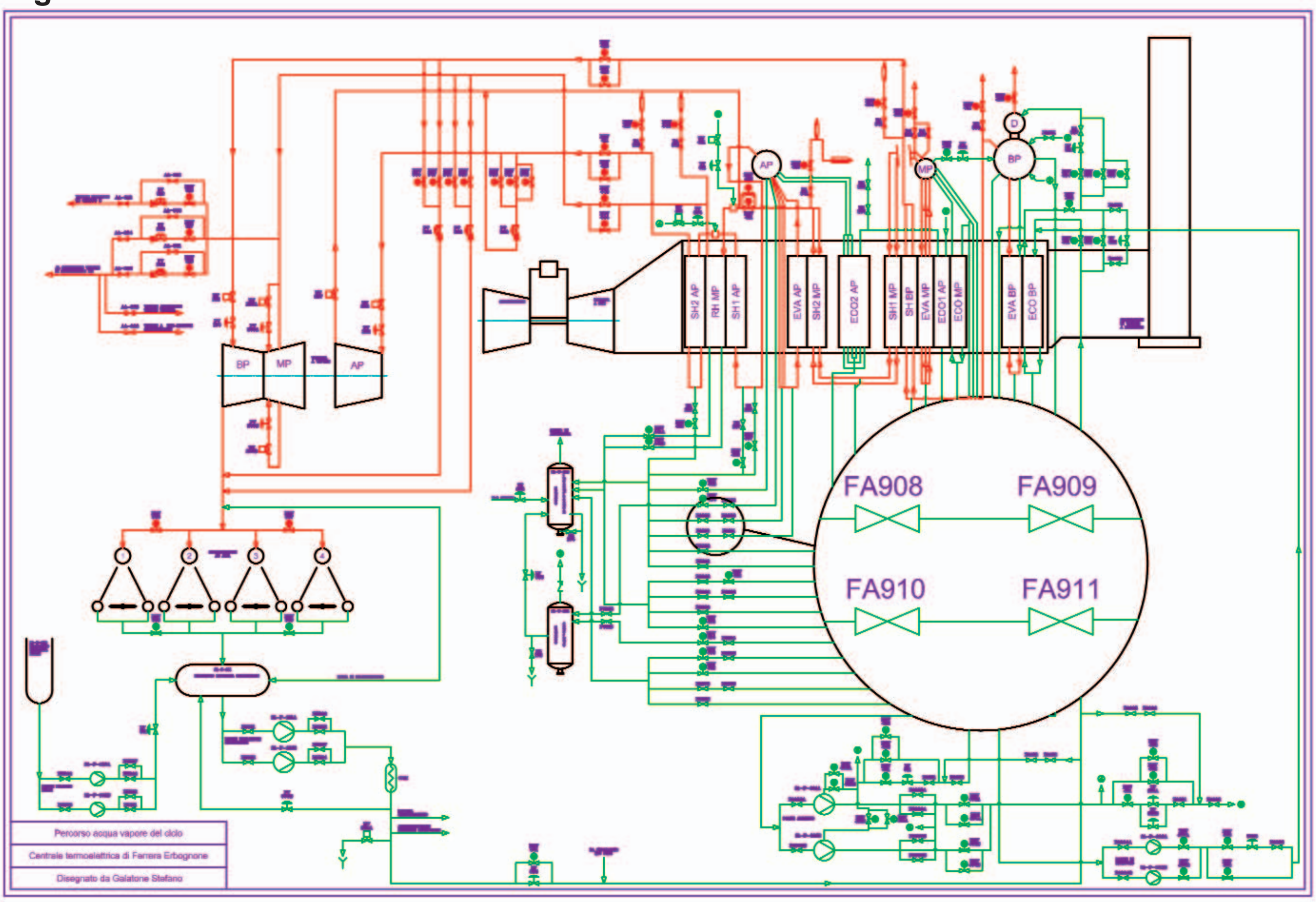

Fig. 3A

Fig. 3B

borne by the drain valves of the high pressure section, and mainly of the evaporator (EVA), the description here of the sequence is restricted accordingly:

- during normal operation, the feed water entering the control valve of the boiler drum level at 150 bar pressure, undergoes lamination down to 110 bar and is heated to 300°C.
- during start up, along the drum pressure ramp, the drum level is set by draining the excess through the FA 908 - 909 and FA 910 – 911 valves, (Fig. 3) which pour about 60 tons per hour of saturated water from a pressure up to 100 bar to atmospheric pressure.

Due to the recovery effect, atmospheric pressure is not immediately reached at the trim outlet, but further on in the drain tank, where the section is sufficiently larger than that of the trim, so that at the trim outlet the fluid, and even more so the external jets, are still under pressure: precisely the conditions needed to produce cavitation, the typical damage caused to the trim surface, and of fluid loss and chimney plume (see Fig. 3A and Fig. 3B).

Moreover, cavitation triggers initial leakage, producing a flow with a differential pressure equal to the line pressure, thus an increase in erosion, as can be seen from the ever larger chimney plume even if it grows less rapidly than at the beginning under the effect of cavitation. Of course, the leakage will continue and increase unless action is taken.

Evaluation of steam loss due to leakage through the drain valves.

We estimated the amount of steam loss after two years of operation at about 50 tons per hour. The initial steam loss was probably around 20 tons per hour.

The evaluation was made by taking into consideration the difference between the flow from the feed pump and the flow actually handled by the utilities (see Fig. 1).

The leakage flow rates of the three blow down lines deriving from the three units at three different pressure levels are called as follows:

- P_{LHP} , derived from the high pressure flow rate, P_{HP} ,
- P_{LMP} , derived from the medium pressure flow rate P_{MP} ,
- P_{LBP} , derived from the low pressure flow rate P_{BP} ,
- and for the sake of completeness, we have inserted also the flow rate P_{PH} , the flow necessary to reset and maintain the characteristics of the process feed water.

The total replenishing flow P_{RT} is:

$$P_{RT} = P_{PH} + P_{LHP} + P_{LMP} + P_{LBP}$$

The P_{PH} flow is negligible at our end, therefore we have:

$$P_{RT} = P_{LHP} + P_{LMP} + P_{LBP}$$

Since over 80% of the total process flow remains in the high pressure loop where the pressure is most severe (more than ten times the low pressure circuit and four times the medium), it is reasonable to consider that the leakage and the relevant replenishing flow affect this loop almost totally (economizer, evaporator, superheater), that is:

$$P_{RT} \cong P_{LHP}$$

Since the three loops handle steam of three different levels of enthalpy, the total cost of the loss strongly depends on their share within the three groups of valves; we should try, therefore, to analyze their distribution and also their influence on total financial loss.

Measuring the various leakage rates would be a cumbersome and disproportionally expensive task, so we are proposing a sort of regressive reasoning, taking into consideration various different assumptions and evaluating the amount of energy/money loss in each case: i.e. leakage concentrated

- exclusively in the economizer (ECO);
- exclusively in the evaporator (EVA);
- and exclusively in the superheaters (SH1, SH2).

A fourth 'reasonable' condition is that an equal leakage trim area exists in all the drain valves, so that the weight flow rate depends on the type of fluid handled; in this case the distribution would be roughly 20% EVA, 60% ECO (19 drain valves), 20% SH1 + SH2.

The calculation can be made by taking directly into consideration the cost per Kg of each type of steam, depending on the relevant degree of enthalpy, or by the loss of energy (which can be assessed in money) deriving from the steam leakage, computed with thermodynamic, mechanical, and electric efficiencies. Both the calculations have been made, although the details have not been quoted, and the values are given in the following table:

	Thermodynamic conditions	CCU Power loss	Approx estimated financial loss at 40 € per MWh
Concentrated ECO loss	Circuit loss 50 t/hT average =241°Cp=113 barh, average= 1076 kJ/kg	1.30%	4.500,00 Euro/day
Concentrated EVA loss	Circuit loss 50 t/hT average =317°Cp=110 barh, average = 2079 kJ/kg	4.50%	16.000,00 Euro/day
Concentrated SH loss	Circuit loss 50 t/hT average =430°Cp=106 barh, average = 3091 kJ/kg	8.00%	30.000,00 Euro/day
60% ECO loss 20% EVA loss 20% SH loss	Circuit loss 50 t/h	3.30%	12.000,00 Euro/day

Data source: ENIPOWER - Ferrera Erbognone Power Plant

As can be seen, the case yielding the minimum loss of energy is that of leakage concentrated exclusively in the ECO, the steam handled there being the least 'valued'. This situation could be 'approached' by providing a tight shut off for the drain valves of the superheater only, or of the superheater and the evaporator; in this case, however, we could also not be sure of avoiding economic loss, but could hope only to reduce it.

The best solution, therefore, is to mount a complete set of *"ad hoc"* valves, which would ensure certain shut off in all the lines throughout the entire lifespan of the installation.

Finally, we describe a type of valve, which has performed very well in this application and can be seen as a satisfactory solution to the problem (see Fig. 4).

Its characterics are the following:

- 'y' style, a design which offers fluid jets an almost straight path, with a very smooth 's' bend;
- reduced port construction, further reducing the bend in the direction of the flow;
- trim shaped for a two-stage operation (double step function) with a large stellited area:
- partialization step, total or partial opening at the same time of the pressure reducing trim and the main seating, the latter offering the flow a much wider passage than that allowed by the partialization trim;
- shut off step, where the main plug reaches its seat when the partialization plug has completely closed its passage.

During the partialization step, the process fluid laps the main seating surfaces at a very low velocity, since in this passage there is almost no pressure drop, such a drop being entirely generated in the pressure reducing trim.

Towards the end of the closing travel, the partialization surfaces almost touch, reducing the flow considerably; the main plug brings this leakage to zero, holding the entire pressure drop under flow just for the (negligible) time necessary to cover the final distance of less than one mm.

With this design (double step design) the seating surfaces do not have to endure a drop in pressure at any stage of the operation under flow, apart from the negligible time in each start up sequence. In this way, no seat damage is caused, and continuous line shut off is guaranteed.

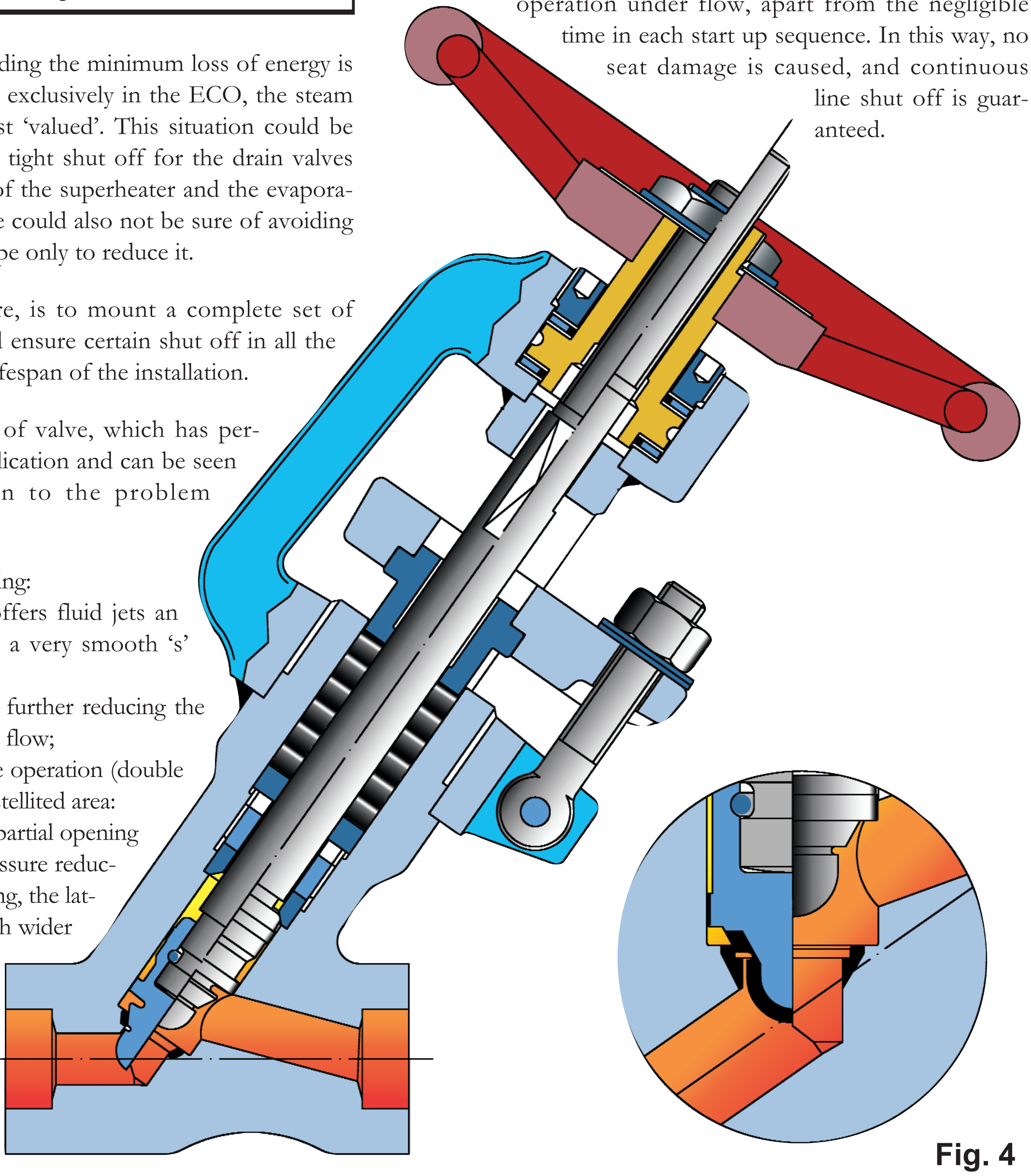

Fig. 4

CESARE BONETTI S.p.A.

I-20024 GARBAGNATE MILANESE (Italy)
Via Cesare Bonetti 17
Telephone: +3902 990721
Telefax: +3902 9952483
Internet web site: http://www.cesare-bonetti.it

Export sales: **Telephone:** +3902 99 072 444
Telefax: +3902 99 072 400
E-mail: export@cesare-bonetti.it

Vendite Italia: **Telefono:** 0299 072 333
Telefax: 0299 072 300
E-mail: italia@cesare-bonetti.it