Research of a diametrical fan with suction channel

V E Saitov¹, V G Farafonov², R G Gataullin³, A V Saitov⁴

¹Professor, Viatka State Agricultural Academy, Kirov, Russia
²Associate Professor, Viatka State Agricultural Academy, Kirov, Russia
³Engineer, Viatka State Agricultural Academy, Kirov, Russia
⁴Student, Viatka State Agricultural Academy, Kirov, Russia
E-mail: vicsait-valita@e-kirov.ru

Abstract. Various grain cleaning machines equipped with pneumatic systems are widely used for cleaning grain from impurities, in which as an air-flow generator, diametric fans are increasingly used to create a uniform airflow over the width of pneumatic systems for high-quality grain cleaning. Installation of fans of this type in the pneumatic system of grain cleaning machines in some cases entails the creation of guiding elements in front of its intake part. A diametric fan with a suction channel located in the initial part of the spiral body and allowing it to be assembled into pneumatic systems of grain cleaning machines without additional or special taps has been developed. Theoretical and practical studies have been carried out to determine the depth \( \Delta h \) of the suction channel. It is established that the most rational value of the depth \( \Delta h \) of the suction channel is 0.05 m for a fan with an outer diameter \( D_2 \) of the impeller 0.30 m. The fan has three operating modes. With the suction canal open, suction of dusty air from the sludge chambers, dust catchers or unloading devices of the air systems (the first mode of operation of the fan) or the air flow into the dust-collecting channel can occur along it to avoid precipitation of impurities in it or to a certain working area where it is necessary to separate the forage grain from light impurities (second mode of operation of the fan). The third operating mode of the fan with the suction channel closed ensures that the air flow is only supplied to the delivery pipe.

1. Introduction

An important part of the technology of post-harvest grain processing is its purification from various weed impurities. The various grain cleaning machines equipped with open, closed or combined pneumatic systems, are used to perform these operations [1–8].

In most pneumatic systems of grain cleaning machines, centrifugal fans are used as an air flow generator. These fans do not provide a uniform airflow over the width of the pneumatic systems, which worsens the quality of cleaning the grain material. Therefore, as a generator of air flow, diametric fans are increasingly used to create a uniform airflow along the width of the pneumatic system, which is necessary for a more efficient grain cleaning [9–12].

Installation of fans of this type in the pneumatic system of grain cleaning machines in some cases requires the creation of guiding elements in front of its intake part. Therefore, with the development of universal grain cleaning machines, there is a need for more advanced designs of diametrical fans suitable for performing various functions in the air systems of these machines without the use of additional or special taps.

However, the use of a diametrical fan with a suction channel located in the initial part of the spiral body and allowing it to be assembled into pneumatic systems of grain cleaning machines without additional
or special taps is held back due to the lack of theoretical and experimental information in the scientific and technical literature.

2. Experimental

As an object of researches the experimental exemplar of the diametrical fan with the suction slot located in an initial part of a spiral body is chosen.

The diagram of a diametric fan with a suction channel located in the initial part of the spiral body is shown in Figure 1, and the general view of the experimental installation of this fan is shown in Figure 2.

![Figure 1: Diagram of a Diametric Fan](image)

The diametric fan comprises a spiral body 1 with an inlet window 8 and a discharge nozzle 10 and a rectilinear louver wall 9 separating them, as well as an impeller 2 with forward curved blades 3 installed in the body 1, the body 1 below the entrance edge 7 being provided with a curved louver grating 4, the louveres of which are directed from the impeller 2, and above the entrance edge 7 of the body 1 there is a pivotally fixed continuous curved surface 5 terminating on the fan body 1 at point A behind the curved louver the grating 4 and 6 forming the suction channel [13].

The fan impeller 2 with forwardly curved blades 3 was manufactured with an outer diameter $D_2$ equal to 0.3 m. The rotational speed of impeller 2 was 1060 min$^{-1}$. The width of the experimental setup was 0.1 m. At the output end of the discharge pipe of the experimental installation, replaceable dampers-diaphragms were installed, which made it possible to change the operating mode of the fan.

To measure the air flow parameters in the flowing part of the experimental setup, a Pito-Prandtl tube, a micro manometer MMN and static pressure sensors were used.

In the investigation of the operation of a diametric fan with a suction channel located in the initial part of a spiral case, standard and particular techniques were used, using mathematical and physical modeling, modern instruments and computer technology with a package of programs for processing the results of experiments [14–16].
3. Results and Considerations

In operation of the diametrical fan with the suction channel located in the initial part of the spiral body, the air flow is sucked through the inlet port 8 and injected into the rotary impeller 2, from which it again passes through the impeller 2 and is forced into the pipe 10. The body 1 forms and directs the air flow, coming off the impeller 2, and the wall 9 divides the incoming and outgoing air streams. In this case a large vortex is formed, the center of rotation $O_1$, of which is stabilized by a rectilinear louver wall 9 and is located in the region of the radial clearance $\Delta_2$ between the impeller 2 and the rectilinear louver wall 9. With increasing load on the fan the center of rotation $O_1$ of the large vortex rotates by an angle $\Delta \alpha$. In addition, in the region of the radial clearance $\Delta_1$, between the impeller 2 and the inlet edge 7 of the body 1, a small vortex is formed. As a result of the vacuum created by the rotary impeller 2, a small vortex is displaced along the direction of rotation of the impeller 2 towards the suction channel 6. As a result, additional air flow through the suction passage 6 to the fan casing 1 occurs. However, air sucking through the suction path 6 can occur until such a limit as the flow rate $Q$ exceeds a certain flow limit $Q_{\text{pred}}$ (the first operating mode of the fan), determined by the resistance of the network in which the fan is installed. If $Q$ is less than $Q_{\text{pred}}$ (the second mode of the fan operation), a positive static pressure will be observed in the suction channel 6, and air will be injected from the body 1 into the suction channel 6. This allows the fan to be used to perform various auxiliary operations as part of the grain cleaning machines. To transfer the diametrical fan with the suction channel 6 to the normal (third) operating mode, the articulated solid curved surface 5 is rotated towards the curved louver grating 4, until it contacts the inlet edge 7. In the first and second modes of the fan operation, the total output $Q$ of the diametrical fan will be:

$$Q = Q_1 \pm Q_2,$$

where $Q_1$ is air flow through the inlet window of the diametrical fan, m$^3$/h; $Q_2$ is air flow through the suction channel of the diametrical fan, m$^3$/h.

The signs “plus” and “minus” in the equation (1) indicate whether the air flow is sucked or injected into the suction channel 6. The additional quantity of air $Q_2$ entering (emerging) through the suction channel depends on the area $F$ of the curved louver grating, the coefficient $\mu$ live section, average speed $v_{sp}$ air and is:

$$Q_2 = \mu \cdot v_{sp} \cdot F.$$
Thus, knowing the average air flow rate \( v_{sp} \) and the curved louver grating area \( F \), it is possible to determine the amount of air \( Q_2 \) coming from the suction channel into the air main flow, or vice versa, the amount of air \( Q_2 \) exiting the suction path as the network resistance rises above a certain limit.

However, in practice it is rather difficult to apply equation (2), since it is difficult to measure the average velocity \( v_{sp} \) of the air flow because of the limited space inside the suction channel and the turbulent movements of air near the curved louver surface plates. It can be done more simply by using static pressure sensors installed in the flowing part of the suction channel.

Then the air flow \( Q_2 \) in the suction channel can be determined by the Equation [1, 2]:

\[
Q_2 = \mu_c \cdot \Delta h \cdot B \cdot \sqrt{2 \cdot \frac{P_{sp,s}}{\rho_a}},
\]

where \( \mu_c \) is the flow coefficient, which depends on the Reynolds number \( Re \) and the shape of the hole, \( \mu_c = 0.1 \ldots 0.5 \); \( \Delta h \) is the depth of the suction channel located above the inlet edge of the casing of the diametrical fan, \( m \); \( B \) is useful width of the diametrical fan, \( m \); \( P_{sp,s} \) is average static pressure in the suction channel of the fan, \( Pa \); \( \rho_a \) is density of air, \( kg/m^3 \).

In Equation (3) it is necessary to take into account that the largest coefficient \( \mu_c \) refers to the smallest values of \( \Delta h \), and the smallest \( \mu_c \) refers to the largest values of \( \Delta h \). In addition, the average static pressure \( P_{sp,s} \) should be taken in modulus, and the sign should be taken into account after calculation.

To determine the average velocity \( v_{sp} \) of the air flow passing through the curvilinear lattice, we equate the Equations (2) and (3) and obtain a convenient equation for practical calculations:

\[
v_{sp} = \frac{\mu_c \cdot \Delta h \cdot B}{F} \cdot \sqrt{2 \cdot \frac{P_{sp,s}}{\rho_a}}.
\]

When determining the depth \( \Delta h \) of the suction channel in the zone of the inlet edge of the casing of the diametrical fan, the Equation (4) takes the form:

\[
\Delta h = \frac{\mu_c \cdot v_{sp} \cdot F}{\mu_c \cdot B \cdot \sqrt{2 \cdot \frac{P_{sp,s}}{\rho_a}}},
\]

Next, determine the average static pressure \( P_{sp,s} \) in the suction channel:

\[
P_{sp,s} = \frac{\mu_c \cdot v_{sp} \cdot F}{\mu_c \cdot \Delta h \cdot B \cdot \sqrt{2 \cdot \frac{P_{sp,s}}{\rho_a}}},
\]

It is not possible to analytically determine the value of \( \Delta h \), since the values of the average speed \( v_{sp} \) and the static pressure in the suction channel depend on the load on the diametrical fan and are determined by its aerodynamic properties. Therefore, the rational value of \( \Delta h \) and its influence on the aerodynamic characteristics of the diametrical fan has been studied experimentally.

Figure 3 shows the dependence of the air flow velocity \( v_{sp} \) on the performance of a diametrical fan with a change in the depth of its suction channel \( \Delta h \) from 0.05 m to 0.15 m.

The analysis of the dependencies shows that they can be divided into a two-part conditional imaginary axis \( Q_{pred} \): the "\( Q_2 \)" zone (the region of positive static pressures) and the zone "\( +Q_2 \)" (the region of negative static pressures). In the "\( Q_2 \)" zone, the air flow is pumped from the fan casing to the suction channel, and from there to the atmosphere, while the fan flow is reduced by \( Q_2 \). This part of the dependencies graphically has the form of descending curves. In the "\( +Q_2 \)" zone, phenomena opposite to the "\( -Q_2 \)" zone occur and the dependencies have the form of linear functions. In general, analyzing Figure 3, it can be noted that the curves \( v_{sp} = f(Q) \) are uniform and congruent to each other. This indicates the stability of the speed mode in the suction channel of the diametrical fan.
Figure 3. Dependences of airflow velocity $v_{sp}$ on the performance $Q$ of a diametrical fan with a change in the depth of the suction channel, where 1 is at $\Delta h = 0.05$ m; 2 is at $\Delta h = 0.10$ m; 3 is at $\Delta h = 0.15$ m.

Thus, the highest airflow rates over the entire range of fan performance change are observed at $\Delta h = 0.05$ m. This is also confirmed by the dependence $v_{sp} = f(\Delta h)$ shown in Figure 4 with the maximum air flow rate $Q_{\text{max}} = 1300 \text{ m}^3/\text{h}$ and by the nominal flow rate $Q_n = 1070 \text{ m}^3/\text{h}$.

Dependence analysis shows that when the depth of the suction channel $\Delta h$ decreases, the air flow speed $v_{sp}$ increases and at the value $\Delta h = 0.05$ m reaches the maximum values. The interval of variation $\Delta h$ from 0 to 0.05 m from the technical and economic point of view is inexpedient, since the design $\Delta h < 0.05$ m requires rather accurate manufacturing of the diametrical fan design, especially for grain cleaners with a wide air path.

Figure 4. Dependences of the air flow speed $v_{sp}$ from the depth $\Delta h$ of the suction channel of the diametrical fan at different capacities $Q$.

Investigation of the qualitative structure of the air flow in the delivery nozzle of a diametrical fan with a suction channel located in the initial part of the spiral housing showed that at values of $\Delta h = 0.05; 0.10$ and 0.15 m, the maximum rate variation coefficients $\gamma$, respectively, are 0.034, 0.067 and 0.078. This determines the stable operation of the fan.

4. Conclusion

Thus, on the basis of the conducted experimental studies of a diametrical fan with a suction channel located in the initial part of the spiral body, it follows that the most rational value of the depth $\Delta h$ of
the suction channel is 0.05 m or $\Delta h = 0.17 D_2$. At the same time, changing the operating mode of the diametric fan, you can use the suction channel to perform various functions. When the diametric fan is operating in the $Q > Q_{\text{pred}}$ mode, it is possible to extract dusty air from the sedimentation chambers, dust collectors or unloading devices of the air systems without creating additional branches from the suction nozzle of the fan, thereby exporting a dusty air stream for repeated dust cleaning. When the diametric fan is operating in the $Q < Q_{\text{pred}}$ mode, it is possible to direct the air flow into the dust-collecting channel to avoid precipitation of impurities therein or to a certain work area where it is necessary to separate the feed grain from light impurities. With the suction port closed, the air flow is only supplied to the delivery pipe.

References
[1] Saitov V E 2012 Innovations in post-harvest processing of grain material (Saarbrucken: Lap Lambert Academic Publishing) (in Russian)
[2] Saitov V E et al 2012 Investigation of processes in working bodies of grain separators (Saarbrucken: Lap Lambert Academic Publishing) (in Russian)
[3] Blenk H and Trier H 1951 Grundlagen der Landtechnik 2 17–25 Retrieved from URL: http://440ejournals.uni-hohenheim.de/index.php/Konstrukteur/article/view/1210/1053
[4] Wessel I 1963 Grundlagen der Landtechnik 18 27-34 Retrieved from URL: http://440ejournals.uni-hohenheim.de/index.php/Konstrukteur/article/view/1212/1056
[5] Saitov V E et al 2013 International Journal of Applied and Fundamental Research 2 Retrieved from URL: http://www.science-sd.com/455-24419
[6] Murata S and Nisihara K 1976 Bulletin of JSME 129(19) 314-321
[7] Mechanical Seed Cleaning and Handling Agriculture Handbook 354 Retrieved from URL: https://naldc.nal.usda.gov/download/CAT87208718/PDF
[8] Schwanz H and Kutter W 1980 Agratechnik 30(11) 495-497 Retrieved from URL: http://440ejournals.uni-hohenheim.de/index.php/agratechnik/article/viewFile/5985/5691
[9] Coester R 1959 Theoretische und experimentelle Untersuchungen an Querstromgeblasen (Zürich: Mitteilungen aus dem für Aerodynamik) 28
[10] Finkbeiner T 1966 Landtechnischen Forschung 16(3) 96-99 Retrieved from URL: http://440ejournals.uni-hohenheim.de/index.php/LTF/article/view/8833/8763
[11] Laakso H 1957 Heizung-Luftung-Haustechnik 8(12) 324-325
[12] Furuno Y et al 2008 Journal of the Japanese Society of Agricultural Machinery 3(70) 58-64
[13] Bolotov A K et al 2000 RF Patent 2156380 Byull. Izobret. 26 (in Russian)
[14] Zaydel A N 2009 Errors in measuring physical quantities (Moscow: Lan’) (in Russian)
[15] Gmurman V E 2015 Theory of Probability and Mathematical Statistics (Moscow: Urait Publishing House) (in Russian)
[16] Leontiev V P 2014 Work on the computer 2014: Windows 8.1 (Moscow: OLMA Media Group) (in Russian)