# MATHEMATICAL DESIGNING OF CORRECTION DIAGRAMS FOR STEAM TURBINES

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*Objectives: Correction diagrams for steam turbines it's a quickly, faster and simple method to find influential of an specify parameter variation on the end of the thermodynamic chain, respectively, for the turbogenerator group, variation at the electrical generator. Correction diagrams is not an exact method to determinate that modifications, but they allow a good approximation about processes, so that, without a quickly and powerful instrument of interpretation, to can take a correct decision about an specifying intervention into the termoenergetic live process.*

*Methods: To represent a good approximation instrument of thermoenergetic processes, at machine level, correction diagrams must be risen individual. Because along the time the thermodynamically and hidrodynamically characteristics of a steam turbine will modifying, that will modify the anterior risen correction diagrams.*

*Mathematical designing of correction diagrams for steam turbines persist into creation of a one set of functional equations based on the state dates obtained from thermodynamic process along functioning, witch will characterize real thermonergetic, thermodynamic and hydrodinamic modifications, at the machine level.*

*Results: Studying the DSL 50-1 steam turbine correction diagrams, we can find the mathematical equations that determine the structure of characteristic curves, and based on it, we create a application who can generate characteristic curves function of machine parameters.*

*Conclusions: Parameters, based on it, will be create the functioning diagrams, will be collected on a long time period so that, on this period, system will go into the almost all evolution steps, so that representing to be much precisely and most real.*

**Keywords:** steam turbine**,** correction diagrams, mathematical designing.

## 1. Introduction

The functioning of steam turbines implicates the need of knowing there behavior at transitory regimes and at loads and partial charges. To know the

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possible evolution of the thermo-energetic process inside the turbine at a certain parameter variation, or of a group of certain parameters (pressure, temperature or flow rate), computations and steam turbines functioning diagrams rising was used, diagrams that can be consider self-computing charts, based on which can be anticipated the influence of a certain parameter variation, especially on the mechanic power generated on the machine couple, or on the electric power generated at the generator hub.

The mathematic modeling is a method based on the realizing of computation models starting from the physical characteristics of the analyzed objects using the rules that described the phenomena and the actions that take place on them. From the realization of the modeling point of view we have:

Dynamic regime modeling, that analyze the passing from an equilibrium stage to another, in which the time component plays an important role, being about transient phenomena, this approach of the mathematic modeling needs a very good knowledge of the phenomena in every moment.

The stationary regime modeling, in which equilibrium states of the systems are analyzed, approach that does not need a very good knowledge of the physic phenomena in every moment, but needs a good knowledge of the bounds between the certain components of the system.

In which concern the modeling of thermo-mechanic equipments which enter in the component of central heating electric power stations, have been made, by certain authors, dynamic models as well as static models. Teaching into account that the processes that take place inside such a power station are of long term (because of the thermic and mechanic inertia and in general the entire chain of thermo-dynamic transformations with great temperature and time gradients) and that for this paper in no need of knowing the phenomena in every moment, the stationary computation models are sufficient, applied for different functioning regimes of the installations.

For the mathematic models to have results as closed to the real equipment as possible an astride and a verification of them is needed starting from the data obtained in current exploitation. This has to be made inside as many regimes as possible, with great variations of the measured parameters. The computed measures have to have errors as small as possible on the entire real variation interval of the measured equipments.

In order to realize these objectives sets of measurement points have to be establish needed for the astride and the verification of the mathematic models, starting from the rating to the un-nominal regimes. In the presented applications, these sets of values needed for the thermo-energetic cycle of a power station equipped with DSL 50-1 and DKUL 50-1turbines will be determined, starting from the computation methods presented.

## 2. The study of a condensation turbine with two adjustable mashes

Starting from the steam expansion diagram, inside a condensation turbine with two adjustable mashes, tracing in *i-s* coordinates we will obtain, for a theoretic expansion, a direct line limited by the points "0" (the steam inlet in the turbine) and "c" (the steam exit in the condenser), this being the classic diagram of steam expansion inside a turbine that is functioning after a cycle that uses recuperative preheating, without reheating, having an expansion diagram similar to the one presented in fig. 2.1. The circulation of the steam flow rates inside the turbine that is functioning after the diagram presented in fig. 2.1, starting from $m_0$, and the live steam flow rate enters the turbine, until $m_c$, the steam flow rate evacuated to the condenser is presented in fig. 2.2.

Using this scheme and taken into account the consume equation of the turbine without the mashes:

$$P_{tb} = \eta_m \dot{m}_0 H_i \qquad (2.1)$$

Can be deduced the balance equation of a steam turbine with adjustable mashes:

$$P_{tb} = \eta_m \left[ \dot{m}_0 h_{i1} + \left( \dot{m}_0 - \dot{m}_i \right) h_{i2} + \left( \dot{m}_0 - \dot{m}_i - \dot{m}_t \right) h_{i3} \right] \qquad (2.2)$$

were :

$h_{ix}$ – are the drops of enthalpy between the turbine steps.

the mass balance equation being: $\dot{m}_0 = \dot{m}_i + \dot{m}_t + \dot{m}_c$ (2.3)

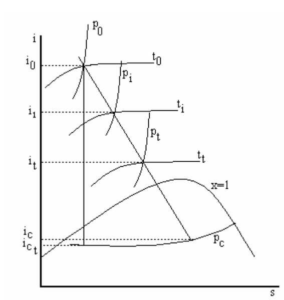


Fig. 2.1 The expansion chart in *i-s* coordinates for a condensing turbine with two adjustable mashes

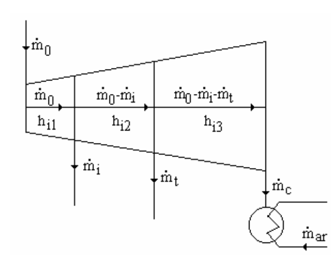


Fig. 2.2 The steam flow chart in the condensing turbine with two adjustable mashes

If we express the equation (2.2) related to steam enthalpy, for each section, under the expression:

$$P_{tb} = \eta_m \left[ \dot{m}_0 (i_0 - i_i) + \left( \dot{m}_0 - \dot{m}_i \right) (i_i - i_t) + \left( \dot{m}_0 - \dot{m}_i - \dot{m}_t \right) (i_t - i_c) \right] \qquad (2.4)$$

we obtain :

$$P_{tb} = \eta_m \left[ \dot{m}_0\, i_0 - \dot{m}_i\, i_i - \dot{m}_t\, i_t - \left( \dot{m}_0 - \dot{m}_i - \dot{m}_t \right) i_c \right] \tag{2.5}$$

From equation (2.5), maintaining all the parameters at a constant value (pressure, temperature, mass flow) at one of the turbine mashes, except one of them, it can obtain an expression like:

$$\Delta P_{tb} = C + f(x) \tag{2.6}$$

where: with *C* we noted the constant part of this expression.

The graphic expression of a mathematical function family, under the form express by the relation (2.6) will lead to the generation of a self-computing chart for the turbine power variation at the machine couple (or for the electrical power – gross output – in the case of a turbo-generator group), related to the variation of a thermic parameter on the turbine. For special cases, when interfere many variations of the initials parameters, the self-computing chart can be obtain by the composition of the individual variation chart of each parameter, in view of that the variation of one parameter, usually, in any point of the turbine, may conduct to the variation of the parameters measured surety of that respective point.

The correct marking and evaluation make the functioning diagrams (also named correction diagrams) a fast calculus and pretty accurate tool, that the operators may successfully use for a rapid and accurate enough evaluation of the effects of the variation of some parameters on the outgo parameters, especially for the turbine power at the machine couple, or for the gross output of the electrical generator for the turbo-generators groups.

By statement as a study objective a district heating condensing turbine, with two adjustable mashes (for example the DSL 50-1 turbine), it may be establish the following types of charts:

**1. The correction diagram of the gross electrical output related to the temperature variation of the working steam;**

**2. The correction diagram of the gross electrical output related to the pressure variation of the working steam;**

**3. The correction diagram of the gross electrical output related to the temperature variation at the industrial mash of the turbine;**

**4. The correction diagram of the gross electrical output related to the pressure variation at the district heating mash of the turbine;**

**5. The correction diagram of the gross electrical output related to the temperature variation of the cooling water in the condenser.**

In this paperwork will be presented only the equations and the characteristic functions of this five types of correction diagrams.

1. The characteristic function for the correction diagram of the gross electrical output related to the temperature variation of the working steam:

$$\Delta P = f(\Delta t_0) \quad (2.7)$$

with the equations : $\Delta P_{el} = C + I_0(\Delta t_0)\Big|_{p_u, t_u, \dot{m}_u, p_i, t_i, \dot{m}_i = ct}$ (2.7')

$$\Delta P_{el} = C + \eta_m \eta_e \sum \dot{m}_x \, \Delta i_x (\Delta t_x)_{p_0 = ct} \quad (2.7'')$$

2. The characteristic function for the correction diagram of the gross electrical output related to the pressure variation of the working steam:

$$\Delta P = f(\Delta p_0) \quad (2.8)$$

with the equations : $\Delta P_{el} = C + I_0(\Delta p_0)\Big|_{p_u, t_u, \dot{m}_u, p_i, t_i, \dot{m}_i = ct}$ (2.8')

$$\Delta P_{el} = C + \eta_m \eta_e \sum \dot{m}_x \, \Delta i_x (\Delta p_x)_{t_0 = ct} \quad (2.8'')$$

3. The characteristic function for the correction diagram of the gross electrical output related to the temperature variation at the industrial mash of the turbine:

$$\Delta P = f(\Delta p_i) \quad (2.9)$$

with the equations : $\Delta P_{el} = C + I_i(\Delta p_i)\Big|_{p_0, t_0, \dot{m}_o, p_u, t_u, \dot{m}_u = ct}$ (2.9')

$$\Delta P_{el} = C + \eta_m \eta_e \sum \dot{m}_x \, \Delta i_x (\Delta p_x)_{t_i = ct} \quad (2.9'')$$

4. The characteristic function for the correction diagram of the gross electrical output related to the pressure variation at the district heating mash of the turbine:

$$\Delta P = f(\Delta p_u) \quad (2.10)$$

with the equations : $\Delta P_{el} = C + I_i(\Delta p_u)\Big|_{p_0, t_0, \dot{m}_o, p_u, t_u, \dot{m}_u = ct}$ (2.10')

$$\Delta P_{el} = C + \eta_m \eta_e \sum \dot{m}_x \, \Delta i_x (\Delta p_x)_{t_u = ct} \quad (2.10'')$$

5. The characteristic function for the correction diagram of the gross electrical output related to the temperature variation of the cooling water in the condenser:

$$\Delta P = f(\Delta t_r) \quad (2.11)$$

with the equations : $\Delta P_{el} = C + I_c(\Delta t_r)\Big|_{p_0, t_0, \dot{m}_o, p_i, t_i, \dot{m}_i, p_u, t_u, \dot{m}_u = ct}$ (2.11')

$$\Delta P_{el} = C + \eta_m \eta_e \sum \dot{m}_c \, \Delta i_c (\Delta t_r) \quad (2.11'')$$

The generation of a mathematical model for building-up a functioning chart for a steam turbine presume a good mathematical apparatus and a large data collection collected directly from the installation in which the turbine work. Among this two aspects of the problem, it assess the necessity of a background made of rich and complex data base that include precise values of the water-steam diagram, on the base we will determinate the enthalpy, the entropy, the specific volume, the pressure, the temperature, in relation to the entry dates.

The generation of a data base containing the values of enthalpy, entropy, and specific volume, usually based on the temperature and pressure, allow, on the base of complex interpolation equations, the exact determination, at an exact time or in an exact point, of the characteristic parameters of the thermic process in the turbine blade step. Theoretically, but practically also, with the help of the calculus techniques, it can be modulated with an enough precision the stem expansion in the turbine, if we note the fact that every physical element, individually, bring his uptake for leading the thermodynamic process to a balance point.

## 3. The study of a back-pressure turbine with one adjustable mashes

Starting from the expansion diagram of the steam, for a back-pressure turbine with one adjustable mashes, in *i-s* coordinates, will obtain, for a theoretical expansion, a line between the point '0' (the steam admission into the turbine) and the point 'c' (the steam discharge at the turbine back-pressure), this being the classical steam expansion diagram into a turbine functioning under a cycles with regenerative preheating, without intermediary superheating. This diagram is close to the diagram presented by the fig. 3.1. The circulation of steam flows into the turbine, starting from $m_0$ (the steam flow), and reaching $m_{cp}$ (the steam flow at the back-pressure), is presented in the picture 3.1.

Using the flow chart as in fig. 3.2 and keeping in mind the consume equation for a turbine without mashes (3.1), we deduce the energetic balance equation for the back-pressure turbine with one mashes:

$$P = \eta_m[\dot{m}_0 h_{i1} + (\dot{m}_0 - \dot{m}_i)h_{i2}] \tag{3.1}$$

where: $hix$ – the enthalpy break-downs between the turbine compounds;
The mass balance equation will be :

$$\dot{m}_0 = \dot{m}_i + \dot{m}_{cp} \tag{3.2}$$

Developing the equation (3.1), we will obtain:

$$P = \eta_m[\dot{m}_0(i_0 - i_i) + (\dot{m}_0 - \dot{m}_i)(i_i - i_{cp})] \tag{3.3}$$

and developing the equation (3.3), after we make the calculus, we will obtain the following form of the equation (3.1), convenient for any following develops:

$$P = \eta_m[\dot{m}_0 i_0 - \dot{m}_i i_i - (\dot{m}_0 - \dot{m}_i)i_{cp}] \tag{3.4}$$

Starting from the energetic balance equation under the form (3.1), written under the form (3.4), we may deduce the equation which stays on the base of the mathematical apparatus used for the construction of gross output power for a back-pressure turbine with one mashes:

$$\Delta P = C + f(X) \tag{3.5}$$

Under this generalised form will be presented the equation which define the correction charts.

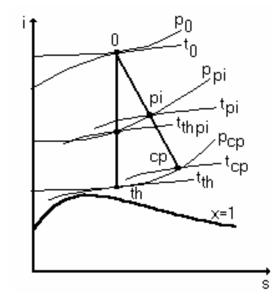


Fig.3.1 The i-s chart for the functioning cycle for the back-pressure turbine with one adjustable mashes

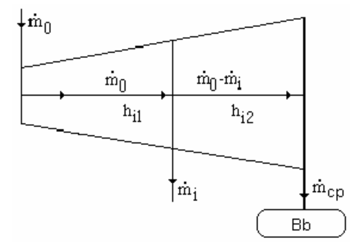


Fig. 3.2 The flow chart into the back-pressure turbine with one adjustable mashes

By considering as study object a district heating, back-pressure turbine with one adjustable mash (we considered, as example, the DKUL 50-1 turbine) we can find the following functioning diagrams:

**1. The power correction diagram in function of the pressure variation at admission;**

**2. The power correction diagram in function of the temperature variation at admission;**

**3. The power correction diagram in function of the pressure variation at industrial mashes;**

**4. The power correction diagram in function of the pressure variation at back-pressure.**

In this paperwork will be presented only the equations and the characteristic functions of this four types of correction diagrams.

1. The characteristic function for the power correction diagram in function of the pressure variation at admission:

$$\Delta P = f(\Delta p_0) \tag{3.6}$$

with the equations:

$$\Delta P_{el} = C + I_0(\Delta p_0)\Big|_{t_0, \dot{m}_0, p_i, t_i, \dot{m}_i = ct} \tag{3.6'}$$

$$\Delta P = C + \eta_m \eta_e \sum \dot{m}_x \, \Delta i_x (\Delta p_x)_{t_0 = ct} \tag{3.6''}$$

2. The characteristic function for the power correction diagram in function of the temperature variation at admission:

$$\Delta P = f(\Delta t_0) \tag{3.7}$$

with the equations :

$$\Delta P_{el} = C + I_0(\Delta t_0)\Big|_{p_0, \dot{m}_o, p_i, t_i, \dot{m}_i = ct} \tag{3.7'}$$

$$\Delta P = C + \eta_m \eta_e \sum \dot{m}_x \, \Delta i_x (\Delta t_x)_{p_0 = ct} \tag{3.7''}$$

3. The characteristic function for the power correction diagram in function of the pressure variation at industrial mashes:

$$\Delta P = f(\Delta p_i) \quad (3.8)$$

with the equations:

$$\Delta P_{el} = C + I_i(p_u)\Big|_{p_0, t_0, \dot{m}_o, p_u, t_u, \dot{m}_u = ct} \quad (3.8')$$

$$\Delta P = C + \eta_m \dot{m}_x \, \Delta i_x(\Delta p_x)_{t_i = ct} \quad (3.8'')$$

4. The characteristic function for the power correction diagram in function of the pressure variation at back-pressure:

$$\Delta P = f(\Delta p_{cp}) \quad (3.9)$$

with the equations :

$$\Delta P_{el} = C + I_i(\Delta p_u)\Big|_{p_0, t_0, \dot{m}_o, p_u, t_u, \dot{m}_u = ct} \quad (3.9')$$

$$\Delta P = C + \eta_m \eta_e \sum \dot{m}_i \, \Delta i_{cp}(\Delta p_{cp})_{t_{cp} = ct} \quad (3.9'')$$

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