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LIMITED OPERATING CONDITIONS OF THE JET MILL INJECTOR

Three critical operating modes of a jet mill injector are submitted and conditions of their acting are shown. Values of injection factor corresponding to critical modes are found.

Introduction. The basic parameters of jet mills are plant productivity and ready product dispersion. These parameters depend on speed and concentration of colliding particles which optimum values are provided by a choice of operating modes, the geometrical sizes of a milling unit flowing part and thermo physical properties of injected and working flows. It is experimentally established [1, 2], that the mentioned parameters interrelations have nonlinear and in most cases extreme character. Therefore at jet mills designing the optimization problem of the system parameter choice with the purpose of the minimal specific expenses achievement is always solved.

Now theoretical researches available in this researches area don't give the full answer on the assigned task because of complexity processes proceeding in milling unit. The most of results are received on the basis of experimental researches and new projects on making plant are based, mainly, on experimental data.

According to the accepted model of working process in the jet device [3], in accelerating tube (mixing chamber) injected and working flows enter as two separate flows. At the subsonic outflow of a working flow from nozzle pressure upon a nozzle section is equal to pressure in the grinding chamber; hence, on an input in accelerating tube flow pressures are identical. At the supercritical pressures ratio in nozzle pressure upon a section can differ essentially from injected flow pressure. If nozzle is made not extending or with incomplete expansion, the flow after an output from nozzle will extend, thus its speed will be supersonic. Injected flow on this place can be accelerated, reaching sound speed if between chamber walls and a supersonic jet the constriction is formed.

In this connection the consideration of possible limited operating modes of the jet device has practical interest, i.e. such modes when at a supersonic degree of working flow expansion in nozzle in any accelerating tube section, the speed injected or mixed flow reaches sound speed.

The analysis of such modes is important (even key) moment at construction of the jet device characteristic as its productivity will be limited by approaching of this mode. Therefore further we shall consider possible limited modes.

Main part of research. As it is marked in work [4], the limited mode can arise both on a place on which the working and injected flows have essentially various speeds and on a place where the mixed flow jets.

There are three limited modes which can be realized on length of the accelerating tube (see fig. 1):

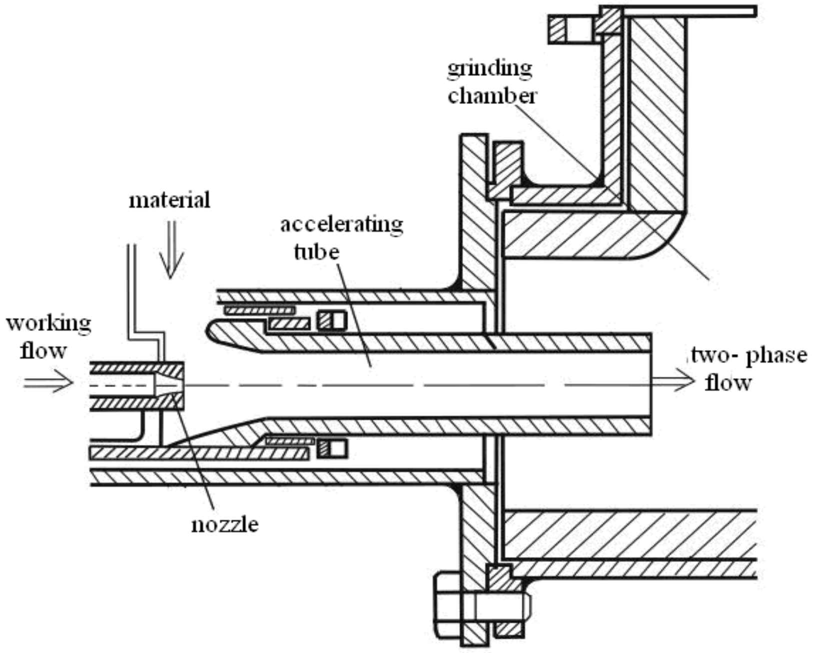

Fig. 1.
1 – in section on an input of a cylindrical part;
2 – in intermediate section between an input and an output;
3 – in output section of the accelerating tube

The first limited mode which is realized in section (we shall conventionally name it s-s), is characterized by the following parameter ratio (see fig. 2):

$$p_{ps} \geq p_{нs} = \pi^{*}_{н}\, p_{н}\,;\; w_{нs} = a^{*}_{н};\; w_{ps} \geq a^{*}_{p}\,, \tag{1}$$

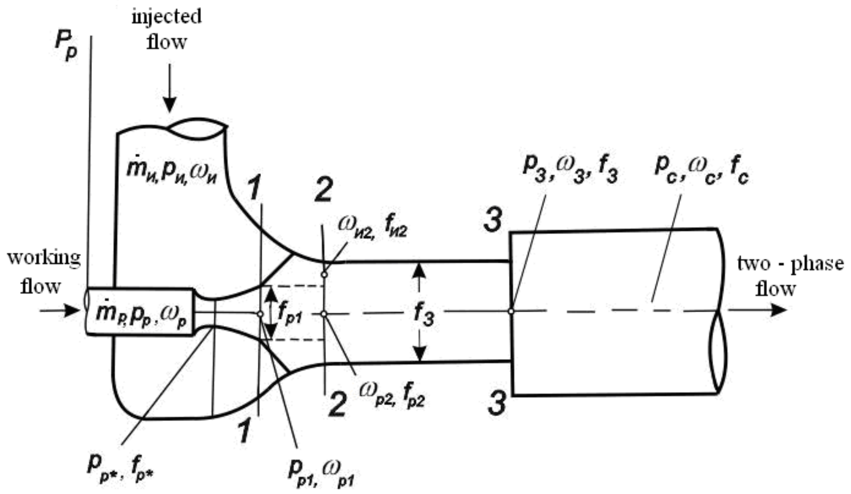

Fig. 2

i.e. injected and working flows have different pressures and different speeds, at the same time injected flow speed is equal to critical one, working flow speed is more than it.

According to injector accelerating tube these conditions can be written as following. In accelerating tube input section ($f_s = f_2$) speed injected flow reaches critical value, i.e. $\lambda_{\text{н}s} = \lambda_{\text{н}2} = 1$; $f_{\text{н}s} = f_{\text{н}2} = f_{\text{н}*}$. Then the limited discharges of injected and working flows are computed on formulas:

$$(\dot{m}_{\text{н}})_{\text{пр}1} = \frac{k_{\text{н}} \pi_{\text{н}}^{*} p_{\text{н}} f_{\text{н}}^{*}}{a_{\text{н}}^{*}}. \tag{2}$$

$$\dot{m}_{p} = \frac{k_{p} \pi_{p}^{*} p_{p} f_{p}^{*}}{a_{p}^{*}}. \tag{3}$$

Hence, the injection coefficient at the first limited mode

$$u_{\text{пр}1} = \frac{(\dot{m}_{\text{н}})_{\text{пр}1}}{\dot{m}_{p}} = \frac{k_{\text{н}}}{k_{p}} \frac{\pi_{\text{н}}^{*}}{\pi_{p}^{*}} \frac{p_{\text{н}}}{p_{p}} \frac{f_{\text{н}}^{*}}{f_{p}^{*}} \frac{a_{p}^{*}}{a_{\text{н}}^{*}}. \tag{4}$$

Apparently, the injection coefficient increases with increase of the injected flow area ratio to the nozzle critical section area and with reduction of a working flow expansion degree.

If at the first limited mode the working flow section area on an input in accelerating tube is accepted to be equal to nozzle exit area, it is possible to write

$$f_{\text{н}}^{*} = f_{3} - f_{p1} = f_{3} - f_{p}^{*} / q_{p1}. \tag{5}$$

Subject to the ratio (5) equation (4) will become

$$u_{\text{пр}1} = \frac{k_{\text{н}}}{k_{p}} \frac{\pi_{\text{н}}^{*}}{\pi_{p}^{*}} \frac{p_{\text{н}}}{p_{p}} \frac{a_{p}^{*}}{a_{\text{н}}^{*}} \left(\frac{f_{3}}{f_{p}^{*}} - \frac{1}{q_{p1}} \right). \tag{6}$$

In the cylindrical accelerating tube $f_3 = f_{p2} + f_{\text{н}2}$, where f_{p2}, $f_{\text{н}2}$ are the areas occupied by the working and injected flows. The flow section area can be expressed by critical section f^* and the resulted mass velocity q by the formula $f = f^{*} / q$.

Then, using these formulas, it is possible to determine the ratio of the accelerating tube section area to the nozzle critical section area:

$$\frac{f_3}{f_p^*} = (1+u)\frac{a_c^*}{a_p^*}\frac{k_p}{k_c}\frac{\pi_p^*}{\pi_c^*}\frac{p_p}{p_c}\frac{1}{q_{c3}}. \qquad (7)$$

The formula shows, that the areas ratio depends on injection coefficient which at approach of the first limited mode becomes equal to limited value.

As a result of the equation transformation (6), with consideration of the formula (7), finally we receive dependence for injection coefficient calculation at the first limited mode:

$$u_{\text{пр}1} = \frac{\frac{k_{\text{н}}}{k_c}\frac{\pi_{\text{н}}^*}{\pi_c^*}\frac{p_{\text{н}}}{p_c}\frac{a_c^*}{a_{\text{н}}^*}\frac{1}{q_{c3}} - \frac{k_{\text{н}}}{k_p}\frac{\pi_{\text{н}}^*}{\pi_p^*}\frac{p_{\text{н}}}{p_p}\frac{a_p^*}{a_{\text{н}}^*}\frac{1}{q_{p1}}}{1-\frac{k_{\text{н}}}{k_c}\frac{\pi_{\text{н}}^*}{\pi_c^*}\frac{p_{\text{н}}}{p_c}\frac{a_c^*}{a_{\text{н}}^*}\frac{1}{q_{c3}}}. \qquad (8)$$

During the analysis of the second limited mode we proceed from the accepted process plan, which does not take into account mixing the working and injected flows on a part between a plane 1-1 (a nozzle section) and intermediate section s-s, where a limited mode acts. The second limited mode is characterized by the following conditions.

In flows the identical static pressures are established which are equal to critical injected flow pressure:

$$p_{ps} = p_{\text{н}s} = p_{\text{н}}^* = p_{\text{н}}\pi_{\text{н}}^*.$$

Speed injected flow is equal to critical value: $w_{HS} = a_H^*$.

In this section

$$\pi_{ps} = \frac{p_{ps}}{p_p} = \frac{p_{\text{н}}}{p_p}\pi_{\text{н}}^* = \pi_p\pi_{\text{н}}^* < \pi_p^*,$$

hence, the working flow has supersonic speed.

Let express discharges by the parameters corresponding to the second limited mode:

$$\cdot(\dot{m}_{\text{н}})_{\text{пр}2} = \frac{k_{\text{н}}\pi_{\text{н}}^* p_{\text{н}} f_{\text{н}}^*}{a_{\text{н}}^*} = \frac{k_{\text{н}}\pi_{\text{н}}^* p_{\text{н}}(f_3 - f_{ps})}{a_{\text{н}}^*}; \qquad (9)$$

$$\dot{m}_p = \frac{k_p \pi_p^* p_p f_p^*}{a_p^*}. \tag{10}$$

The injection coefficient in this case is equal to the mass discharges ratio in the section s-s:

$$u_{\text{пр}2} = \frac{(\dot{m}_{\text{н}})_{\text{пр}2}}{\dot{m}_p}. \tag{11}$$

Then we receive

$$u_{\text{пр}2} = \frac{k_{\text{н}}}{k_p}\frac{\pi_{\text{н}}^*}{\pi_p^*}\frac{p_{\text{н}}}{p_p}\frac{a_p^*}{a_{\text{н}}^*}\left(\frac{f_3}{f_p^*} - \frac{1}{q_{ps}}\right). \tag{12}$$

The areas ratio is determined by the formula (7), value q_{ps} is determined from gas-dynamic tables at known $\pi_{ps}=\pi_{\text{н}*}\, p_{\text{н}}/ p_p$.

Let transform the formula (12), having substituted in it the formula (7). In result we receive dependence for calculation of jet device injection coefficient at the second limited mode:

$$u_{\text{пр}2} = \frac{\dfrac{k_{\text{н}}}{k_c}\dfrac{\pi_{\text{н}}^*}{\pi_c^*}\dfrac{p_{\text{н}}}{p_c}\dfrac{a_c^*}{a_{\text{н}}^*}\dfrac{1}{q_{c3}} - \dfrac{k_{\text{н}}}{k_p}\dfrac{\pi_{\text{н}}^*}{\pi_p^*}\dfrac{p_{\text{н}}}{p_p}\dfrac{a_p^*}{a_{\text{н}}^*}\dfrac{1}{q_{ps}}}{1-\dfrac{k_{\text{н}}}{k_c}\dfrac{\pi_{\text{н}}^*}{\pi_c^*}\dfrac{p_{\text{н}}}{p_c}\dfrac{a_c^*}{a_{\text{н}}^*}\dfrac{1}{q_{c3}}}. \tag{13}$$

Apparently, the formula (13) differs from (8) for parameter q_{ps} which for the first limited mode is equal to q_{p1}. If $q_{p1}> q_{ps}$, then $u_{\text{пр}1}> u_{\text{пр}2}$. Usually for nozzle we have $q_{p1}> q_{ps}$. However in nozzle with an overexpansion working flow, i.e. at small $q_{p1}=f_p^*/f_{p1}$, it can be $u_{\text{пр}1} <u_{\text{пр}2}$. For these conditions the second mode cannot be realized, as the first limited mode comes earlier. At some expansion degree of working flow when $q_{ps} =q_{p1}$, both limited modes can simultaneously arise.

The third limited mode comes when λ_{c3}=1, i.e. when speed of the mixed flow reaches critical value. Realization of such conditions is possible only theoretically. But for preservation of material statement sequence about limited modes we shall consider also this case.

At the given mode the discharge of the mixed flow can be presented by injection coefficient as

$$(\dot{m}_c)_{\text{пр}3} = \dot{m}_p(1+u_{\text{пр}3}), \tag{14}$$

whence we find injection coefficient

$$u_{пр3} = \frac{(\dot{m}_c)_{пр3}}{\dot{m}_p} - 1 . \tag{15}$$

The discharge of the mixed flow through critical section *f3** is expressed by dependence

$$(\dot{m}_c)_{пр3} = \frac{k_c \pi_c^* p_c f_3}{a_c^*} . \tag{16}$$

The discharge of a working flow is determined under the formula (11).

Hence, the injection coefficient of the jet device at the third limited mode is equal to

$$u_{пр3} = \frac{k_c}{k_p} \frac{\pi_c^*}{\pi_p^*} \frac{p_c}{p_p} \frac{a_p^*}{a_c^*} \frac{f_3}{f_p^*} - 1 . \tag{17}$$

From the equation it follows that at a present pressure value before injector and the given the areas ratio, for each pressure value in accelerating tube the quite definite limited value of injection coefficient corresponds.

Conclusion. In summary we note that for construction and research of injector characteristics it is necessary to take the smallest of three determined limited values of injection coefficient.

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