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CONTRIBUTIONS TO THE STUDY OF AN AXIAL COMPRESSOR STAGE BY THE MEANS OF THE GENERALIZED REACTION DEGREE CONCEPT

Keywords: generalized reaction degree, fluid flow into a stage, axial compressor, reaction force, reaction degree.

BASIC THEORETICAL ASPECTS

For the case of a generalized nozzle, where simultaneously occur variations of mass and geometry, changes of the thermal and thermodynamical parameters, the thrust is given by the following equation:

$$T = \alpha \cdot \frac{\bar{M}^2 \cdot \bar{T}^*}{\bar{P}^*} + \beta \cdot \bar{P}^* \cdot \bar{S} + \gamma \bar{M} \cdot \sqrt{\bar{T}^*} - \delta \cdot \bar{S} + \varepsilon \tag{1}$$

where:

$$\alpha = C_1 \cdot \frac{\bar{R}}{\bar{a}} \cdot h_1 \cdot \sqrt{\bar{T}^*} \cdot q(\lambda_1) \cdot \dot{M}_1; \quad \beta = C_2 \cdot \bar{a} \cdot \bar{R} \cdot h_1 \cdot \sqrt{\bar{T}^*} \cdot \frac{1}{q(\lambda_1)} \cdot \dot{M}_1;$$

$$\gamma = C_3 \cdot \bar{R} \cdot h_1 \cdot \sqrt{\bar{T}^*} \cdot \dot{M}_1; \quad \delta = d = \frac{P_a}{P_1^*} \cdot \sqrt{\bar{T}^*} \cdot \frac{1}{q(\lambda_1)} \cdot \dot{M}_1;$$

$$\varepsilon = \delta - z(\lambda_1) \cdot h_1 \cdot \sqrt{\bar{T}^*} \cdot \dot{M}_1.$$

The reaction degree ρ_c of an axial compressor stage is defined as the parameter which appreciates the percentage from the effective work of the fluid static compression developed in the entire stage Δp_T, that is to be accomplished into the rotating blade rows Δp_R.

Considering a certain geometry of the fluid flow path inside the stage of an axial compressor, as it is shown in fig. 1, the reaction degree ρ_c could be expressed in different ways, according to the characteristics of the flow:

a) the case of the uncompressieble fluid flow

$$\rho_{c_c} = \frac{p_2 - p_1}{p_3 - p_2} = \frac{\Delta p_R}{\Delta p_T} \tag{2}$$

b) the case of the compressieble fluid flow

$$\rho_{c_i} = \frac{i_2 - i_1}{i_3 - i_2} = \frac{\Delta i_R}{\Delta i_T} \tag{3}$$

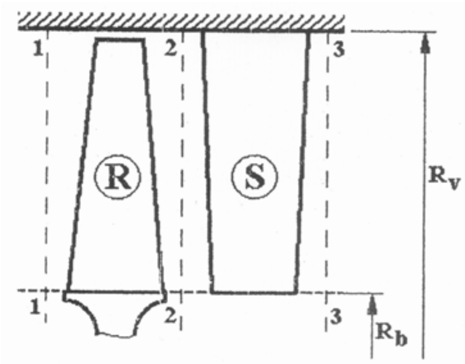


Fig. 1.

According to the principle of the thermodynamics, for the adiabatic evolutions, the variation of the entalpy is:

$$\Delta i = \int \frac{dp}{\rho} \tag{4}$$

It comes up that the variation of the entalpy Δi represents an image of the variation of the static pressure, i.e. of the fluid compression aventually; this is valid for either both the rotating part Δi_R and the entire stage Δi_T .

As it follows from (1), the pressure variation increases the fluid force which acts upon the row blades of the stage. This is the reason to define the parameter ρ_c as the reaction degree.

It is convenient to express the correlation of the reaction degree with the reaction forces developed by the blade row T_{R_R} and by the entire stage T_{R_T} . Under these circumstances, the reaction degree R_c should be redefined analityticaly in a more general way, such as

$$R_c = \frac{T_{R_R}}{T_{R_T}} \tag{5}$$

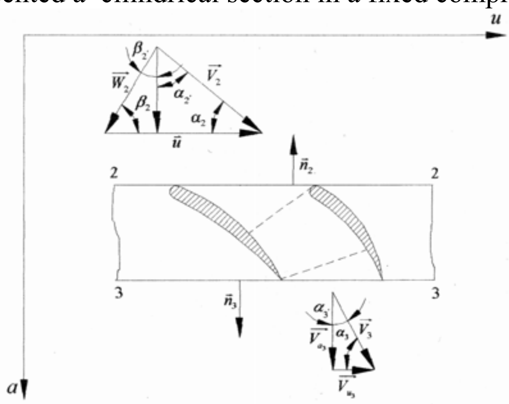
THE THRUST OF THE AXIAL FLOW COMPRESSOR STAGE

Generaly speaking, the axial fllow compressor stage consists of a mobile row which is capable to transform part of the mechanical work in energy by air breaking in blade to blade chanels and a fixed row in wich continues air compression. We will treate one at a time the thrust in both of these rows and finally we will establish the thrust of the whole stage. Now, we consider the equation of the thrust in an absolute reference system:

$$T = M_2 V_2 \cos\alpha_2^{'} - M_1 V_1 \cos\alpha_1^{'} - p_1 S_1 \cos\varphi_1 + p_2 S_2 \cos\varphi_2 + \\ + p_H (S_1 \cos\varphi_1 - S_2 \cos\varphi_2) \qquad (6)$$

The thrust developed by the stator

In fig. 2 it is represented a cilindrical section in a fixed compressor row.



Using (6), it results the relation for the trust of the stator:

$$T_s = M_3 V_3 \cos\alpha_3^{'} - M_2 V_2 \cos\alpha_2^{'} - p_2 S_2 \cos\varphi_2 + p_3 S_3 \cos\varphi_3 + \\ + p_H (S_2 \cos\varphi_2 - S_3 \cos\varphi_3) \qquad (7)$$

where the reaction T_{SR} and pressure T_{SP} components are:

$$T_{SR} = M_3 V_3 \cos\alpha_3^{'} - M_2 V_2 \cos\alpha_2^{'} \qquad (8)$$

and

$$T_{SP} = p_3 S_3 \cos\varphi_3 - p_2 S_2 \cos\varphi_2 + p_H (S_2 \cos\varphi_2 - S_3 \cos\varphi_3)$$

or

$$T_{SP} = S_3(p_3 - p_H)\cos\varphi_3 - S_2(p_2 - p_H)\cos\varphi_2 \tag{9}$$

In fig.2 the deviations angles of n_2 and n_3 refered to axial *r-a* plane are nuls: $\varphi_2=\varphi_3=0$
The thrust components of the stator are:

$$T_{SR} = M_3 V_3 \cos\alpha_3^{'} - M_2 V_2 \cos\alpha_2^{'}$$

and

$$T_{SP} = S_3(p_3 - p_H) - S_2(p_2 - p_H) \tag{10}$$

We mention that in the stator there is no fluid mass apport and for the mass flow in the fundamental sections it is valable the relation:

$$M_2 = M_3 = M \tag{11}$$

The expresions of the two components of the thrust (reaction and pressure) are:

$$T_{SR} = M(V_3 \cos\alpha_3^{'} - V_2 \cos\alpha_2^{'} \tag{12}$$

$$T_{SP} = S_3 p_3 - S_2 p_2 - p_H(S_2 - S_3) \tag{13}$$

If the axial component of the absolute speed is an invariant $(V_{a1}= V_{a2}= V_{a3}= V_a)$ then:

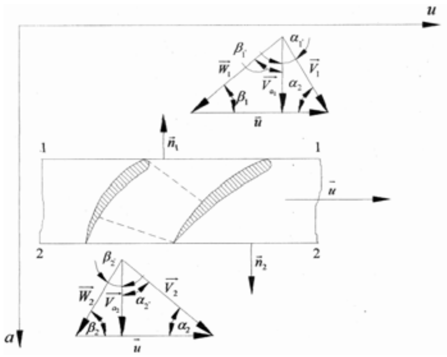
$$V_1 \cos\alpha_1^{'} = V_2 \cos\alpha_2^{'} = V_3 \cos\alpha_3^{'} \tag{14}$$

and the reaction component of the thrust of the stator is T_{SR}=0.
In this case, the force applied on the stator is:

$$T_S = T_{SP} = S_3(p_3 - p_H) - S_2(p_2 - p_H) \tag{15}$$

2.2 The thrust developed by the rotor

The geometry of the mobile row is presented in fig.3.



Using (6) applied in a mobile reference system:

$$T_R = M_2 W_2 \cos\beta_2^{'} - M_1 W_1 \cos\beta_1^{'} - p_1 S_1 \cos\varphi_1 + p_2 S_2 \cos\varphi_2 + \\ + p_H\left(S_1 \cos\varphi_1 - S_2 \cos\varphi_2\right) \tag{16}$$

It could be also use the assumption $\varphi_1=\varphi_2=0$ and in this case, the expressiomn of the thrust of the rotor is:

$$T_R = M_2 W_2 \cos\beta_2^{'} - M_1 W_1 \cos\beta_1^{'} - S_1\left(p_1 - p_H\right) + S_2\left(p_2 - p_H\right) \tag{17}$$

The expressions of the two components T_{RR} (the reaction component) and T_{RP} (the pressure component) are:

$$T_{RR} = M_2 W_2 \cos\beta_2^{'} - M_1 W_1 \cos\beta_1^{'} \tag{18}$$

$$T_{RP} = S_2\left(p_2 - p_H\right) - S_1\left(p_1 - p_H\right) \tag{19}$$

If there is no fluid mass apport, we have:

$$M_1 = M_2 = M \tag{20}$$

and the reaction component could be write as:

$$T_{RR} = M\left(W_2 \cos\beta_2^{'} - W_1 \cos\beta_1^{'}\right) \tag{21}$$

If the axial component of the absolute speed is an invariant then:

$$W_1 \cos\beta_1^{'} = W_2 \cos\beta_2^{'} = V_a = ct. \tag{22}$$

and T_R =0

Then, the thrust developed by the rotor is the result of the thrust obtained by air compression in blade to blade chanels:

$$T_R = T_{RP} = S_2(p_2 - p_H) - S_1(p_1 - p_H) \tag{23}$$

THE GENERALISED REACTION DEGREE

The reaction degree is, by definition, give as a solution of (3) in which, the reaction component is given by (21) and the reaction component of the stage thrust is given by:

$$T_{RT} = T_{RR} + T_{SR} \tag{24}$$

where T_{SR} is given by (12).

CONCLUSIONS

The generaliyed degree of reaction R being a function of the ratio l^*c/i^* depends mainly on the magnitude of the mechanical work on the compression l^*c and the value of the pressure ratio π_c^*, respectively and it is influenced by the ambient and flight conditions (in terms of pressure, temperature and flight speed) by the means of the total enthalpy, l_l^*.
It folows up that a more general way to optimiye the flow into an axial stage of a compressor is to take into consideration the relation between the mechanical work on compression and the generaliyed degree of reaction.

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