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FUNCTION OF THE AERODYNAMIC BLADE LOADING AS THE CRITERION TO THE DESIGN OF THE CENTRIFUGAL IMPELLER

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SUMMARY

The general outline of function of the aerodynamic blade cascade loading of centrifugal impeller was considered as a criterion of its rational designing. It was proved that the distribution of function of aerodynamic load along the radius has significant influence on the efficiency and performance characteristics of impellers.

INTRODUCTION

The classical methods of designing centrifugal impellers of fans, pumps and compressors are fundamentally based on the accumulated empirical material and principally resolve themselves into calculating geometry in inlet and outlet section of a row of blades. The very blade on the other hand, is formed after circular arc. This form, however, has no rational justification as far as aerodynamics of flow is concerned. Also in a number of cases the divergence from circular form does not even influence the valuation of the producibility of impellers.

At that very moment the problem of defining criteria arises which would in a synthetic way characterize the flow and which could, in a suitable form for the constructors, be applied to evaluate the geometry of blade cascade. The presented general outline of function of the aerodynamic blade loading of centrifugal impeller according to the definition

$$\Delta\pi = \frac{\Delta p}{\frac{1}{2}\varrho w^2} \tag{1}$$

serves as a suggestion of such a criterion.

The dimensionless function $\Delta\pi = f(r)$ is defined as a ratio of the static pressure difference Δp on both sides of a blade to the dynamic pressure of stream filament in a section with the radius r (fig. 1). The values expresed in $\Delta\pi$ function, i.e. the mean relative velocity

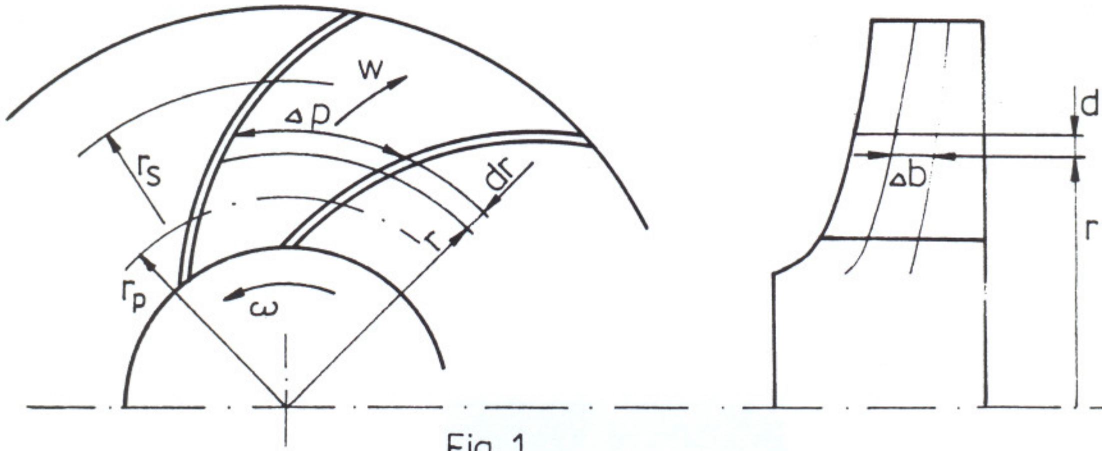


Fig. 1

"w" and the static pressure difference "Δp", are the most important parameters characterizing the flow in the rotating vane passage. The values "w" and " p", i.e. also the function Δπ, can be calculated by means of various methods. Below a relatively simple algorithm of the calculations of Δπ function, is presented.

THE ALGORITHM OF THE CALCULATIONS OF AERODYNAMIC LOAD FUNCTIONS

The initial equation is Euler's equation of motion

$$\frac{d\bar{c}}{dt} = -\frac{1}{\varrho}\,\mathrm{grad}p, \qquad (2)$$

which for peripheral direction can be written in the form

$$c_r\,\frac{d(rc_u)}{dr} = -\frac{1}{\varrho}\,\frac{\partial p}{\partial \varphi} \qquad (3)$$

Passing on to difference approximation of the above differential equation, one obtains

$$-\frac{1}{\varrho}\,\frac{\partial p}{\partial \varphi} \approx \frac{1}{\varrho}\,\frac{\Delta p}{\Delta \varphi} = c_r\,\left.\frac{d(rc_u)}{dr}\right|_m \qquad (4)$$

The "m" index denotes that a given value is calculated in the middle of the vane passage.

Taking into consideration that the finite result of the angular pitch comprises the vane passage i.e. that

$$\Delta\varphi = \frac{2\pi\tau}{z} \tag{5}$$

and taking no account of the "m" index, one finally obtains

$$\Delta p = \frac{2\pi\tau}{z} c_r \frac{d(rc_u)}{dr} \tag{6}$$

In the above formula the following values appear:

ϱ - mass density

z - number of blades

τ - tangential blockage factor, defined as

$$\tau = 1 - \frac{zg}{2\pi} \tag{7}$$

where g is angular blade thickness on the radius "r",

c_u - tangential celocity which is calculated from the formula

$$c_u = u - c_r \mathrm{ctg}\beta, \tag{8}$$

c_r - radial velocity which is calculated from the equation of stream continuity.

The introduced notion of function of the aerodynamic blade loading refers fundamentally to stream filament the width of which $\Delta b = \Delta b(r)$ and then the equation of continuity has the form:

$$m = 2\pi r \tau \varrho c_r \Delta b \tag{9}$$

For single curvature blades the calculations can be carried out for the stream comprising the whole width of the impeller. Then the equation of continuity is applied in the following form:

$$\dot{m} = 2\pi r \tau \varrho b c_r \tag{9a}$$

The mean relative velocity "w" which is indispensable to calculate $\Delta\pi$ function according to the formula (1), is calculated from the self--ewident dependence

$$w = c_r/\sin\beta \tag{10}$$

The assignment of the distribution of the mean flow angle $\beta = \beta(r)$ requires certain assumptions. Thus it is suggested here to distinguish three zones (fig. 1) in which the angle of the stream β will be described by the dependencies resulting from various premises. In the middle zone the angle of the stream can be assumed as equal to the vane angle, where-as in the inlet and outlet zones, the angle of the stream will be the resultant of the reaction of the blades and of the flow conditions at the rotor inlet and outlet. The particular zones are separated by r_p radius from which it is assumed that the influence of the conditions in the entry to the row decays. The zones are also separated by r_S radius which is the so-called STANITZ-radius [1]. The r_p radius can be approximately defined by means of the following dependence

$$r_p = r_1\left(1 + \frac{\pi}{z}\sin 2\beta_1^*\right) \tag{11}$$

where β_1^* is the vane angle in the inlet.

Finally in the specified three zones as far as the distribution of mean flow angle $\beta = \beta(r)$ is concerned, one can assume the following assumptions:

$$\begin{aligned}
&- \text{for} \quad r < r_p; && \beta = a_1 + b_1 r + c_1 r^2 \\
&- \text{for} \quad r_p < r < r_S; && \beta = \beta^* \\
&- \text{for} \quad r > r_S; && \beta = a_2 + b_2 r + c_2 r^2
\end{aligned} \tag{12}$$

The coefficients a_1, b_1, c_1, a_2, b_2, c_2 are calculated correspondingly in virtue of the following conditions: the angle of the stream in the inlet or outlet, the vane angles in the section with r_p or r_S radius, as well as the derivative values of the vane angle in the same sections.

If in the case of the inlet angle of the stream β_1, its imposed value is the kinematics of flow, then in the case of the outlet angle of the stream β_2, its value must result from satisfying Kutta-Joukowski condition. The value of β_2 angle is thus defined here by means of iteration so as to satisfy the condition $\Delta p = 0$ in the outlet section.

The presented algorithm of calculations enables one to ascertain that the distribution of the function of the aerodynamic blade loading of the centrifugal impeller is dependent on:

- the form of the blade
- the geometry of the impeller in the meridional section
- the number of the blades of the impeller
- the thickness of the blades
- the working point of the impeller.

EXAMPLES OF THE APPLICATION OF THE FUNCTION OF THE AERODYNAMIC LOADING

In order to illustrate the influence of the form of the blade on the distribution of the aerodynamic loading function, the impeller with the blades of the same inlet and outlet angles (β^*_1 and β^*_2), was considered. The first time the blades were formed by the circular arc, the second time, however, according to the dependence $\mathrm{tg}\, \beta^* = a + b\nu^2$ (where $\nu = r/r_2$). The distribution of the vane angles was shown in fig. 2 whereas the distribution of the function of the aerodynamic blade loading was presented in fig. 3. As far as the same impellers are concerned, additionally fig. 4 and 5 show the formation of $\Delta\pi$ function in the case of three values of volumetric flow coefficient.

The data named in the paper [2] are another example pointing to the advisability of the application of the aerodynamic loading function in the process of designing. Experimental investigations of impellers were carried out in the above mentioned paper. These impellers had the same inlet vane angle $\beta^*_1 = 30^\circ$ and outlet angle

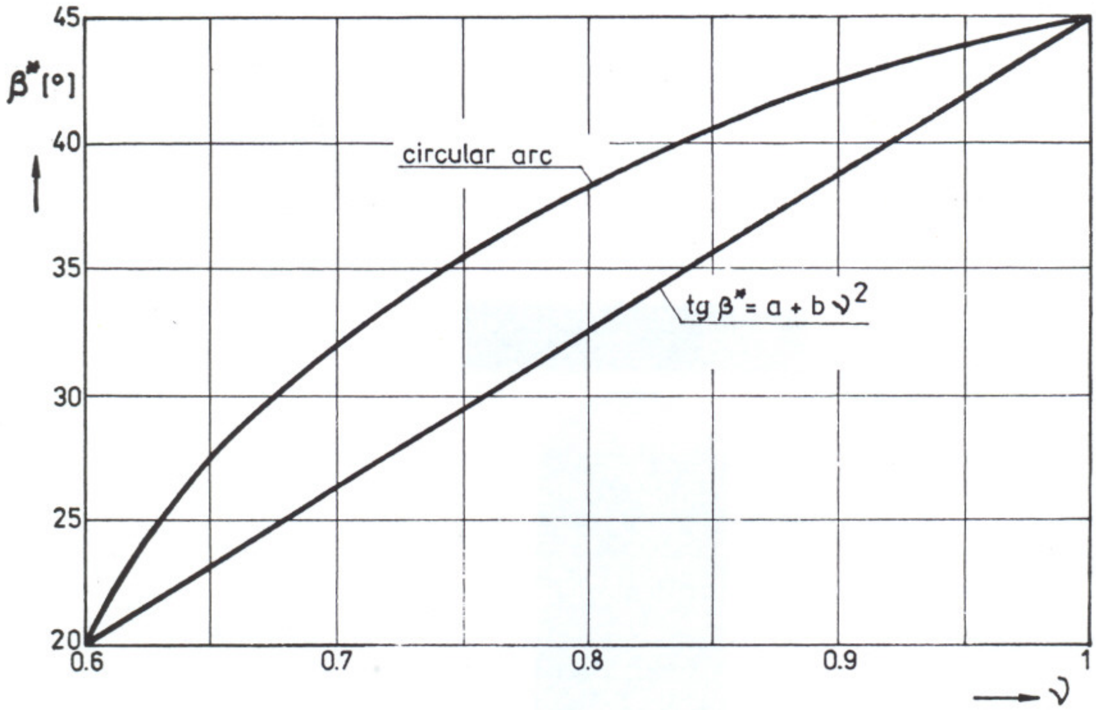

45
β^* [°]
40
35
30
25
20
circular arc
tg β^* = a + b ν^2
0.6
0.7
0.8
0.9
1
ν

Fig. 2

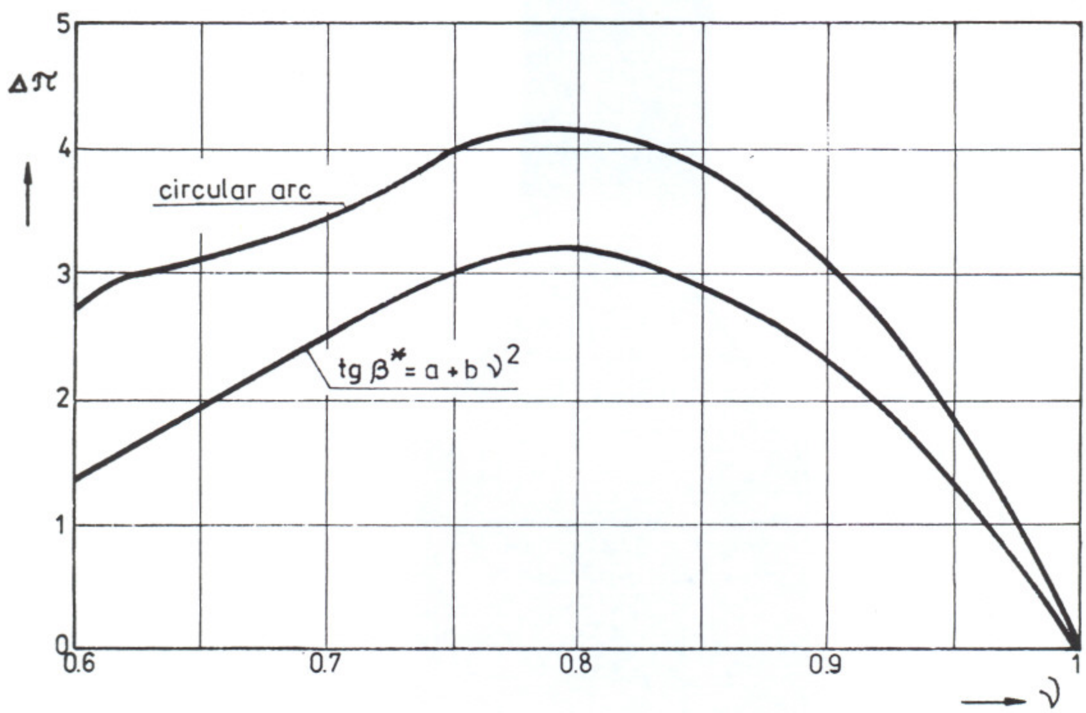
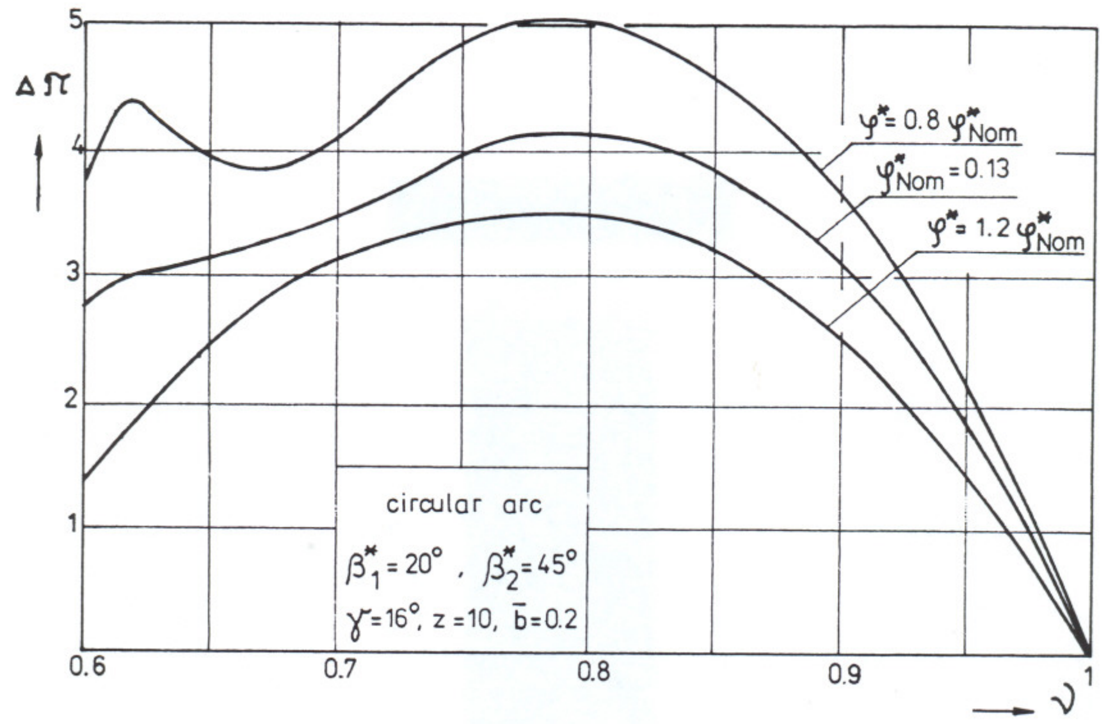
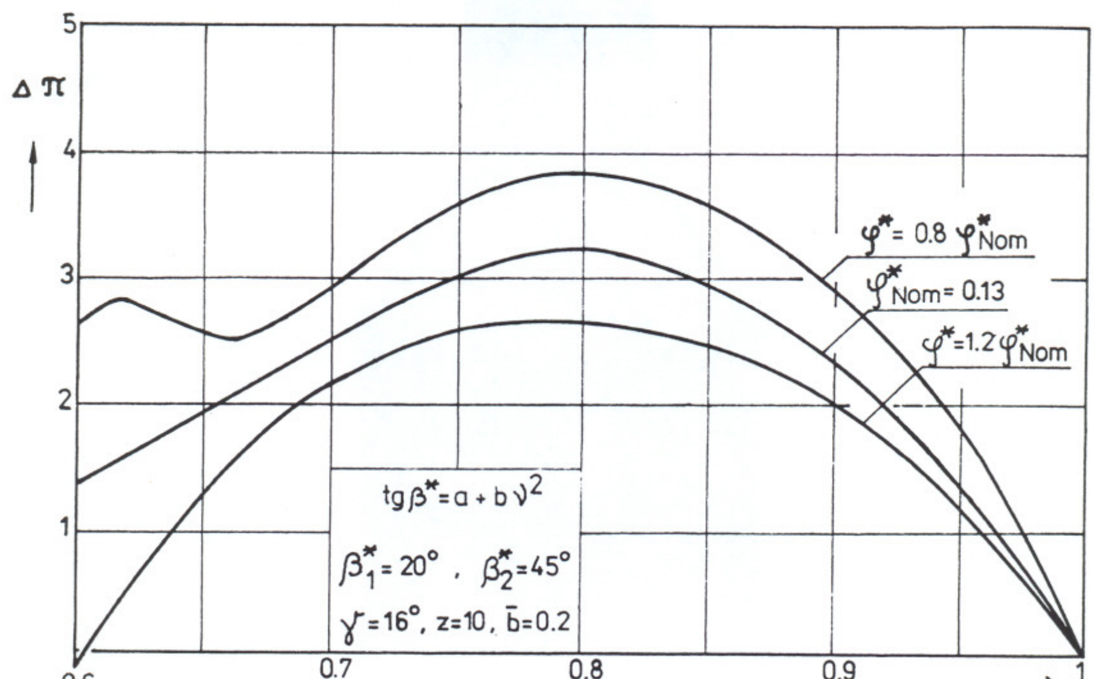

5
$\Delta\pi$
4
3
2
1
0
circular arc
tg β^* = a + b ν^2
0.6
0.7
0.8
0.9
1
ν

Fig. 3



Δπ
φ* = 0.8 φ*Nom
φ*Nom = 0.13
φ* = 1.2 φ*Nom
circular arc
β*1 = 20° , β*2 = 45°
γ = 16°, z = 10, b̄ = 0.2
0.6
0.7
0.8
0.9
1
ν

Fig. 4



Δπ
φ* = 0.8 φ*Nom
φ*Nom = 0.13
φ* = 1.2 φ*Nom
tg β* = a + b ν²
β*1 = 20° , β*2 = 45°
γ = 16°, z = 10, b̄ = 0.2
0.6
0.7
0.8
0.9
1
ν

Fig. 5

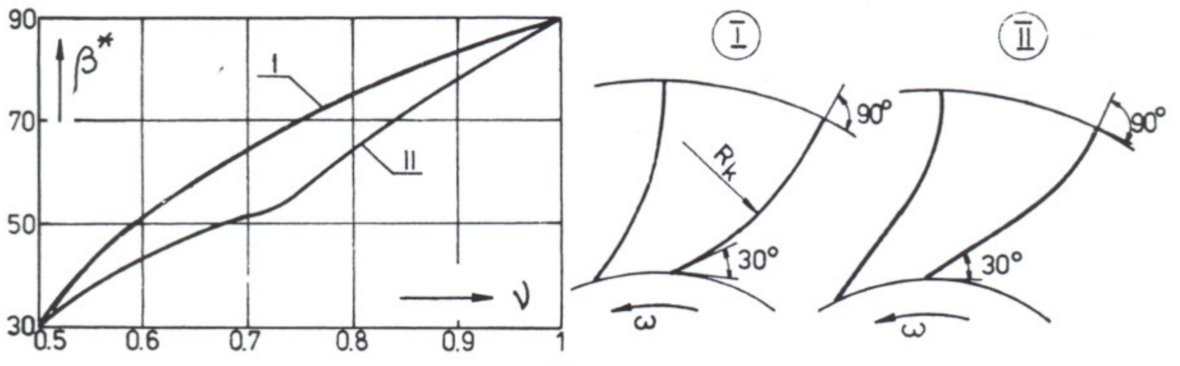


Fig. 6

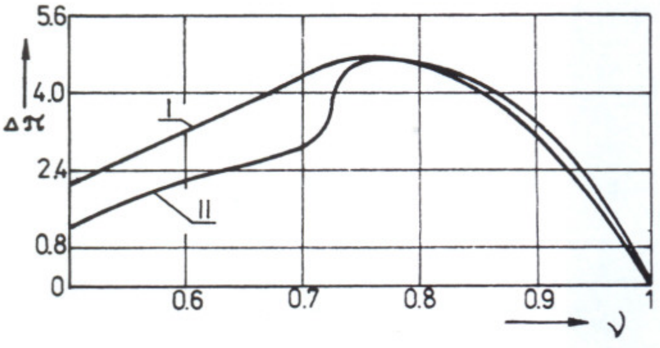


Fig. 7

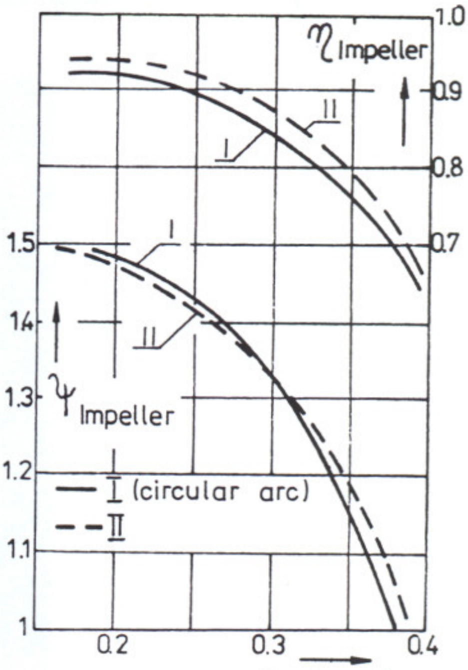


Fig. 8 $\varphi_{2r} = c_{2r}/u_2$

$\beta_2^* = 90^\circ$, whereas the distribution of the vane angle along the radius trended variously, which was presented in fig. 6. The distribution of the aerodynamic loading function calculated for this case, was shown in fig. 7, whereas the performance characteristic of impellers was named in fig. 8.

CONCLUSIONS

The estimation of the function of aerodynamic loading requires the accumulation of the suitable evidence, which is already possible to do making use of the results of measurements concerning the performance characteristics of various impellers.

The investigations which have been carried out hitherto, have made it possible to formulate the following hypotheses:

- there is a boundary, maximum value of $\Delta\pi$ function of loading, the overstepping of which causes a considerable reduction of the impeller efficiency: According to preliminary valuations this maximum (permissible) value $\Delta\pi$ trends on the level about 3.
- out of two impellers of a similar, maximum aerodynamic loading exceeding the boundary value $\Delta\pi = 3$, the impeller giving evidence of a lower value of the function of loading in the inlet section will be characterized by higher efficiency (see fig. 7 and 8).

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