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PROGRAM FOR DETERMINATION OF UNEQUAL SPECIFIC WORK DISTRIBUTION OF ELEMENTARY STAGES IN THE LOW-PRESSURE AXIAL FLOW FAN DESIGN PROCEDURE

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Abstract. *In order to minimize the spatial curvature of the fan blades and fan hub length, a method for designing low-pressure axial flow fans using different specific work of all elementary stages is recommended and presented in this paper, instead of the common practice method of defining equal specific work of all elementary stages in the fan runner. The paper also gives the distribution function of specific work of all elementary stages, according to which averaged axisymmetrical flow surfaces of the fan runner have a negligibly small deviation from the cylindrical flow surfaces. In a given distribution function, the specific work of elementary stages near the fan hub can be reduced up to 60% with no significant influence on the fan axisymmetry. Finally, a computational code developed for calculation of the elementary stage specific work for known operating parameters of the fan runner and some predefined initial values (r_o, $y_{k,i}$) is presented.*

Key words: *Axial Flow Fan, Elementary Stages, Specific Work*

1 INTRODUCTION

The most usual design of low-pressure axial flow fan comprise only a fan runner. Therefore, the kinetic energy of circumferential component of absolute flow velocity at fan outlet ($c_{u2}^2/2$, where c_{u2} is a circumferential component of absolute velocity in the fan outlet) is permanently lost in the flow space behind the fan runner. Formally this loss can be added to the total mechanical energy losses of the fan, causing the largest nominal (i.e. maximal) hydraulic efficiency 65% [1].

One of the basic assumptions of turbomachinery designing is axisymmetrical flow surfaces. Elementary stage represents a flow space between elementary immediate axisymmetrical flow surfaces while the intersection of axisymmetrical flow surface S_m and blades defines the blade profile cascade of the elementary stage (Fig. 1).

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The common practice for designing axial flow fans is to obtain an equal specific work of all elementary stages, in order to maintain cylindrical or nearly cylindrical flow surfaces in the fan runner [2,3,4]. According to this principle, the fan blade profiles near the fan hub have a significantly larger inclination angle and a larger arc curvature than the blade profiles at the fan runner periphery. It produces substantially larger c_{u2} near the fan hub than at the fan runner periphery. Therefore, in order to minimize the spatial curvature of the fan blades and fan hub length, and to reduce the kinetic energy of the circumferential component of absolute velocity at the fan outlet, it is possible to design the low-pressure axial fan runner with different specific work of elementary stages. The designing principle suggested in this paper recommends employment of smaller specific work of elementary stage at the fan hub than at the fan periphery.

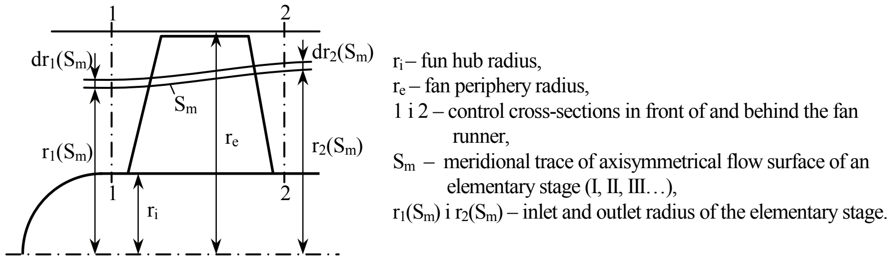

Fig. 1 The schema of meridional cross-section of a fan runner

The flow space of the fan runner can be split into an infinite number of elementary stages, but in order to determinate the fan blade shape it is sufficient to determine blade profiles at 7 to 12 elementary stages, which are approximately evenly distributed along the blade height. Flow values in control cross-sections in front of and behind the fan runner are denoted as 1 and 2 (p_1, c_1 and p_2, c_2), and if flow values are related to the elementary stage it is also specified (for example $p_1(S_m)$, $c_1(S_m)$, S_m= I, II, III,…) [5]. Control cross-sections in front of (1) and behind (2) the fan runner are placed far enough from the blade runner; therefore, it can be assumed that flow parameters of the cross-sections do not depend on circumferential coordinate ($\partial p_{1,2} / \partial \varphi = 0$, $\partial c_{1,2} / \partial \varphi = 0$).

Due to negligible changing of the gas density flowing through the low-pressure fan, it can be written $\rho_1 = \rho_2 = \rho = \text{const.}$

For the fan runner construction $p_{t_1} = \text{const.}$ and $c_{u1} = \text{const.}$ (axial inlet flow).

The specific work of the fan runner elementary stage is (Euler's equation for tubomachinery):

$$y_k(S_m) = \omega \cdot r_2(S_m) \cdot c_{u_2}(S_m) = u(S_m) \cdot c_{u_2}(S_m)_2, \quad \text{if } c_{u1} = 0 . \tag{1}$$

The total pressure increase in the elementary stage is:

$$\Delta p_t(S_m) = p_{t_2}(S_m) - p_{t_1}(S_m) = p_{t_2}(r_2(S_m)) - p_{t_1} = \eta_h(S_m) \cdot \rho \cdot y_k(S_m), \tag{2}$$

Then the hydraulic efficiency of elementary stage $\eta_h(S_m)$ can be written in the form:

$$\eta_h(S_m)=\frac{\Delta p_t(S_m)}{\rho y_k(S_m)}=1-\frac{\Delta y_g(S_m)}{y_k(S_m)},$$

where $\Delta y_g(S_m)=\Delta y_{g_{1-2}}(S_m)$ is mechanical loss of flow energy in the elementary stage of the fan runner.

When designing the fan runner according to the model of equal specific work of elementary stages ($y_k(S_m)=\text{const.}=y_k^+$, y_k^+ – designed specific work of the fan runner), when the flow surfaces are cylindrical (r=const.), the assumption is that hydraulic efficiency of elementary stages are equal ($\eta_h(S_m)=\text{const.}=\eta_h^+$, η_h^+ – designed hydraulic efficiency of the fan). This assumption, in the rough approximation, also retains in designing model of different specific work of elementary stages (proposed in this paper) [6].

The flow rate of the gas flowing through the flow space between the fan hub and the axisymmetrical flow surface S_m, $(Q(r(S_m)))$, is represented in the form:

$$Q(r(S_m))=2\pi\int_{r_i}^{r_1(S_m)} c_{z_1}(r)r\mathrm{d}r=2\pi\int_{r_i}^{r_2(S_m)} c_{z_2}(r)r\mathrm{d}r, \tag{3}$$

where c_{z_1} and c_{z_2} are distribution functions of axial component of flow velocity in control cross-sections in front of and behind the fan runner, and have to fulfill the requirement:

$$Q=2\pi\int_{r_i}^{r_e} c_{z_1}(r)r\mathrm{d}r=2\pi\int_{r_i}^{r_e} c_{z_2}(r)r\mathrm{d}r. \tag{4}$$

For known function $y_k(r)$, the specific work of the fan runner can be calculated by the formula:

$$Y_k=\frac{1}{Q}\int_{A_2} y_k(r)\cdot \mathrm{d}Q=\frac{1}{Q}\left(2\pi\int_{r_i}^{r_e} y_k(r)c_{z_2}(r)r\mathrm{d}r\right). \tag{5}$$

2 OBTAINING CYLINDRICAL FLOW SURFACES IN THE CONTROL CROSS-SECTION IN FRONT OF AND BEHIND THE FAN RUNNER

Control cross-sections are placed in the space which is physically bounded by cylindrical surface of the fan hub (r_i=const.) and the fan shroud (r_e=const.), as shown in Fig. 1. It is eligible to obtain profile leading edge curvature $K\leq 1/r_i$.

The equation of steady fluid flow of the inviscous fluid can be written in the form:

$$-[\vec{c},\mathrm{rot}\vec{c}]=-\frac{1}{\rho}\mathrm{grad}p_t. \tag{6}$$

The previous equation (6), for the flow on cylindrical surfaces ($c_r=0$, $\vec{c}=c_u\vec{u}^o+c_z\vec{z}^o$), becomes:

$$c_z\frac{\partial c_z}{\partial r}+\frac{c_u}{r}\frac{\partial(rc_u)}{\partial r}=\frac{1}{\rho}\frac{\partial p_t}{\partial r}. \tag{7}$$

Consequently, for gas flow in front of the fan runner $c_{u_1} = 0$, $p_{t_1} = \text{const}$, and equation (7) becomes: $\partial c_z / \partial r = 0$, i.e. $c_{z_1} = \text{const}$.

If all elementary stages of the fan runner operates with equal hydraulic efficiency, and $y_k(S_m) = y_k(r)_2$, the total pressure in the control cross-section of the fan runner is:

$$p_{t_2}(r) = p_{t_1} + \rho\eta_h y_k(r)_2 . \tag{8}$$

Therefore,

$$c_{u_2} = \frac{1}{r\omega} y_k(r)_2 . \tag{9}$$

For obtaining cylindrical surfaces in the control cross-sections behind the fan runner (for $p_t=p_{t2}$, $c_z=c_{z2}$, $c_u=c_{u2}$) equation (7) modifies as follows:

$$c_{z_2}\frac{\partial c_{z_2}}{\partial r} = \left(\eta_h - \frac{1}{r^2\omega^2} y_k(r)\right)\frac{\partial y_k(r)}{\partial r} . \tag{10}$$

where: $\eta_h - y_k(r)/(r^2\omega^2) > 0$.

Analysis of equation (10) shows [6] that if specific work of elementary stages changes, $\partial y_k(r) / \partial r > 0$, then $\partial c_{z_2}(r) / \partial r > 0$. For $c_{z1} = \text{const.}$ it is obtained $r_2(S_m) > r_1(S_m)$, which leads to the conclusion that cylindrical flow surfaces in the cross-sections in front of and behind the fan runner do not remain cylindrical inside the fan runner.

3 FUNCTION $y_k(r)$

In order to obtain the reduced specific work of elementary stages near the fan hub, and to achieve a nearly cylindrical flow surface inside the fan runner, it is suggested that the following distribution function of elementary stages specific work [6]:

$$\left.\begin{aligned} & y_k(r) = A + 2r_oB\cdot r - B\cdot r^2, \quad \text{for } r_i \le r \le r_o \\ & \text{and} \quad y_k(r) = y_{k.o} = \text{const.}, \quad \text{for } r_o \le r \le r_e \end{aligned}\right\} \tag{11}$$

where, $\partial y_k(r) / \partial r = 0$, for $r = r_o$.

Function $y_k(r_o)$ is defined according to previously accepted parameters r_o and $y_{k.i} = y_{k.i}(r_i)$, and the recommendation for choosing these values is:

$$r_o \le \frac{1}{2}(r_i + r_e) \quad \text{and} \quad y_{k.i} = (0{,}6 \div 0{,}7)Y_k^+ .$$

Calculations showed that with each value r_o and $y_{k.i}$, accepted according to the previous recommendation, flow surfaces inside the fan runner slightly deviate from the cylindrical surfaces.

The graph of function $y_k(r)$, defined by equation (11) is shown in Fig.2.

The unknown value of specific work $y_{k.0}$, can be determined according to the requirement that the specific work obtained by equation (5) is equal to the nominal specific work of the fan runner.

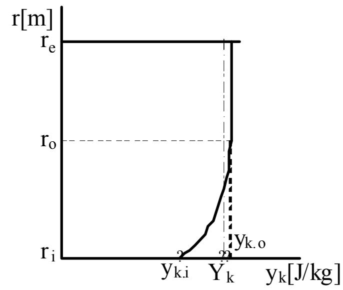

Fig 2 Function $y_k(r)$

Value $y_{k.0}$ can be determined only by using the iterative procedure, where, respectively $y_k(r)$, coefficient A and B (equation (11)) can be calculated by using the formula:

$$B = \frac{y_{k.o} - y_{k.i}}{(r_o - r_i)^2} \quad \text{and} \quad A = y_{k.o} - r_o^2 B\,. \tag{12}$$

Assuming that flow surfaces are cylindrical in control cross-section behind the fan runner, due to equations (10) and (11) is obtained:

$$\left.\begin{array}{l} \dfrac{\partial c_{z_2}^2}{\partial r} = \alpha - \beta \cdot r + \dfrac{\gamma}{r} - \dfrac{\delta}{r^2}, \quad \text{for } r_i \le r \le r_o \\ \text{and } \; c_{z_2} = \text{const.} = c_{z_2}(0), \quad \text{for } r_o \le r \le r_e \end{array}\right\} \tag{13}$$

where coefficients are:

$$\alpha = 4r_o B\left(\eta_h + \frac{3B}{\omega^2}\right),\ \beta = 4B\left(\eta_h + \frac{B}{\omega^2}\right),\ \gamma = 4B\frac{A - 2r_o^2 B}{\omega^2} \text{ and } \delta = \frac{4r_o AB}{\omega^2} \tag{14}$$

Integral of first equation (13), where $c_{z_2}(r_o) = c_{z_2}(0)$, becomes:

$$c_{z_2}(r) = \sqrt{(c_{z_2}(0))^2 - \alpha(r_o - r) + \frac{1}{2}\beta(r_o^2 - r^2) - \gamma \ln\frac{r_o}{r} + \delta\left(\frac{1}{r} - \frac{1}{r_o}\right)}\,. \tag{15}$$

An unknown value of velocity $c_{z_2}(0)$ (axial component of flow velocity in the part of the control cross-section $r_o \le r \le r_e$ behind the fan runner) can be defined according to the requirement that the flow rate calculated by equation (4) is equal to the designed flow rate of the fan ($Q = Q^+$). Function $c_{z_2}(r)$ is dependent on value $y_{k.o}$ and equations (4) and (5), used in the iterative procedure of determination $y_{k.o}$ and $c_{z_2}(0)$, can be now derived into forms:

$$Q = 2\pi\int_{r_i}^{r_o} c_{z2}(r)r\,dr + \pi c_{z_2}(0)(r_e^2 - r_o^2)\,, \tag{16}$$

$$Y_k = \frac{1}{Q}2\pi\int_{r_i}^{r_o} y_k(r)c_{z_2}(r)r\,dr + \frac{1}{Q}(\pi y_{k.o} c_{z_2}(0)(r_e^2 - r_o^2))\,, \tag{17}$$

4. The Algorithm and Computer Code for Calculation of Values $y_{k.0}$ and $c_{z2}(0)$

Values $y_{k.o}$ and $c_{z_2}(0)$ can be determined only by iterative procedure, and it is a double iterative procedure, since in each step of determining $y_{k.o}$ it should be determined $c_{z_2}(0)$ as well using another iterative procedure.

In order to reduce the number of iterative steps for determining $y_{k.o}$, this value is obtained in the first iterative step, using formula:

$$y_{k.o}^{(1)} = \frac{Y_k^+ - k \cdot y_{k.i}}{1-k}, \tag{18}$$

where $k=k(r_o, r_i, r_e)$: $$k = \frac{r_o^2(r_o^2 - r_i^2) + 0,5(r_o^4 - r_i^4) - 1,333 r_o (r_o^3 - r_i^3)}{(r_e^2 - r_i^2)(r_o - r_i)^2}. \tag{18'}$$

The assumption is that the axial components of flow velocities in the control cross-section behind the fan runner change negligible (for c_{z_2}= const. $=\overline{c}_z$). Using value $y_{k.o}^{(1)}$, the procedure of determining $y_{k,0}$ is finished in maximum of two iterative steps, due to small changing of $c_{z_2}(r)$ values, compared to specific work $y_k(r)$ changing.

A correction of $y_{k.o}$ value is performed in every iterative step, and due to the formula (17) the calculated Y_k slightly differs from Y_k^+ ($\left|Y_k - Y_k^+\right| / Y_k^+ \le 0,005$).

In each iterative procedure of determining $y_{k,0}$ value $c_{z_2}(0)$ is also obtained by iterative procedure. In the first iterative step it can be taken $c_{z_2}(0) = 1,2\overline{c}_z$, where:

$$\overline{c}_z = Q^+ / [\pi(r_e^2 - r_i^2)]. \tag{19}$$

A correction of $c_{z_2}(0)$ value is performed in iterative steps, if the calculated flow rate Q (formula (16)) slightly differs from Q^+ ($\left|Q - Q^+\right| / Q^+ \le 0,005$). Integrals in formulas (16) and (17) are calculated using a trapezoid rule, whereat in the integration area $(r_o - r_i)$ calculation points are distribute for the iterative step i = 0,0001m (0,1mm). In the created numerical code (using C#), besides calculated values $y_{k.0}$ and $c_{z_2}(0)$, values $y_k(r)$, $c_{z_2}(r)$ and $Q(r)$ (for $r \in [r_i, r_o]$) are also printed for each iterative step. According to data for Q(r) a functional relation of cylindrical axisymmetrical flow surface radius in front of and behind the fan runner [6] can be established. Relation $r / r_1(r)$ can be used to evaluate a deviation between the axisymmetrical and the cylindrical flow surfaces:

$$r_1(r) = \sqrt{r_i^2 + \frac{Q(r)}{\pi \overline{c}(z)}}. \tag{20}$$

An algorithm for calculation $y_{k.0}$ and $c_{z_2}(0)$ is represented in Fig. 3.

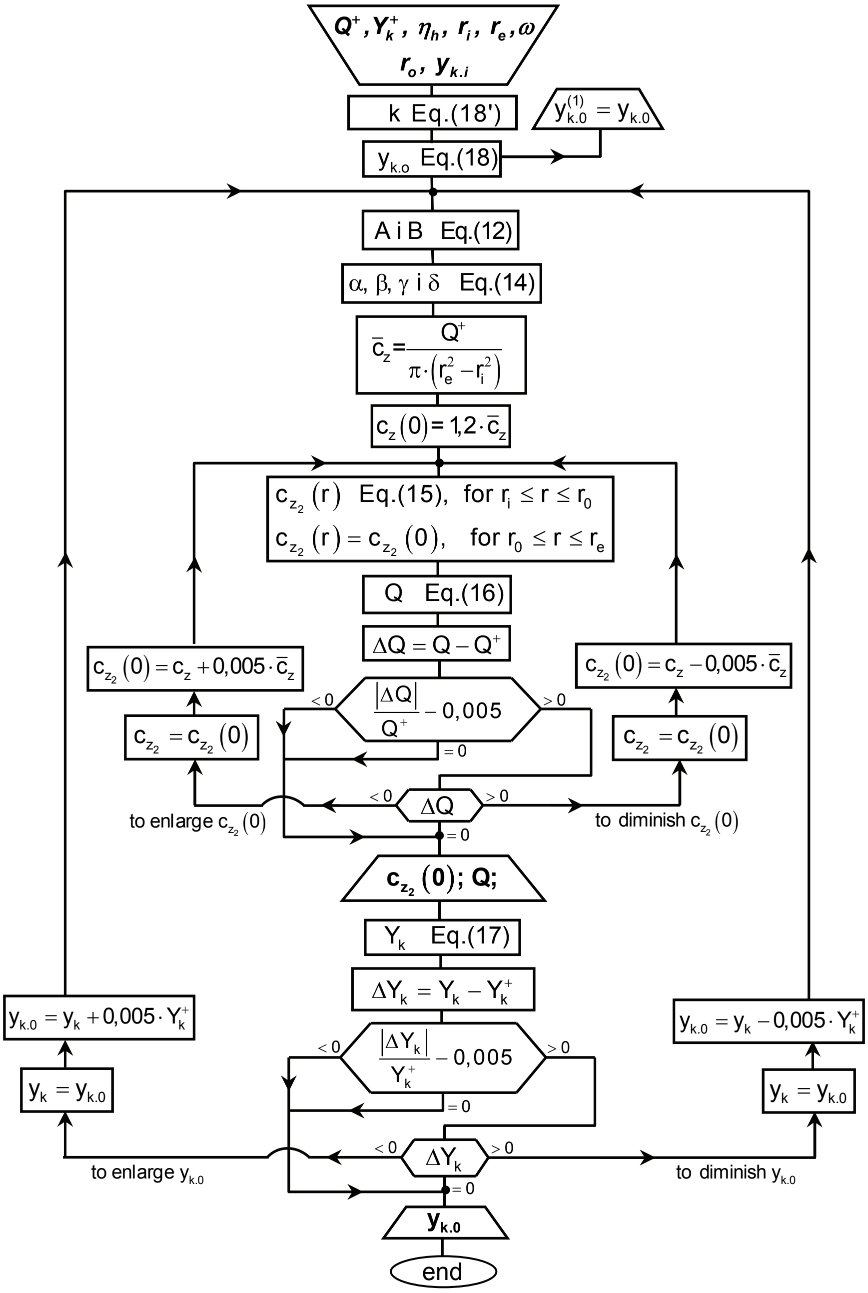

Fig. 3 The algorithm of iterative procedure

Furthermore, the computational code obtained by C# is represented.

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;

namespace ConsoleApplication1
{
    class Program
    {
        static void Main(string[] args)
        {
            double q,gamakplus, mi, ri, rq, r0, yki, k, greska;
            System.Console.WriteLine("Uneti vrednost za q+ [m3/s]");
            q = Convert.ToDouble(System.Console.ReadLine());
            System.Console.WriteLine("Uneti usvojenu vrednost za r0 [m]");
            r0 = Convert.ToDouble(System.Console.ReadLine());
            System.Console.WriteLine("Uneti usvojenu vrednost za yki
[J/kg]");
            yki = Convert.ToDouble(System.Console.ReadLine());
            System.Console.WriteLine("Uneti vrednost za Yk+ [J/kg]");
            gamakplus = Convert.ToDouble(System.Console.ReadLine());
            System.Console.WriteLine("Uneti vrednost za proracunski
hidraulicki stepen korisnosti [-]");
            mi = Convert.ToDouble(System.Console.ReadLine());
            System.Console.WriteLine("Uneti vrednost za ri [m]");
            ri = Convert.ToDouble(System.Console.ReadLine());
            System.Console.WriteLine("Uneti vrednost za re [m]");
            rq = Convert.ToDouble(System.Console.ReadLine());
            k=(r0^2*(r0^2-ri^2)+0.5*(r0^4-ri^4)-1.333*r0*(r0*^3-
ri^3))/((rq^2-ri^2)*(r0-ri)*(r0-ri));
            double yk0;
            yk0 = (gamakplus - k * yki) / (1 - k);
            System.Console.WriteLine("Vrednost yk0 (prva iteracija) je");
            System.Console.WriteLine(yk0);
            double A,
B,cz2r,r,intcz2r,i,Q,deltaQ,test,j,ykr,intYk,p,Yk,deltaYk,test1,alfa, beta,
gama, delta,cznadvuceno,czdvaod0;
            System.Console.WriteLine("Uneti vrednost omega [rad/s]");
            double omega;
            omega = Convert.ToDouble(System.Console.ReadLine());
            System.Console.WriteLine("Uneti relativnu gresku
izracunavanja");
            greska = Convert.ToDouble(System.Console.ReadLine());
            do
            {
                B = (yk0 - yki) / Math.Pow(r0 - ri, 2);
                A = yk0 - Math.Pow(r0, 2) * B;
```

```
                alfa = 4 * r0 * B * (mi + (3 * B) / Math.Pow(omega, 2));
                beta = 4 * B * (mi + B / Math.Pow(omega, 2));
                gama = 4 * B * (A - 2 * Math.Pow(r0, 2) * B) /
Math.Pow(omega, 2);
                delta = 4 * r0 * A * B / Math.Pow(omega, 2);
                cznadvuceno = q / (Math.PI * (Math.Pow(rq, 2) -
Math.Pow(ri, 2)));
                czdvaod0 = 1.02 * cznadvuceno;
                System.Console.WriteLine("pocetrno cz2(0)");
                System.Console.WriteLine(czdvaod0);
                do
                {
                    i = 0.0001; r = ri;
                    cz2r = Math.Sqrt(Math.Pow(czdvaod0, 2) - alfa * (r0 -
r) + 0.5 * beta * (Math.Pow(r0, 2) - Math.Pow(r, 2)) - gama * Math.Log((r0
/ r), Math.E) + delta * (1 / r - 1 / r0));
                    intcz2r = 1 / 2 * cz2r * r * i;
                    r = r0;
                    cz2r = Math.Sqrt(Math.Pow(czdvaod0, 2) - alfa * (r0 -
r) + 0.5 * beta * (Math.Pow(r0, 2) - Math.Pow(r, 2)) - gama * Math.Log((r0
/ r), Math.E) + delta * (1 / r - 1 / r0));
                    intcz2r = intcz2r + 1 / 2 * cz2r * r * i;
                    r = ri;
                    r = r + i;
                    while (r < r0)
                    {
                        cz2r = Math.Sqrt(Math.Pow(czdvaod0, 2) - alfa * (r0
- r) + 0.5 * beta * (Math.Pow(r0, 2) - Math.Pow(r, 2)) - gama *
Math.Log((r0 / r), Math.E) + delta * (1 / r - 1 / r0));
                        intcz2r = intcz2r + cz2r * r * i;
                        r = r + i;
                    }
                   Q = 2 * Math.PI * intcz2r + Math.PI * czdvaod0 *
(Math.Pow(rq, 2) - Math.Pow(r0, 2));
                   deltaQ = Q - q;
                   test = Math.Abs(deltaQ) / q;
                    if (test - greska > 0)
            czdvaod0 = czdvaod0 - Math.Sign(deltaQ) * greska * cznadvuceno;
                    }
                while (test - greska > 0);
                System.Console.WriteLine("Vrednost za cz2(0)=");
                System.Console.WriteLine(czdvaod0);
                System.Console.WriteLine("Vrednost za Q");
                System.Console.WriteLine(Q);
                j = 0.0001;
                p = ri;
                ykr = A + 2 * r0 * B * p - B * Math.Pow(p, 2);
                cz2r = Math.Sqrt(Math.Pow(czdvaod0, 2) - alfa * (r0 - p) +
0.5 * beta * (Math.Pow(r0, 2) - Math.Pow(p, 2)) - gama * Math.Log((r0 / p),
Math.E) + delta * (1 / p - 1 / r0));
```

```
                intYk = 0.5 * ykr * cz2r * p * j;
                p = r0;
                ykr = A + 2 * r0 * B * p - B * Math.Pow(p, 2);
                cz2r = Math.Sqrt(Math.Pow(czdvaod0, 2) - alfa * (r0 - p) +
0.5 * beta * (Math.Pow(r0, 2) - Math.Pow(p, 2)) - gama * Math.Log((r0 / p),
Math.E) + delta * (1 / p - 1 / r0));
                intYk = intYk + 0.5 * ykr * cz2r * p * j;
                p = ri;
                p = p + j;
                while (p < r0)
                {
                   ykr = A + 2 * r0 * B * p - B * Math.Pow(p, 2);
                    cz2r = Math.Sqrt(Math.Pow(czdvaod0, 2) - alfa * (r0 -
p) + 0.5 * beta * (Math.Pow(r0, 2) - Math.Pow(p, 2)) - gama * Math.Log((r0
/ p), Math.E) + delta * (1 / p - 1 / r0));
                    intYk = intYk + ykr * cz2r * p * j;
                    p = p + j;
                }
                Yk = (1 / Q) * 2 * Math.PI * intYk + (1 / Q) * Math.PI *
yk0 * czdvaod0 * (Math.Pow(rq, 2) - Math.Pow(r0, 2));
                deltaYk = Yk - gamakplus;
                test1 = Math.Abs(deltaYk) / gamakplus;
                 if (test1 - greska > 0)
                    yk0 = yk0 - greska*Math.Sign(deltaYk) * gamakplus;
            }
            while (test1 - greska > 0);
            System.Console.WriteLine("Stampaj B");
           System.Console.WriteLine(B);
           System.Console.WriteLine("Stampaj A");
           System.Console.WriteLine(A);
            System.Console.WriteLine("Izracunavanje   koeficijenta   alfa,
beta, gama i delta prema formulama...");
           System.Console.WriteLine("Koeficijent alfa je:");
           System.Console.WriteLine(alfa);
           System.Console.WriteLine("Koeficijent beta je:");
           System.Console.WriteLine(beta);
           System.Console.WriteLine("Koeficijent gama je:");
           System.Console.WriteLine(gama);
           System.Console.WriteLine("Koeficijent delta je:");
           System.Console.WriteLine(delta);
           System.Console.WriteLine("Vrednost yko je");
           System.Console.WriteLine(yk0);
           Console.ReadKey();
        }
    }
}
```

For the fan runner with operating parameters: r_i=0,150m, r_e=0,315m, Q^+ = 3,61 m^3/s, ($\overline{c}_z = 15$ m/s), Y_k^+=214 J/kg, η_h^+=0,70 ($\Delta p_{t.v}^+ = \rho\eta_h^+ Y_k^+$=180 Pa) and ω = 147 rad/s (n=1405 rev/min), and for adopted values $y_{k.i}$=0,6Y_k^+ (=129 J/kg) and r_o = 0,220 m, it is obtained:

$$y_{k.o}=222{,}72 \text{ J/kg } (=1{,}05Y_k^+) \text{ and } c_{z_2}(0) = 15{,}28 \text{ m/s } (=1{,}02 \cdot \overline{c}_z).$$

Therefore in the range $0{,}150 \le r \le 0{,}220$ m, function $y_{k.o}(r)$ and $c_{z_2}(r)$ becomes:

$$y_{k.o}(r) = -703{,}02 + 8415{,}83 \cdot r - 19126{,}89 \cdot r^2$$

And

$$c_{z_2}(r) = \sqrt{\begin{array}{c} 15{,}28^2 - 56477{,}07(0{,}22 - r) + 60637{,}43\left(0{,}0484 - r^2\right) \\ +9044{,}32\ln\dfrac{0{,}22}{r} - 547{,}6\left(\dfrac{1}{r} - 4{,}545\right) \end{array}}$$

The analysis of the fan blades geometry obtained by the presented designing method shows that under the cylindrical flow surface $r = r_o$ = 0,220m, in the control cross-section behind the fan runner, passes 32,5% of the computational flow rate ($Q(r_o)$=0,325Q^+) [6]. Since the deviation between axisymmetrical and cylindrical flow surfaces is negligibly small (less than 1,6% in the part of maximal flow surface deviation for $0{,}170 \le r \le 0{,}180$m), the calculation is performed using the model of cylindrical flow surfaces.

5. Conclusion

The fan blade profiles can be defined according to the unequal distribution of specific work of the elementary stages near the fan hub, for the fan runner radius range $r_i \le r \le r_o$, where ro $\le (r_i + r_e) / 2$, in order to obtain a much smaller spatial curvature of the fan blades (compared to the fun blades defined according to the equal distribution of specific work of all elementary stages). This designing principle reduces the kinetic energy of the circumferential component of absolute velocity at the fan outlet, also reducing the total mechanical energy losses of the fan.

The algorithm for calculation values $y_{k.o}$ and $c_{z_2}(0)$ required for defining specific work of elementary stages, is represented in the paper, as well as computational code created using C#. Relative error of 0,5%, given in the algorithm, which satisfies the technical practice, enables obtaining $y_{k.o}$ and $c_{z_2}(0)$ values in just few iterative steps, due to good convergence of the numerical procedure.

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PROGRAM ZA ODREĐIVANJE NEJEDNIOLIKE RASPODELE JEDINIČNOG RADA ELEMENTARNIH STUPNJEVA PRI PROJEKTOVANJU NISKOPRITISNIH AKSIJALNIH VENTILATORA

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Da bi se smanjila prostorna zakrivljenost lopatica i dužina glavčine ventilatorskog kola, kao i gubici kinetičke energije kružne komponente apsolutne brzine na izlazu iz radnog kola, u ovom radu je predložena i prikazana metoda projektovanja niskopritisnih aksijalnih ventilatora sa različitim jediničnim radovima kola elementarnih stupnjeva oko glavčine, umesto uobičajene prakse definisanja jednakih jediničnih radova za sve elementarne stupnjeve ventilatorskog kola. U radu je data i funkcija raspodele jediničnih radova svih elementarnih stupnjeva, prema kojoj osrednjene osnosimetrične strujne površine u ventilatorskom kolu zanemarljivo malo odstupaju od cilindričnih strujnih površina. U datoj funkciji raspodele, jedinični rad kola elementarnih stupnjeva uz glavčinu može se smanjiti i do 60% proračunskog jediničnog rada, sa neznatnim uticajem na osnosimetričnost. Takođe je u radu dat i program razvijen za proračun jediničnog rada kola elementarnog stupnja za proračunske radne parametre ventilatorskog kola i zadate početne vrednosti r_o, $y_{k.i}$.

Ključne reči: *aksijalni ventilator, elementarni stupanj, jedinični rad*