FLUID KINETICS PRINCIPLE AND DESIGN CRITERIA OF ATOMIZER ①

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ABSTRACT Based on the mechanism of fluid kinetics, the working principle of the vortical loop slot jet nozzle has been studied and analyzed, the results showed that fluid medium projected out from the nozzle does not focus, but forms a hollow double cone. In order to avoid choking up, the stretching length of the leak pipe should be located at such a position that the negative pressure zone of the gas cone is closed.

Key words atomizer fluid medium fluid kinetics vorticit

1 INTRODUCTION

Atomizing is an ordinary but effective technique of preparing metal powder, its core technique is an atomizer which includes not only the jet nozzle of drawing fluid medium but also the combination of jet nozzle and leak pipe. In fact, it is senseless to study atomizing principle of jet nozzle separately without consideration of the leak pipe leading metal melt flowing. Vortex-loop-slot jet nozzle is employed widely for its good effect of atomizing and high ratio of fine powders[1-3], however during atomizing it is blocked easily which seriously affects the atomizing efficiency. In this paper the working mechanism of vortex jet nozzle is deeply analyzed on the basis of a large number of experiments, bring the basic reason of blocking the jet nozzle to light. The results indicate that taking a geometric vertex located at the focal point on the axis of swirl-loop-slot jet nozzle as the reference position of stretching length of leak pipe is wrong. Actually, the stretch of leak pipe can be far beyond the so-called focal point and the nozzle is not blocked; this is because, for swir/-loop-slot jet nozzle, atomizing medium ejected from jet nozzle forms a hollow double cone without a so-called focal point. The jet nozzle will be blocked unless the outstretching length of leak pipe is so long that the negative pressure zone in the upper cone of jet nozzle is closed, excluing the influence of the temperature.

2 WORKING PRINCIPLE OF ATOMIZER

Actually, atomizer is a transformer of energy, which transfers the energy of high-pressure atomizing medium into the surface energy of metal powder. When substance surface increases, it will absorb energy; and in the case of metal atomizing, that means to overcome surface tension and to do work. Raising temperature of the melt can reduce its viscosity, with result of reducing surface tension. Atomizing efficiency mainly depends on kinetic energy of atomizing medium, assuming the mass of medium is M and the outlet linear velocity is v, then its kinetic energy is $E = Mv^2/2$.

It means that, under the same mass condition, the velocity of atomizing medium flowing out from the jet nozzle is a key factor affecting the quantity of the kinetic energy[4], therefore, it is of first importance to raise the outlet velocity of atomizing medium. On the other hand, the effect of height difference between the entrance and exit of jet nozzle can be ignored and the gas can be taken as incompressible fluid, according

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to Bernoulli equation[5, 6], we have

$$\frac{p_1}{\gamma}+\frac{\alpha_1 v_1^2}{2g}=\frac{p_2}{\gamma}+\frac{\alpha_2 v_2^2}{2g}+h_w$$

where p_1 and p_2 are the pressure under which atomizing medium goes into and out of the jet nozzle respectively, γ the density of fluid medium, v_1 and v_2 are the linear velocity of medium' going into and out of the jet nozzle respectively, g the acceleration of gravity; α_1 and α_2 are the revision coefficient of kinetic energy, their quantity are connected with the uniform degree of velocity distribution, the less even it is, the larger the value is. On the average, α is supposed to be 1.2; h_w is the loss of pressure, it includes process loss Σh_g and local loss Σh_j, i.e. $h_w = h_g + h_j$.

The process loss includes the energy used to overcome the inner friction of the fluid and the friction between fluid and walls. Obviously, the higher the manufacturing precision of the walls is, the less the process loss is. The local loss includes the bend loss and the outlet loss, etc, the larger the bend curvature is, the less the local loss is. However, the local loss at the outlet is much more complex. In one hand, we need small area of cross-section at the outlet to get high speed of fluid; in another hand, the local resistance loss will be increased with decreasing the area of cross-section. So we must design reasonably the jet nozzle.

Fig. 1(a) shows the moving state of the atomizing medium in a vortical-loop-slot jet nozzle. After getting into the jet nozzle at a tangent direction, atomizing medium will move in swirling and then swirl off the jet nozzle outlet.

Fig. 1(b) shows that certain mass point of atomizing medium at position a begins to swirl off the edge of the jet nozzle, as mentioned above. And then the swirling movement, when the medium mass point at point a along spiral locus reaches point b at the other side of the jet nozzle, flies away along the tangent direction at point b. Obviously, the flying directions do not intersect with the central axis of the jet nozzle and will keep certain space distance. Fig. 1(c) shows schematically the combination of above mentioned flowing line of the atomizing medium ejected out in a circular state around the jet nozzle, which implies that the combination

Fig. 1 Moving state of fluid medium in vortex jet nozzle

flows form a hollow double cone. Fig. 1 (d) shows the case that large quantity of medium swirls off the jet nozzle and then diffuses. Here, the outer profile of hollow double cone pictured with dotted line is used to show that there is not such a locus made by atomizing medium, and is actually made up the tangents of a spiral stated above. We can divide the hollow cone into two parts, of which the upper part is called upper cone. Assuming that the inner cone angle of the upper cone is β, the double lines will meet with the central axis at point G, which is different from the focus J on the central axis determined by the double lines of the vertex angle α of the nozzle. Point J is a stable arithmetic point, but point G is determined not only by the structure of the nozzle, but also by the pressure of atomizing medium and other factors as well. It is evident that the higher the pressure is, and the more accurate inner surface of the nozzle is, the higher swirling speed of the medium is, and then the greater value β is. Otherwise value β will be smaller. Using d_0 for minimal diameter or the dimension of bottle neck of the inner cone, when the diameter of leak pipe $d < d_0$, the leak pipe can not jam up the bottle neck (Fig. 2(a)), moreover, atomizing medium will swarm to the negative pressure zone above bottle neck, leading atomizing metal drops to adhere to the edge of jet nozzle, and be gradually concentrated. Finally, the atomizing metal drops are frozen together with leak pipe and then nozzle blocking will be occurred. Nozzle blocking is a serious phenomenon during atomizing, which may lead the atomizing process be prevented. When $d = d_0$, i. e. the outstretched leak pipe just approach the bottle neck, atomizing of melt will occur. In this case, the bottle neck is blocked up resulting that atomizing medium with atomizing melt drops can not swarm to negative pressure zone above the bottle neck (Fig. 2(b)); If the outstretching length of the leak pipe is too long, atomizing medium can not interact with the melt flowing from the leak pipe. In this case, the leak pipe will be cooled by atomizing medium and then atomizing will be interrupted.

Fig. 2 Combination shape of jet nozzle and leak pipe

When $d > d_0$, i. e. the outstretching leak pipe just approach the hollow cone neck, the atomizing effect will be better. In general, we should adopt this method. Because in this case, the adherence can be avoided, and the energy of atomizing medium can be concentrated, which are helpful to atomization. Certainly, nozzle blocking is not only concerned with the diameter and the outstretching length of leak pipe, but also with temperature of the melt etc. If we do not solve the problem of the combination of jet nozzle and leak pipe, no atomizing will occur.

As shown in Fig. 2(d), it will become the case shown in Fig. 2(a) when pressure of atomizing medium is too high, d_0 is greater than d_1 (the possible maximum diameter of the leak pipe) limited by the structure of jet nozzle. Therefore, after the design of nozzle has been decided, there should has an upper limitation for the pressure, which is worth considering.

As for how swirl-loop-slot nozzle makes the melt atomizing, the research shows that the melt is not atomized by atomizing medium impacting directly[1, 7], but mainly by scissoring of atomizing medium.

It should be point out that when atomizing medium flushs the jet nozzle, the edge of jet nozzle will cause mechanic vibration and propagate outward through atomizing medium. Gas flow moving at high speed, with the help of inner friction(or viscous force), will quickly drive the medium in the circulation of inner side of gas cone to swirl violently. Under the combination action of the vibration and gas swirl, the melt from the leak pipe will be smashed up a lot of melt drops. Therefore, with the help of gas swirling, those melt drops will be taken to the inner side of the medium cone and be further sheared, and will spread with the flowing gas and form a large quantity of fine atomized drops of metal, and then they will become spherical powders due to the action of surface tension. The reason that the atomizing medium can smash the melted metal into powder is that, when the metal was melted, the inner friction force in the metal is decreased, which makes it possible to smash the metal by atomizing medium, here high pressure of atomizing medium is the origin of power force.

As shown in Fig. 3(a), when a drop of melted metal meets the atomizing medium at high speed, it gets a velocity of v at the meeting point then. Referring to the flow character of fluid, its speed will be gradually reduced in the vertical direction, and the velocity gradient is du/dy. Disregarding of the drop's initial speed, its speed will be reduced to zero at last.

When the melt drops meet with fast running atomizing medium, it gets a certain velocity, at the same time it also gets the great acceleration, leading to produce inertia force. When inertia force is greater than the resultant force of the inner friction or the visous resistance (which is proportional to viscosity and gradient

Fig. 3 The velocity distribution and shearing process of a drop of metal

of velocity) and surface tension of the melt drops, melted metal is sheared and smashed (Fig. 3(b)). Obviously, a higher atomizing medium speed can lead to a greater acceleration of the melt because of the greater velocity in a short time can be gotten, i. e. there is a greater gradient of velocity. The greater the acceleration is, the greater the inertia force is. Moreover, the greater temperature of the melt is, the smaller the viscosity is and then the smaller the viscous friction is. These all benefit the melt to be sheared. Actually, shearing is not finished in one time. As long as smashed drops is not cooled, shearing phenomenon will continuously take place due to the turbulence and friction between medium and drops of metal (Fig. 3(c)). It is not difficult to imagine, the nearer the bottle neck to the melt, the more violent the shear action. Because of high speed of the atomizing medium, the melt drops are sheared and brought out before arriving at the internal of the atomizing media. So the outer part of the medium cone does not work much. When the outer cone angle is larger than the inner cone angle, atomizing medium's energy is not so concentrated, which will decrease the efficiency of atomizing. Therefore, the spread angle of medium should be considered while designing a jet nozzle.

3 DESIGN CRITERIA OF THE ATOMIZER

(1) The internal chamber of jet nozzle should be as flat as possible, and its surface should be as smooth as possible so as to reduce process and local losses of high-pressure atomizing media.

(2) The outlet of jet nozzle should not be too narrow in order to increase the velocity of the atomizing medium, otherwise it will cause greater local loss. In addition, in order to ensure the concentration of energy, a reasonable spread angle should be considered while designing the structure of the jet nozzle.

(3) For swirl jet nozzle, loop-slot type should be adoptd because it fits for the character that the angle of outlet varies with the pressure of atomizing medium.

(4) The diameter of the leak pipe should not be less than the diameter at the neck of the hollow double cone caused by atomizing medium, its outstretching length should be reasonable so as to close up the negative pressure zone of the upper gas cone.

4 CONCLUSIONS

(1) Swirl jet nozzle makes atomizing medium swirl out of the nozzle in a spiral pattern and move along the direction of the spiral tangent at the edge of the nozzle's entrance, which won't intersect the central axis of the nozzle. The space angle between tangent and central axis varies with the variation of medium's pressure, so the swirl-loop-slot nozzle should be adopted.

(2) Atomizing medium ejected from swirl-loop-slot nozzle will form a hollow double cone.

(3) The diameter of leak pipe should not be less than that of the neck of atomizing medium hollow cone. The outstretching length of leak pipe must be reasonable so as to close up the negative pressure zone of the upper cone.

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