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THE ANALYSIS OF LONGITUDINAL AND EXPANSION VELOCITIES IN THE FOCUSING TUBE OF ABRASIVE WATERJET CUTTING HEAD

ANALÝZA PODÉLNÉ A EXPANZNÍ RYCHLOSTI V USMĚRŇOVACÍ TRUBICI ŘEZACÍ HLAVICE ABRAZIVNÍHO VODNÍHO PAPRSKU

Abstract

After the rearrangement of equations used in the presented article, the calculation of mean longitudinal velocities along the path of the jet was made more accurate. The rearrangement of equations consists in the determination of a constant in the equation for calculation concerning the initial section of the jet by using an equation by Hlaváč.

On the basis of analysis of longitudinal velocities in the cutting head, the mean value of expansion velocity that can be used for the calculation of pressure below atmospheric pressure in the mixing chamber was determined.

Abstrakt

Po úpravě rovnic použitých v uváděném článku došlo ke zpřesnění výpočtu průměrných podélných rychlostí podél dráhy paprsku. Úprava rovnic spočívá v určení konstanty v rovnici pro výpočet počátečního úseku paprsku s využitím rovnic Hlaváče.

Na základě analýzy podélných rychlostí v řezací hlavici byla určena střední hodnota expanzní rychlosti, kterou lze použít pro výpočet podtlaku ve směšovací komoře.

1 INTRODUCTION

In the article [1] the authors made a partial analysis of velocities of the pure waterjet (henceforth referred to as jet) in the course of its flowing through the cutting head with the shut-off supply of abrasive (Fig.1) on the following assumptions

- the liquid was incompressible,
- the liquid remained in the jet, any accumulation of it did not occur in the mixing chamber,
- the jet was not aerated,
- in the calculations, the turbulent flow of water in the jet was taken as steady flow with the flow field that was characterised by mean time values of fluctuating quantities [2].

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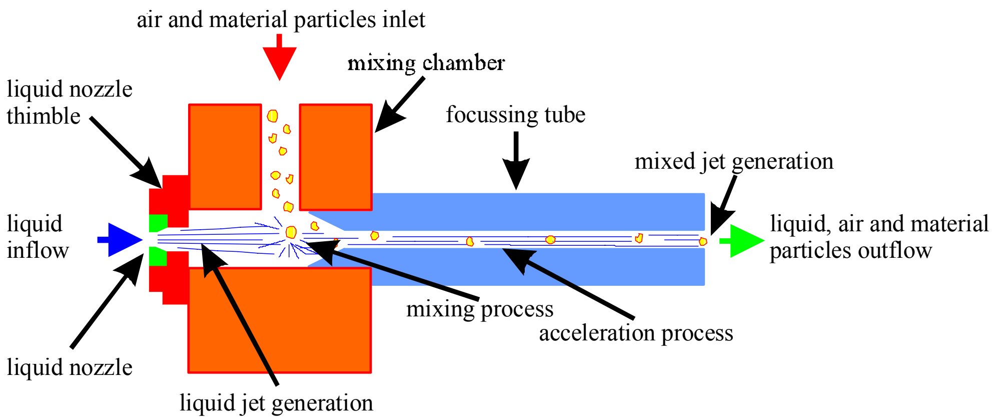

Fig. 1. A diagrammatical section through the cutting head of abrasive waterjet with the representation of processes leading to the generation of abrasive liquid jet at its exit.

In the course of analysis, equations by Milovič and Hlaváč were used. Furthermore, the internal path of the jet was defined as a sum of the length of mixing chamber and that of focusing tube.

2 PARAMETERS OF WATERJET AND CUTTING HEAD

For solving the equations, the following values of temperature t, water density ρ, pressure p_0 and mean velocity v_0 were used for the waterjet at the entry into the mixing chamber: t = 20°C, ρ = 998 $kg.m^{-3}$, p_0 = 400 MPa, v_0 = 650 $m.s^{-1}$.

The cutting head was taken as a closed system, i.e. the supply of abrasive was shut off. Head dimensions are as follows:

the jet at the entry into the mixing chamber: (index 0), d_0 = 0.25 mm (r_0 = 0.125 mm),
mixing chamber: (index s), l_s = 13 mm, d_s = 7.14 mm,
focusing tube: (index 1), l_1 = 76 mm, d_1 = 1.02 mm (r_1 = 0.51 mm),
where l is the relevant length and d is the relevant diameter of parts of the cutting head.

3 EQUATIONS USED

The equations by Milovič [3]

a) for the determination of length of the initial section of the jet (the section along which the velocity in the axis of jet is uniform)

$$l_p = 145 d_0 , \tag{3.1}$$

b) for the calculation of maximum longitudinal velocity v1 in the axis of waterjet moving in the air within its compact part behind the initial section

$$v_1 = \frac{145 v_0 d_0}{l} . \tag{3.2}$$

The equation by Hlaváč (expansion velocity of jet in the direction perpendicular to the axis of flow) [4]

$$v_e = \left[\frac{2}{p_0} \left(p_0 - \frac{1}{2} \rho_0 v_{0u}^2 - p_{at} \right) \right]^{-\frac{1}{2}}, \tag{3.3}$$

where p_0 is the pressure of liquid before the nozzle, ρ_0 is the density of liquid under normal conditions, v_{0u} is the velocity of waterjet at the entry into the mixing chamber taken approximately as equal to v_0.

4 SUMMARY OF RESULTS ACHIEVED

a) initial section

$$l_p = 36 \text{ mm}, \tag{4.1}$$

b) maximum longitudinal velocity v1 in the axis of waterjet at the end of focusing tube

$$v_1 = 265 \text{ m.s}^{-1}, \tag{4.2}$$

c) expansion velocity of the jet in the direction perpendicular to the axis of flow

$$v_e = 615 \text{ m.s}^{-1}. \tag{4.3}$$

5 REARRANGEMENT OF EQUATIONS BY MILOVIČ FOR THE HIGH-PRESSURE WATERJET

Hlaváč derived the dependence of velocity field of high-pressure jet in its cross-section on the distance from the nozzle (Fig. 2) and verified experimentally the obtained relation [5].

If we compare the achieved results with the curve of velocity field (Fig. 2), then it is evident that the used equations by Milovič, which were derived for common waterjets (of lower pressures), do not provide any acceptable results. For high-pressure jets it will be probably necessary to rearrange the stated equations in a certain way; the formal forms of the equations must be preserved.

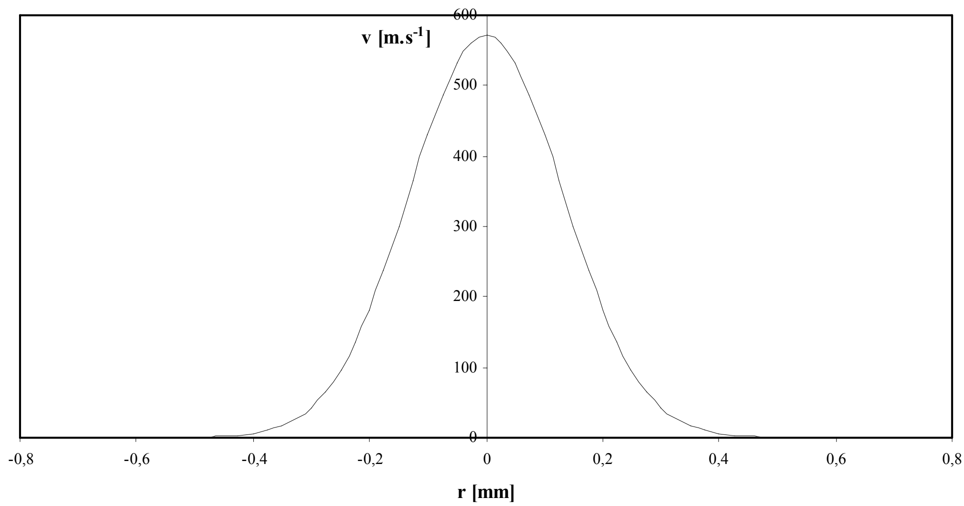

Fig. 2 Velocity field of high-pressure jet in its cross-section 89 mm from the nozzle

For the next analysis of velocities of high-pressure waterjet we shall use the assumption that relations between quantities in the equations by Milovič are formally correct, but the constant in the equation (3.1) has a different value, as a basis. To determine this value the authors selected the approach given below.

Into the equation (3.2) the initial section expressed by the equation (3.1) was put. After rearrangement we shall obtain

$$l_p = \frac{v_1}{v_0} l . \tag{5.1}$$

On the graph of velocity field (Fig. 2) the value of velocity v = 571 $m.s^{-1}$ in the axis of jet at the end of focusing tube, i.e. for l = 89 mm, will be read off. Then

$$l_p = 78 \text{ mm}. \tag{5.2}$$

From the known value of initial section, the value of constant being searched for designated now as A will be determined.

$$A = \frac{l_p}{d_0} = 312 \tag{5.3}$$

We shall write the Milovič equation (3.1) for the high-pressure waterjet having the stated parameters in the following form

$$l_p = 312 d_0 . \tag{5.4}$$

The value of constant A will change depending upon the values of pressure p_0, velocity v_0 and diameter of input nozzle.

$$A = f(p_0, v_0, d_0) , \tag{5.5}$$

The procedure for the determination of value of constant A will be, however, the same as in the case presented by us.

Now, we are able to determine the mean axial velocity of jet along the internal path behind the initial section.

$$\overline{v}_2 = \frac{1}{l_x} \int_{l_p}^{l} \frac{312 v_0 d_0}{x} dx = 608 \text{ m.s}^{-1} \quad \Rightarrow \quad \overline{v}_2 \in \langle 571, 650 \rangle \text{ m.s}^{-1}, \tag{5.6}$$

where $l_x = l - l_p = 11$mm. The total time required for travelling the internal path is

$$t = \frac{l_p}{v_0} + \frac{l_x}{\overline{v}_2} = 1.38 * 10^{-4} \text{s}. \tag{5.7}$$

6 ANALYSIS OF WATERJET DIVERGENCE

The waterjet expands in the course of flowing; the divergence of waterjet occurs in the direction radial towards the axis of flow. The equation (3.3) for the calculation of expansion velocity after the exit of jet from the nozzle gives a high value of 615 $m.s^{-1}$. However, this is a case of initial value of expansion velocity. Immediately after that, the divergence of the jet is very quickly attenuated, which is proved by the cross-section of the jet at the exit from the cutting head, which is smaller here than the cross-section of the focusing tube. Between the jet and the walls of the focusing tube, an air gap is there. Its presence is indicated by the approximately uniform value of pressure in the mixing chamber at the shut off supply of abrasive (experimentally verified by Hlaváč). The air is partially taken away by the jet and flows along it (or in the course of its aeration together with the jet) out of the cutting head. Along the walls of focusing tube, the air flows in the opposite direction back to the mixing chamber. Thus a dynamic balance occurs the result of which is the uniform value of pressure in the mixing chamber.

The functional dependence of decrease in expansion velocity along the internal path depending upon time is not determinable because complicated processes take place inside the cutting head. Nevertheless, on the basis of previous considerations and by using the graph (Fig. 2), we are able to determine the mean value of expansion velocity along the internal path of the jet. As a basis we shall use the assumption that the attenuation of expansion of the jet must be connected with the quantity the value of which is considerable and that describes simultaneously the flow of the jet. After making the analysis of equation (3.3), the initial pressure p_0 was taken as the quantity affecting the attenuation of expansion. The mean value of expansion velocity along the internal path of the jet will be determined from the relation as given below

$$\overline{v}_e = H\left[\frac{2}{\rho_0}\left(p_0 - \frac{1}{2}\rho_0 v_{0u}^2 - p_{at}\right)\right]^{\frac{1}{2}}, \qquad H = k\sqrt{\frac{\rho_0}{p_0}} \tag{6.1}$$

The value of quantity "k" modifies the magnitude of mean value of expansion velocity according to the distance from the axis of flow over which the jet expands. From the graph (Fig. 2) we shall determine the radius of the jet at the exit from the cutting head as that point in the cross section behind which a very rapid decrease in longitudinal velocities in the jet cross-section occurs

$$y_1 = 0.424\,\text{mm}\,. \tag{6.2}$$

By deducting the jet radius r_0 at the exit from the nozzle, we shall obtain the path of expansion in the radial direction

$$y = y_1 - r_0 = 0.299\text{mm}\,. \tag{6.3}$$

From the expansion path and the total time the value of quantity k will be determined

$$k = 2.2 \quad . \tag{6.4}$$

The mean value of expansion velocity is

$$\overline{v}_e = 2.16\ \text{m.s}^{-1}\,. \tag{6.5}$$

In the case of another length of internal path, the value of quantity k will be different but the procedure for the determination of it will be the same.

7 CONCLUSION

The work deals with the rearrangement of equations for calculation concerning the initial section of high-pressure waterjet and with the calculation of mean values of longitudinal velocities in the axis of the jet in the course of its flow through the cutting head. A new value of constant for the expression of linear dependence of initial section of the jet on the cross section of input nozzle was determined. The value of the stated constant is more than double the value of constant in the case of low-pressure jet. The calculated mean value of longitudinal velocity in the axis between the initial section of the jet and the exit from the cutting head lies within the interval between the entry and the exit value of the jet velocity.

On the basis of analysis of the divergence of waterjet, the mean value of expansion velocity along the internal path of the jet was determined by introducing a quantity taking into account a considerable decrease in expansion velocity in time. The value of this quantity is a constant for the given cutting head; in the case of another head, the procedure for determining this constant remains the same.

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