Exploration on the Structure Parameters of Nozzle-to-Throat Clearance in Vacuum Generator

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Abstract. Nozzle-to-throat clearance is one of the main factors affecting the injection coefficient of the vacuum generator. The increase of nozzle-to-throat clearance will lead to the aggrandizement of the annular duct area which the driving fluid passes, thereby amplifying the ejector flow rate of ejector tube and the injection coefficient. On the contrary, Keenan [1] obtained the result through the experiment that the injection coefficient decreased as nozzle-to-throat clearance increases, because the accretion in nozzle-to-throat clearance would increase the pressure of inlet plane of the mixing chamber, resulting in the decrease of the driving pressure difference of the driving fluid, hence the injection coefficient diminished. In this paper, the numerical simulation method is used to obtain the optimal nozzle-to-throat clearance parameter size.

1. Introduction

With the recovery of the global economy, the manufacturing industry has also gained unprecedented opportunities. In the vacuum industry and the pneumatic industry, the vacuum generator has gradually received extensive attention at home and abroad because of its small size, simple structure, maintenance-free, low noise and convenient control. It can effectively put an end to the delamination of conveying materials and ensure the homogeneity of the composition of the mixture. At present, it is widely used in tablet presses, capsule filling machines, dry granulators, packaging machines, vibrating screens and other machinery for automatic feeding.

However, various types of vacuum generators on the market are currently mixed. Moreover, the theoretical research on the structure of vacuum generators is relatively lacking at home and abroad. There is no corresponding reference standard for the influence of the structural dimensions of different parts of the vacuum generator on its working efficiency. Therefore, in order to meet the transportation requirements in production, the vacuum generator with different specifications is generally adopted for final selection of experiments, but this method is cumbersome and inefficient. This paper mainly discusses the influence of the structural parameters of nozzle-to-throat clearance on the working efficiency of the vacuum generator. By using the method of numerical simulation, the variation curve of different parameters is obtained, and an optimized structure size is found.

2. Effect of Nozzle-to-Throat Clearance on Injection Coefficient

In this paper, under the condition of 0.45MPa/1.5 (working pressure 0.45 MPA, gas compression ratio 1.5), the geometric structural parameters of vacuum generator are kept consistent, and the vacuum
generators with nozzle-to-throat clearance of 5.4, 9.4, 17.4, 21.4, 29.4, 33.4, 37.4 and 37.4 are simulated to explore the effect of nozzle-to-throat clearance on injection coefficient.

Figure 1 shows the variation process of the injection coefficient of the vacuum generator with the change of nozzle-to-throat clearance. It can be seen that the injection coefficient increases at first and then decreases with the increase of nozzle-to-throat clearance, and reaches the maximum at the peak of the curve, so the corresponding nozzle-to-throat clearance is the optimal clearance.

According to the simulation results, the maximum injection coefficient of the vacuum generator designed under the condition of 0.45MPa/1.5 is 0.667, which corresponds to the nozzle-to-throat clearance of 9.4mm. The range of throat nozzle-to-throat clearance calculated by Sokolov[2] based on steam ejector is 25mm ≤ 33mm, which is very different from the simulation results. Therefore, the working fluid medium is different (the working fluid calculated by Sokolov is steam, and the simulation process uses air as working fluid), which has a great influence on the result. Wang Xiuhui[3] studied the application of the ejector in gas recovery, and obtained the maximum negative pressure when nozzle-to-throat clearance was equal to nozzle throat diameter. The larger the negative pressure, the larger the driving pressure difference, and the higher the ejection fluid flow rate, so the injection coefficient is larger. The nozzle throat diameter of this vacuum generator model is 12mm, so when the nozzle-to-throat clearance is close to the nozzle throat diameter, a larger injection coefficient can be obtained, which is consistent with the conclusion of Wang Xiuhui’s experimental research.

Figure 2 is a Mach number cloud diagram of a vacuum generator with nozzle-to-throat clearances (mm) of 5.4, 9.4, 13.4, 17.4, 21.4, 25.4, 29.4, 33.4, 37.4. It can be seen that as the nozzle-to-throat clearance increases, the distance between the Laval nozzle outlet and the inlet of the mixing chamber becomes larger and larger, and the ejector fluid is prematurely mixed with the working fluid in the receiving chamber of the vacuum generator, which lead to the loss of energy. By observing the Mach number cloud diagram of a vacuum generator with nozzle-to-throat clearances of 5.4mm and 37.4mm, it can be seen that when nozzle-to-throat clearance is too large, the supersonic region generated by the working airflow is significantly reduced, and the jet wake is shortened. Although increasing nozzle-to-throat clearance can increase the area of the annular passage through which the ejector fluid passes [4] (ie, the effective cross-sectional area through which the ejector fluid can pass), the injection coefficient becomes lower due to premature loss of energy in the receiving chamber.
Figure 2. Mach number cloud diagram with different nozzle-to-throat clearance

3. The Influence of Nozzle-to-Throat Clearance on Vacuum Degree

Combined with the injection coefficient variation diagram (Fig.1), although the increase of nozzle-to-throat clearance will increase the annular passage which the ejector fluid passes, the ejector flow rate does not increase continuously, which indicates that the annular channel area is not the only factor that determines the flow of the ejected fluid under the conditions of this paper. According to Wang Xiuhui’s research on the ejector, the vacuum degree of the vacuum generator and the vacuum degree of the ejector tube are statistically analyzed.

Figure 3 shows the double-Y coordinate diagram of the injection coefficient and vacuum degree at different nozzle-to-throat clearance. From the vacuum degree, the vacuum degree has no obvious law as nozzle-to-throat clearance increases when the maximum vacuum is generated at 17.4mm, and nozzle-to-throat clearance is in the range of 5-21.4mm. However, the degree of vacuum drops significantly after the throat distance is greater than 25.4. It can be seen that the injection coefficient is inevitably reduced when the vacuum degree of the vacuum generator is small, but the maximum vacuum degree and the injection coefficient are not significantly consistent.

Figure 3. Injection coefficient and maximum vacuum at different nozzle-to-throat clearance

The maximum vacuum of the vacuum generator should be generated at the shock of the nozzle outlet, and due to the instability of the shock, the negative pressure of the injected fluid cannot be visually
reflected. In this paper, the negative pressure in the ejector tube (the pipe into which the ejector fluid enters) is counted to investigate the amount of negative pressure generated by the vacuum generator of different nozzle-to-throat clearances at the ejector tube. Figure 4 shows the pressure curve of the ejector tube in the Y direction. It can be seen that there is a different point in nozzle-to-throat clearance of the vacuum generator, but the maximum negative pressure position in the ejector tube is basically the same. This position is the entrance position where the ejector tube and the receiving chamber intersect. The negative pressure generated is the largest when nozzle-to-throat clearance is 9.4 mm, while the generated negative pressure is the smallest when nozzle-to-throat clearance is 37.4 mm.

**Figure 4. Y direction pressure curve of ejector tube**

Figure 5 shows the double Y coordinate diagram of the injection coefficient and the vacuum degree of the ejector tube at different nozzle-to-throat clearance. It can be seen from the figure that the variation trend of the injection coefficient is basically the same as the vacuum degree in the ejector tube. As the degree of vacuum becomes larger, the injection coefficient also becomes larger, and the injection coefficient of the vacuum is decreased. Therefore, it can be concluded that there is a closer relationship between the injection coefficient and the vacuum of the ejector tube. On the other hand, the ejector fluid is subsonic and its flow velocity is smaller than that of the working fluid, so the greater the vacuum, the larger the negative pressure, the larger the driving pressure difference of the ejector fluid, and the larger the flow velocity of the ejector fluid. Therefore, the flow rate of the ejector fluid becomes larger as the maximum degree of vacuum in the ejector tube. The vacuum degree of the ejector tube is also inseparable from the area of the annular passage. Especially when nozzle-to-throat clearance is too small, the area of the annular passage (the passage of the ejector fluid into the mixing chamber) is reduced. The jet fluid cannot enter the mixing chamber, and the injection coefficient suddenly drops, resulting in a sharp drop in the maximum vacuum within the ejector tube.

**Figure 5. Injection coefficient and maximum vacuum in ejector tube at different nozzle-to-throat clearance**
4. Conclusion
This paper mainly studies the influence of the geometric parameters of nozzle-to-throat clearance of the vacuum generator on the injection coefficient and vacuum degree. By changing the geometric parameters, the data of each group were simulated separately, and finally the optimal nozzle-to-throat clearance of the vacuum generator designed under the working condition of 0.45MPa/1.5 was obtained. And the relationship between nozzle-to-throat clearance and injection coefficient is preliminarily obtained, which provides reference for the structural size design of vacuum generators of other specifications, and plays a certain role in promoting the development of the pneumatic conveying industry.

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