The Influence of Sliding Pressure Operation on Some Elements of the Thermal Cycle

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Abstract. In the context of the development of energy demand of all categories, the manufacturing industry is directly interested in finding and developing new solutions for its production in accordance with the requirements and standards at the European and global level. These solutions require higher efficiencies and reduced primary energy demand, extended plant life and high safety for plants and people. It is well known that one of the most important method for sustainable development is energy saving. Defined by concepts such as "energy efficient management" or "energy conservation", this will have to be in the attention of both consumers and especially of energy producers. Exploiting energy blocks involves huge costs and responsibilities. That is why their efficient and safe operation is a goal to specialists in this field. In the normal operation of the power group there are inevitable temporary deviations from the technical regulations of some cycle parameters - initial and final pressures of saturated (live) and intermediate superheated steam, steam pressure at adjustable outlets, steam temperature and pressure at condenser. Deviations of the parameters which are within the established normal limits do not cause any danger to the strength of the turbine or boiler elements, as these have been taken into account by the manufacturer.

Keywords: Thermal cycle · Pressure · Flow

1 Theoretical Considerations

Turbine adjustment aims to adapt the power and steam flow delivered to the energy and steam demand of the consumer.

For a turbine without sockets, we have:

$$P_e = D \cdot H_t \cdot \eta_e \tag{1}$$

where:

Pe- effective power

D - the steam flow into the turbine

H_t - enthalpy exchange on the turbine

he - effective efficiency of the turbine

From this equation it follows that: the power of the turbine is proportional to the flow of steam entering the turbine. Power is adjusted by adjusting the steam flow. The

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regulation also affects the enthalpy drop H_t. However, this is an undesirable phenomenon, the yield decreases and therefore should be avoided as much as possible. Given that the convergent-divergent nozzle, although it works with high losses in most of the operating range, has a low flow influenced by the pressure in front of the turbine (which gives stability to the adjustment), we can say that in the first stage it is recommended to use such nozzles [1–3].

The use of convergent - divergent nozzles in the first stage leads to:

1) Stability of the control - by the fact that the flow depends only on the command given by the valves;
2) Processing a large pressure drop.

The flow of steam passing through the nozzles of the first stage is given by the equation:

$$D = A_m \cdot f\left(\frac{p_1}{p_0^{'}}\right) \cdot \sqrt{\frac{p_0^{'}}{V_0^{'}}} \tag{2}$$

where

A_m = za × am.

A_m = the sum of the minimum nozzle sections.

z_a = number of nozzles.

a_m = the minimum section of a nozzle.

p1 = nozzle outlet pressure.

p'_0 v'_0 = pressure, respectively the specific volume of steam after the control valves.

Adjustment through the control valves is a lamination process, which involves $p_o^{'} v_0^{'} = ct. = k$.

Returning to Eq. (1), we have:

$$D = z_a \cdot a_m \cdot f\left(\frac{p'}{p_0^{'}}\right) \cdot \frac{p_0^{'}}{\sqrt{k}} \tag{3}$$

There are two possibilities for controll the flow.

1) Modification p_0' – by mounting in front of the valve nozzles that produce a steam lamination effect (control by lamination - qualitative);
2) Modification z_a - the number of nozzles through which the steam enters (control by intake - quantitative).

2 Lamination Control

The variation of the pressure after the control valve - p_0' - is obtained by inserting a valve placed on the inlet pipe that laminates the steam. The lamination phenomenon takes place at constant enthalpy is being represented in the diagram h-s by the horizontal AA'.

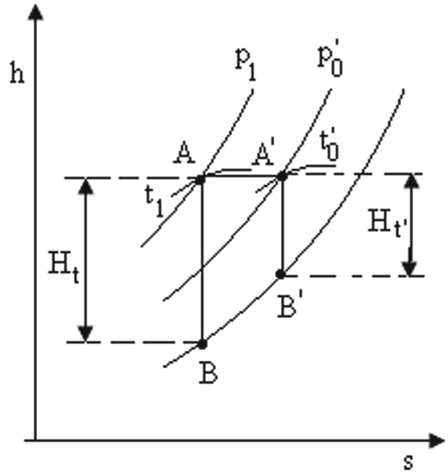

Fig. 1. Control by lamination

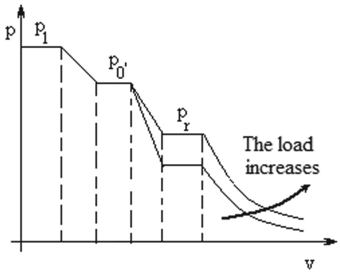

Fig. 2. Variation of pressure in the process of lamination

From the diagram it is observed that by moving the expansion AB to the right in the position A'B' the adiabatic fall decreases, decreases the "working capacity of the steam". Lamination control is uneconomical because it affects turbine efficiency (Fig. 1).

On the other hand, it is simple, inexpensive and has the advantage that for any load the steam enters the same section of the circumference - which leads to uniform heating of the turbine and avoids thermal stresses. Lamination control is used either for small - auxiliary turbines - in which the efficiency is not very important, or for large turbines - with high parameters and power - because it avoids thermal stresses, it is cheap and safe [4, 5]. Regarding the modification of the pressure regime at the lamination control, this can be exemplified graphically as in the (Fig. 2) (Fig. 3).

The steam enters through the valve V, the pressure decreasing from p_1 la p_0', p_0' being the pressure with which it enters in steps.

As the load decreases, the pressure p_0' decreases, according to Flügel equation:

$$p_x = k \cdot D_{xc} \tag{4}$$

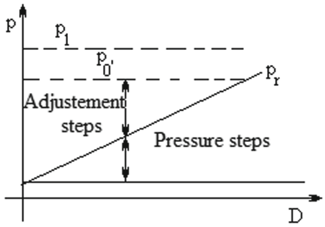

Fig. 3. Variation of useful pressure with the flow

(a particularization and at the same time a simplification of Stodola's relationship) where:

p_x - the pressure at a certain point of the turbine;

D_{xc} – the flow of steam flowing through the turbine between any point x and the outlet (index c).

Results $p_0' = k \times D$. The decrease of pressure p_0' is realized by the valve V which closes as the load decreases.

From the diagram p - D it can be seen that at low flows most of the pressure is lost in the valve – lamination control is uneconomical at low load, because it severely affects the fall of enthalpy H_t and participates decisively in increasing of the specific consumption.

3 Control Through Admission

The second type of control is to change the number of nozzles through which the steam enters.

This problem is solved by grouping the nozzles into several intake sectors (generally for large turbines with 4 sectors). The steam from the boiler enters a distribution box from where it is distributed to the intake sectors. The entrance to each sector is regulated by an inlet valve. The inlet valves open one by one, thus progressively increasing the number of nozzles through which the steam enters. Adjustment by pure inlet, without lamination, is not allowed because by the sudden addition of the flow of a sector the power and flow would vary in steps [6].

However, the turbine power must vary constantly, so mixed control is used. The valve is opened gradually, a lamination appears, applied only to the sector being opened. When the turbine is loaded, valve 1 will be opened gradually, then - when it is fully opened - valve 2 will start to open. Regarding the pressure regime, we can consider an ideal case of a turbine with an infinite number of intake sectors. Thus the flow can be varied continuously without lamination. The pressure p_0'after the control valve remains constant (Fig. 4) (Fig. 5).

The inlet pressure pr in the pressure steps increases linearly with the flow, according to Flügel's equation ($p_r = k \times D$). The difference p_o'- p_r may increase as the flow decreases.

The control step is relatively loaded when the tubing is unloaded. At low flow the control step consumes the largest pressure drop.

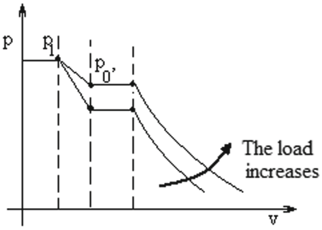

Fig. 4. Control through admission

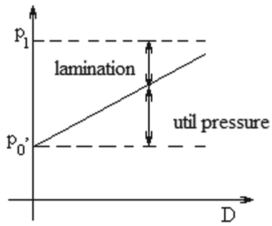

Fig. 5. Variation of the inlet pression in pressure steps

4 Mixed Control

Basically, the assumption made - infinite number of nozzles - is not valid. Lamination occurs during valve opening, with pressure p_0 and D_{sector} flow gradually increasing.

For the sector being opened, the flow through the sector is given by the equation:

$$D_{sec\,tor} = A_{sec\,tor} \cdot f\left(\frac{p_m}{p_0^{'}}\right) \cdot \sqrt{\frac{p_0^{'}}{v_0^{'}}} \tag{5}$$

A_{sector} = the sum of the minimum nozzle sections of a sector.
p_m = minimum pressure.
p_0',v_0' = pressure, respectively the specific volume of steam after VR.
In the lamination process p_0' × v_0' = k:

$$\sqrt{\frac{p_0^{'}}{v_0^{'}}} = \frac{p_0^{'}}{\sqrt{k}} \tag{6}$$

The function $f\left(\frac{p_m}{p_0^{'}}\right)$ varies with respect to $\frac{p_r}{p_0^{'}}$, , respectively with p_0' as follows:

- for $\frac{p_r}{p_0^{'}} = 1 \Rightarrow pr = p_0\text{'}: f\left(\frac{p_m}{p_0^{'}}\right) = 0$;
- for $\frac{p_r}{p_0^{'}} = \beta \;\Rightarrow p_0\text{'} = \frac{p_r}{\beta} : f\left(\frac{p_m}{p_0^{'}}\right)$ = max; unde = β critical rapport;

$\beta = \frac{p_{cr}}{p_0^*}$, p_{cr} = critical pressure,
p_0* inlet pressure (braked parameters);

- for $\frac{p_r}{p_0'} < \beta \Rightarrow$ p0' $> \frac{p_r}{\beta} : f\left(\frac{p_m}{p_0'}\right) =$ const.

Results that for a certain sector the pressure drop p_0'- p_r increases during the opening of the sector, it becomes maximum when the valve has opened completely and then begins to decrease due to the increase of the pressure p_r. The biggest drop occurs when valve V_1 is fully open and the others are completely closed [7]. To avoid overloading and uniform heating of the housings, two valves open simultaneously.

5 Conclusions

One of the main causes that influence the specific heat consumption and efficiency of the group is the loading-unloading regime. In case of operation of the group at tasks other than the nominal load, the net specific consumption changes due to a set of influencing factors such as:

- modification of the boiler efficiency with decreasing tendencies at partial loads;
- variation of lamination losses due to the turbine control system;
- changing the internal efficiency of the turbine;
- change in live and intermediate steam temperatures at the turbine inlet;
- modification of the condenser pressure and of the residual losses at the output of the CJP at partial loads;
- modification of the mechanical efficiency of the group and of the generator efficiency (it will be understood the percentage increase of the mechanical and electrical losses in the total loss);
- increasing the percentage of steam consumption for sealing labyrinths and ejectors;
- changing the consumption of internal services.

By analyzing these factors more closely, we can make some assessments and we will be able to draw some useful conclusions to help find a possible solution to be applied, resulting in an increase in efficiency in conditions of variable load operation of the energy block.

In this order of ideas we can make the following certain statements:

1) the factors from positions described above depend on the load and cannot be influenced during operation if their values are equal to the prescribed performance levels;
2) the temperature of the live steam and in the intermediate superheater in modern groups is practically not influenced by the load. During operation, this parameter must be kept constant or within tight limits.
3) a small reduction reduces the efficiency of the group; a large reduction, in addition to the negative effect on efficiency, can seriously jeopardize the safety of the turbine; an increase of more than 5 °C, although beneficial for the thermal cycle efficiency, is particularly dangerous for the final superheaters, because the unit resistance (σ_z) of steels decrease dangerously.

4) The variation of the lamination losses due to the control system is done together with the load. The higher the load, the lower the lamination losses and vice versa. In other words, by keeping the lamination losses to the lowest possible levels, we can improve specific consumption.

Based on the above, it can be stated that the exploitation of energy aggregates with sliding pressure, without 'destroying' the pressure by lamination can ensure an increase of economy.

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