Dependence of changes in pressure of superheated steam upon reducing heat drop in the throttling regulation of steam turbines

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ARTICLE INFO

***Article history*:**
Received: 05.06.2014.
Received in revised form: 30.12.2014.
Accepted: 08.01.2015.

Keywords:
Steam turbine
Regulation
Throttling
Turbine power

Abstract:

Regulation of the steam turbine can be achieved by optimal, reliable and safe operation. Power regulation adjusts the operation of the steam turbine load current, i.e., it changes the thermal drop (throttling control) or quantity of steam (nozzle control group). An analysis of the throttling regulation reveals the turbine power dependence on the pressure and the supplied amount of steam, and shows the losses due to a pressure drop in the aforementioned regulation.

1 Introduction

The steam turbine [1-4], is a machine of high speed, so it is necessary to establish safe regulation over both the quantity of steam supplied into the turbine and the rotor speed.

The main turbine regulation systems include:
- Power regulation,
- Speed regulation,
- Safety regulation.

Regulation of steam turbine power is defined as a controlled supply of steam needed to maintain the turbine speed due to the load.

The steam turbine has a speed controller which ensures a constant speed when changing the load and protects the turbine from potential disasters at an increasing speed above the nominal speed of rotation of the rotor.

At full rated power, steam turbines operate within minimum speeds, and unloaded by the steam turbine rotor speed they achieve maximum operating speed.

Safety regulation is installed in every turbine, regardless of its application. Each turbine has a designed operating speed of rotation, which is determined by the working conditions of the turbine. In case the speed increases by more than 10 % above the operating speed, safety regulation acts within a timeframe from 0.2 to 0.3 seconds, immediately closing the main valve of inlet steam, and with it also the control valves for each nozzle group.

Besides, safety regulations protect the turbine from disturbances in the pressure and temperature of the steam, pressure and temperature of the oil and increasing vibration.

Power regulation of steam turbines is performed in following ways:
- Changes in heat fall (throttling regulation),
- Changing supplied quantity of steam (regulation by quantity of steam),
- Combining the first and second type.

The throttling regulation is used for turbines in the lower power range, while the regulation of quantity of steam is used for turbines with greater power loads. As the most common form of steam turbine power regulation, this article presents a mathematical model of throttling regulation.

Presented mathematical model of steam turbine power regulation (throttling regulation) can be used for all types of steam turbines (condensing, backpressure).

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2 Regulation of power steam turbines

Through regulation of the power turbines, [5-8], the effect is obtained by means of adapting the current load. For operation and economy, regulation is of major importance. During an increase or decrease in load, the speed changes only slightly (speed control), or the turbine sustains constant pressure (pressure control steam which goes to the industrial network).

The power of the turbine is defined by the expression:

$$Pi = \dot{m} \cdot \Delta h_0 \cdot \eta_i \,, \quad (1)$$

which depends on the quantity of steam $\dot{m}$, the theoretical heat drop Δh_0 and the internal usability of the turbine.

Steam turbine power regulation is divided into several types by changing various quantities:

1. Changing the heat fall, i.e., throttling, *throttling regulation*

2. Changing the quantity of steam, i.e., *regulation quantity of steam (regulation group nozzle or filling nozzle)*

3. Combining the first and second type, i.e., *combined regulation*

2.1 Throttling regulation

In the throttling regulation, the total quantity of steam passes through a throttle valve, in which the steam pressure attenuates (decreases), thus reducing the heat drop in the turbine (Figure 1).

This regulation is rarely used in cases when the turbine is always under the same load, or in case that the construction of the turbine principle does not allow another solution.

The reaction turbine, as a rare exception, can be regulated only by throttling due to full dosing, which is needed by this type of turbine.

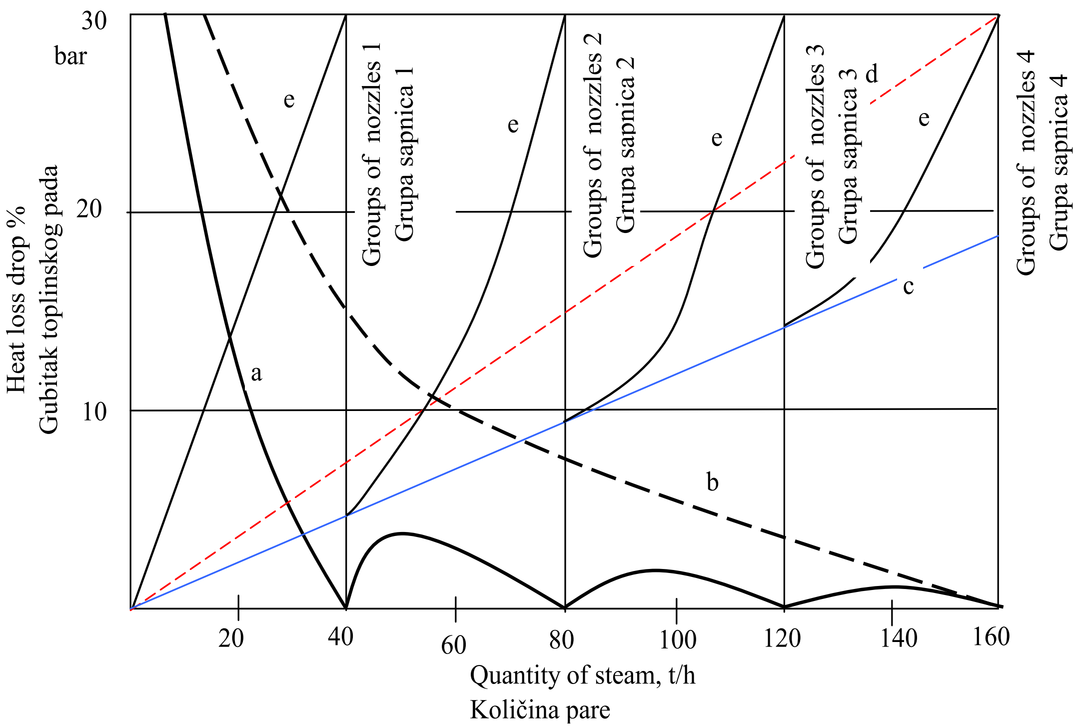

Figure 1. Decrease in heat loss and pressure changes in the valves; the control group of nozzles (solid line), at throttling control (dashed line); a and b decrease in heat loss, c pressure in the first stage, d and e pressure in front of the nozzle.

While providing quantitative regulation with reaction turbines, the first stage which is used for regulation is performing like an action stage.

Mathematical expressions for calculating heat drop in the turbine stage due to throttling are shown as follows.

At full load the adiabatic heat drop is:

$$\Delta h_0 = h_0 - h_{kt}. \qquad (2)$$

Throttling to line h_0 = const. The pressure p_0 to p_1, Figure 2, with a lower load, reducing the adiabatic heat drop to:

$$\Delta h_{01} = h_0 - h_{kt1}. \qquad (3)$$

The loss amounts to:

$$\Delta h_g = \Delta h_0 - \Delta h_{01} = h_{kt1} - h_{kt}, \qquad (4)$$

$$\Delta h_g = \Delta s \cdot T_k. \qquad (5)$$

The ratio of loss due to throttling and adiabatic initial heat drop is:

$$\zeta = \frac{\Delta h_g}{\Delta h_0} = \frac{h_{kt1} - h_{kt}}{h_0 - h_{kt}}. \qquad (6)$$

Herein, it is assumed that the pressure in the condenser remains unchanged.

The loss ζ can be visualized graphically in a diagram as a function of load, or as a function of the pressure behind the throttle valve.

To determine the regulation of steam consumption at partial load, it is necessary to know the distribution of the heat drop of the individual stages of the turbine with changes in the quantity of steam that passes through the turbine.

According to steam consumption, and by knowing the dependence on the flow rate and steam pressure at the inlet of the first stage turbine (after the throttle), the lower the backpressure, the better its curve fits to the curve of steam consumption, which results in linear characteristics. For a sufficiently strong vacuum, it can be said that the amount of steam is approximately proportional to the pressure in front of the first guide vane channels.

The pressure in the turbine stages is changed proportionally according to the inlet steam pressure and quantity of steam. The initial throttle pressure remains h_0=const.

If the quantity of steam is proportional to the pressure in front of the turbines, then it is equal to the ratio $\dot{m} = Kp$ where K is constant; or when $p = \frac{k}{v}$ follows;

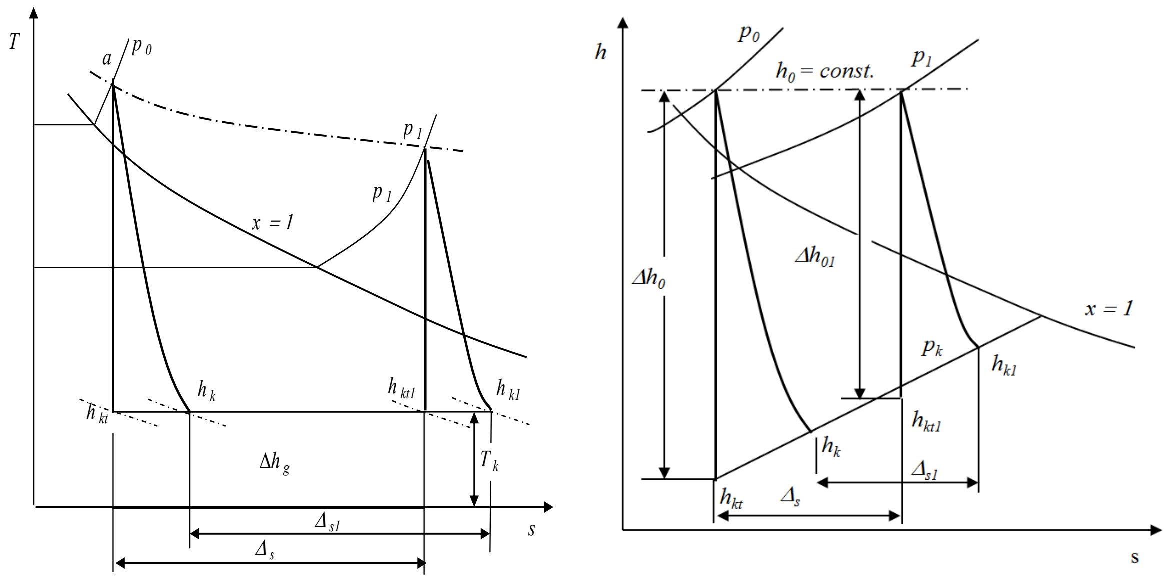

Figure 2. T-s and h-s diagram of the throttling regulation.

$$\dot{m} = K \cdot \frac{k}{v} = \frac{K_1}{v} \rightarrow \dot{m} \cdot v = konst. = K_1 . \qquad (7)$$

With the throttle, the volume of steam passing through the turbine is constant, and it follows:

$$\dot{m} = K \cdot \sqrt{p \cdot p} = K \cdot \sqrt{p \cdot \frac{k}{v}} = K_2 \cdot \sqrt{\frac{p}{v}} \qquad (8)$$

and

$$K_2 = \frac{\dot{m}}{\sqrt{\frac{p}{v}}} . \qquad (9)$$

At a reduced load, maximum power is provided by the first stages of the turbine. Heat drops in these stages undergo almost no changes, while there are significant decreases in the last stage.
The volume of steam which runs at a rate of one second through the turbine at all loads is equal to $\dot{m}\, v = \text{const}$.

The power is proportional to the throttle pressure in front of the dim first guide vane wheel. If the nominal load is valid for the quantity of steam $\dot{m}$ and the pressure of steam p, then for some other load it is valid for the quantity of steam $\dot{m}_1$ and pressure of steam p_1. The interrelation of these values is as follows:

$$\frac{\dot{m}}{p} = \frac{\dot{m}_1}{p_1} = K \Leftrightarrow p_1 = p \cdot \frac{\dot{m}_1}{\dot{m}} . \qquad (10)$$

With the knowledge of steam consumption for a maximum and one less load, according to the example of 50 % or idle, we can apply steam consumption as a function of power, roughly a straight line (Figure 3). This has also given the pressure ahead of the first guide vane wheel, which must be throttled for each load. In addition, using the h-s diagram, the available heat drop can be determined for each load,

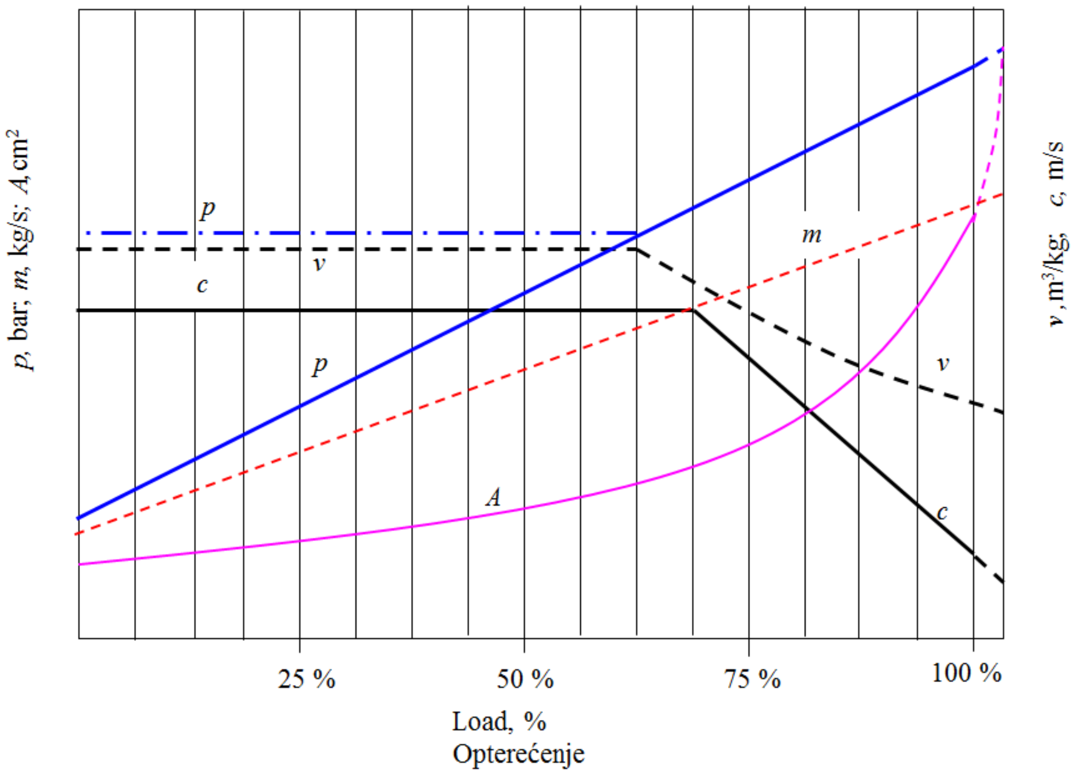

Figure 3. Operating parameters of steam as a function of turbine load for throttling regulation: c-velocity, v-specific volume of steam, p-inlet pressure, m-mass flow, A-throttle area.

The following is an example of determining the coefficient K_2, the internal power of steam turbines, depending on the change in pressure in front of the guide vane channel of the condensing steam turbine with controlled extraction of steam.

The input parameters of the calculation are as follows: p = 20…40 bar, t = 430 °C, p_k = 0.225 bar, $\dot{m}$ = 3…36 t/h.

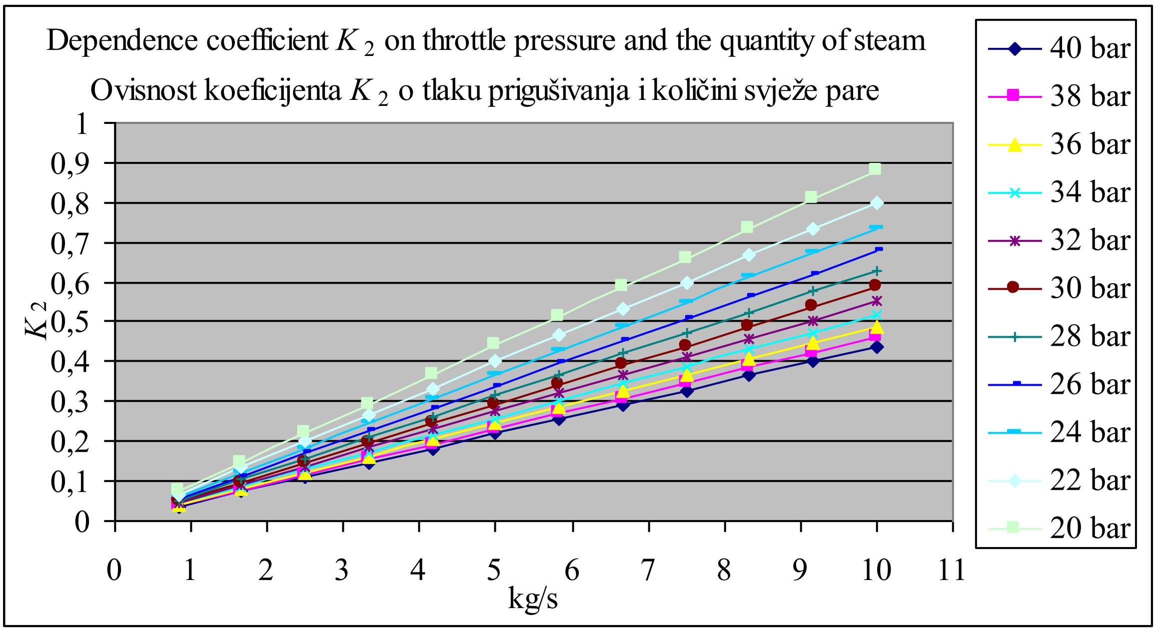

Figure 4. Dependence of coefficient K_2, throttle pressure and the quantity of inlet steam.

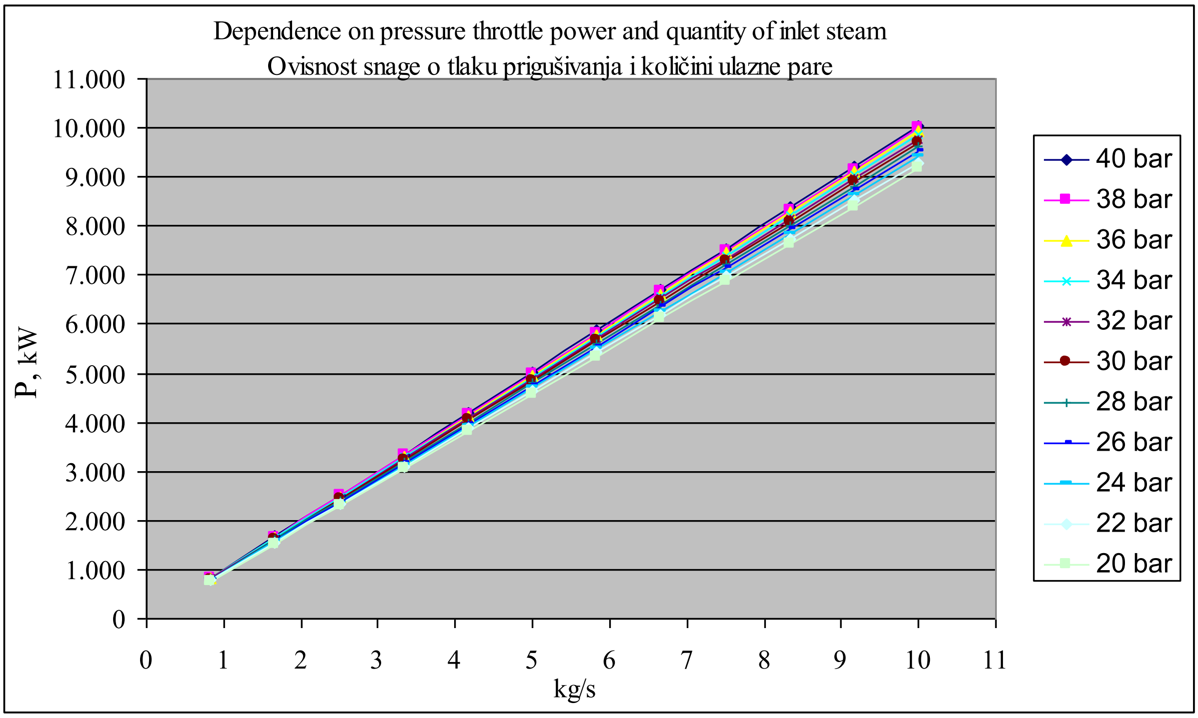

Figure 5. Internal power of the turbine in dependence of throttle pressure and quantity of inlet steam.

The aim of the calculation is to show the changes in the coefficient K_2, and the dependence upon the throttle pressure and changes of the inlet quantity of steam by reducing the pressure of 40 bar in intervals of 2 bar to a final pressure of 20 bar while changing the inlet quantity of steam from 3 t/h, with intervals of 3 t/h, to a maximum flow of 36 t/h. The results are shown graphically in Figure 4.
The loss due to throttle pressure from 40 bar to 20 bar is shown in Table 1. Figure 5 presents the power dependence on throttle pressure and the quantity of inlet steam. From the diagram, it is obvious that the deviation has greater and greater strength with an increasing quantity of steam.

Table 1. The losses due to throttle pressure

Throttle pressure	loss	
38 bar	0,994	0,60%
36 bar	0,987	1,24%
34 bar	0,980	1,93%
32 bar	0,973	2,68%
30 bar	0,965	3,49%
28 bar	0,956	4,36%
26 bar	0,946	5,31%
24 bar	0,936	6,37%
22 bar	0,924	7,52%
20 bar	0,911	8,81%

3 Conclusion

This paper investigated regulation by throttling the steam. We presented an overview of the impact of the coefficient K_2 on internal power of a steam turbine, by changing the pressure in correlation with the pressure and quantity of steam at the turbine inlet. The results gave insight into these relationships which further show that
with an increasing steam pressure, the deviation from the initial steam pressure and the changed steam pressure is linearly increasing. In addition, there is a loss manifested by throttling that varies in the range from 0.6 % to 8.8%. The higher the throttle pressure is, the higher the loss, i.e., the lower the internal power of the turbine.

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