Study of mutual work of Coanda channels in local ventilation systems

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Abstract. Today, the Coanda effect is widely used in many technical areas, in particular, ventilation systems. However, this effect occurs only when a certain combination of many factors affecting the moving stream. The occurrence of the Coanda effect is unstable and is easily disturbed when interacting with another air flow of a non-coincident trajectory. The article describes the method of air supply, which consists in the use of two channels arranged in series in which a stable Coanda effect occurs. The arising effect is explained by the interpretation of the fundamental laws of hydrodynamics. The article presents the results of an experiment on the use of the proposed solution in the recirculation system of aspiration, with the use of which there was an increase in the efficiency of work by 51%

1. Introduction.
To maintain the required microclimate parameters in the rooms, ventilation systems are used, which can be classified into general ventilation and local ventilation. General exchange ventilation systems are designed to supply and remove air directly throughout the room. Local ventilation is designed to supply fresh air to certain places (local ventilation) or to remove polluted air from the places of formation of harmful emissions (local exhaust ventilation). Local exhaust ventilation is used in cases where places of harmful emissions (various dust, harmful gases, odors) are localized and it is possible to prevent their distribution throughout the room. Thus, the use of a local ventilation system can significantly reduce the energy consumption of ventilation systems by localizing the source of harmful emissions.

One of the rational and promising ways of organizing the movement of air flow in both general exchange and local ventilation systems is the Coanda effect. According to the established scientific terminology, the term “Coanda effect” implies several different aero-hydrodynamic phenomena [1], named for the Romanian inventor, who found them practical application by developing several devices [2-5] using one or more of the following flow properties.

One of the fundamental scientific papers on the Coanda effect is the work of Newman [6,7], which contains the results of a study of two-dimensional flow around a circular cylinder (the flow diagram is shown in Figure Figure 1). Newman noted that the Coanda effect when moving along a curved surface is a consequence of the balance of centrifugal force and radial pressure [6,8]. When the jet leaves the nozzle, due to the presence of viscous flow resistance and a solid wall, its contact pressure with the surface is lower than the ambient pressure. This pressure drop is the main cause of flow adhesion and
curved surface. The contact pressure along the surface increases and gradually reaches the value of atmospheric, which causes the separation of the jet from the surface.

![Figure 1. The scheme of the experimental plant Newman [6].](image)

The effect was most widespread in jet pneumatic automation [9-12], but it was not necessary to create a significant theoretical basis for this branch of technology, since only the final position of the jet is determined: the presence of a deviation from the original direction. The Coanda effect is also used in heat and power engineering: it is necessary when operating chamber furnaces of all designs.

The use of the Coanda effect allows to increase the efficiency of ventilation networks due to the formation of flat jets for various tasks. In systems of general ventilation exchange, the Coanda effect is very important, where without its consideration it is impossible to reliably design effective ventilation systems in buildings and rooms [13]. There are also designs of local exhaust ventilation systems using this effect [14-16]. However, the stable Coanda effect occurs only when a combination of certain parameters of both air movement and the design of the channel, which is not always observed. Despite the widespread use of the Coanda effect in various branches of technology [17-18], as well as the initiation of international projects and conferences [19,20], there is a lack of information about the behavior of the Coanda currents [21].

2. Relevance

Consider one of the particular cases of using the Coanda effect in local exhaust ventilation systems: aspiration. Initially, we proposed a method of using the Coanda effect when feeding recirculated air into the reloading chute [15] when the channels are located opposite each other.

However, the use of this solution is not suitable for overloading the material along the vertical chute ($\alpha = 90^\circ$), with certain concerns due to the possibility of material falling into the distribution channel. At the same time, in practice, in most cases, the use of inclined chute takes place, in this connection the use of the structure [15] is unacceptable due to the blockage of the Coanda channels. Therefore, for this reason, a different design of the recirculation aspiration system was developed, which is characterized by the location of the Coanda channels in series with one upper side of the chute [16].

Having previously investigated the work of this design, the authors identified a pattern of the influence of the simultaneous operation of several channels Coand arranged in series, which led to an increase in overall efficiency.

Thus, the identification of the effect and the study of the mutual work of several channels Coand arranged in series is a very urgent task in ventilation systems.

3. Problem statement.

Consider the work of the presented system (Figure 2) in more detail: air is sucked out from the lower cover 2 by the fan 5 through the aspiration tube 4, this air flows through the pressure tube 6 to the inlet of the dust-cleaning device 7 to separate the air-dust concentrate. The purified air through the tube 8
enters the atmosphere or the next stage of cleaning, and the air-dust concentrate due to the bypass pipe 9 is discharged into the distributors 10 of air-dust concentrate located on the upper edge of the reloading chute in series. Distributors 10 of air-dust concentrate provide the supply of air-dust concentrate in the chute 3 through the air Coanda channels 11. At the same time, due to the special form of the air Coanda channels 11, ensuring the occurrence of the Coanda effect, the flow of air-dust concentrate “sticks” to the chute, which allows to increase the angle between the directions of movement of the air-dust concentrate and the air dusty stream moving in the flow. This is explained by the fact that on the one side of the jet of air-dust concentrate the surface of the chute 3 prevents free flow of the air dusty stream, and on the other side the part of the air dusty stream is carried along. As a result, the aerodynamic resistance of the system increases, which reduces air consumption.

The flow rate of the ejection air entering along the chute $Q_g$, is defined as, [22]:

$$Q_g = \frac{F \left( P_e \pm P_{ob} + \Delta P_u \right)}{0.5 \rho \sum \xi},$$

where $F$ – is the cross-sectional area of the chute; $\sum \xi$ – the sum of local resistance coefficients along the path of the ejection air; $P_{ob}$ – is the pressure in the executive devices of the aspirated equipment; $\Delta P_u$ – is the pressure difference caused by the effect of local exhaust (negative pressure in the cover $\Delta P_u$); $P_e$ – is the ejection pressure.

The hydraulic resistance of the system is determined by the total coefficient of local resistance, calculated by the formula:

$$\sum \xi = \xi_v + \xi_g + \xi_n,$$

where $\xi_v$, $\xi_g$, $\xi_n$ – is local resistance coefficients respectively of the upper cover (of the feed conveyor), chute and lower cover (receiving conveyor), related to the air velocity in the chute.

The coefficient of local resistance is determined from the equation of pressure loss on local resistance:
\[
\Delta P = \xi \frac{\rho V^2}{2}
\]  

(3)

where \(\Delta P\) – is the pressure differential, Pa; \(V\) – average velocity over the cross section of the channel in question, m/s; \(\rho\) – is the density of the moving stream, kg/m\(^3\).

Summing up, it can be noted that the task of introducing Coanda channels is to create the greatest aerodynamic resistance to the movement of ejection air \(\xi\\ g\), thereby reducing its consumption [22,23].

To confirm the effect of the mutual influence of the Coanda channels, it is necessary to compare the values of \(\xi\\ g\) for the two options, which is the objective of the study of this article.

4. Study results and discussion.

To study the parameter, we specified, we used the COSMOSFloWorks software complex [24], whose work is based on the Navier–Stokes continuity equation and the stationary spatial flow energy in accordance with the k-\(\varepsilon\) turbulence model.

Studies were carried out for two versions of designs differing in the number of channels. The initial parameters of the experiment were identical, namely, the rate of air entry into the transshipment chute, the volume of air supplied, geometric identity. When studying a variant with two channels, their width \(h\) (Figure 3) was taken to be half the width with one channel, so that the total consumption air flow was equal.

![Figure 3. Current lines (trajectories of air movement) constructed for two variants of the Coanda channels under the same initial conditions: the speed at the entrance to the Coanda canal is 10 m/s, the pressure difference in the upper and lower sections of the reloading chute is 20 Pa.](image)

After analyzing the results of the experiment, we confirmed that when using two channels performed sequentially, an additional Coanda effect really occurs. In particular, for the case of Figure 4, the consumption of ejected air decreased from a value of 0.174 m\(^3\)/s to a value of 0.085 m\(^3\)/s which corresponds to 51\%. The coefficient of local resistance of the reloading chute \(\xi\\ g\) (2), calculated from (3) in this case increased from \(\xi_1 = 9.2\) to \(\xi_2 = 37.9\), that is, 4.11 times.

5. Theoretical part.

Let us try to give a theoretical explanation of the additional emerging Coanda effect, for which we use the fundamental hydrodynamic equation — the Bernoulli equation for an ideal fluid:
\[ z_1 + \frac{P_1}{\rho g} + \frac{U_1^2}{2g} = z_2 + \frac{P_2}{\rho g} + \frac{U_2^2}{2g} = H \] (4)

According to this equation, the sum of static and dynamic pressures is a constant value. In the upper stream No. 1 under consideration (Figure 4), there is the greatest speed, thereby determining a high \( P_{\text{din}} \) value and, therefore, a low \( P_{\text{st}} \). Coanda stream 2, moving in parallel, will be pressed to flow 1 due to the differential static pressures in section 3 and 1, in total increasing thus the effect of Coanda used. This assumption is fully confirmed by the results of our experiment: in Figure 3,a) one can observe a pronounced Coanda effect when using two channels, while at the same time using one channel it is almost absent due to the effect of pressure differential on it.

Thus, our assumption of increasing the operating efficiency of several Coanda channels arranged in series is fully confirmed: the movement of Coand flows becomes much more stable, less susceptible to the influence of other air flows.

6. Conclusion.
The article was first considered the effect that occurs when using two Coanda channels located in series. The experiment showed that the use of the proposed air supply scheme greatly enhances the Coanda effect, its appearance is fully explained theoretically by the Bernoulli equation. When using the proposed scheme of circulating air supply, the reduction in the flow rate of the ejected air was 51\%, and the value of \( \xi \) increased 4 times, which ultimately will affect the energy consumption of aspiration systems and general ventilation. The identified effect can be widely used in various areas of ventilation and air conditioning, however, it is necessary to develop a method for calculating it, which is a further topic of research by the authors.

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