A NEW VACUUM GENERATOR BASED ON TORNADO-LIKE VORTEX FLOW

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Abstract. In this paper, a brand new design to generate the vacuum effect is proposed. The basic idea is to imitate the geometry of a tornado. It is well-known that tornado is one of the severest natural disasters in the world. However, tornado is also able to generate a huge vacuum suction force to lift cars and even houses on the ground into the air. Using CFD simulations, a novel vacuum generator based on tornado-like vortex flow is successfully designed and implemented. This new structure is totally different from the traditional vacuum generator based on the Bernoulli's equation. Finally, two traditional nozzle-type vacuum generators are chosen for the purpose of performance comparing. Experimental studies prove that the new tornado-like vacuum generator can generate acceptably large vacuum pressure while the consumed volumetric airflow-rate is kept at a low level.

Keywords: Pneumatics, Vacuum Generator, CFD, Tornado, Vortex Flow.

INTRODUCTION

In the middle and west area of United States, tornado is perhaps the severest natural disaster because the damage caused by tornados cannot be estimated every year. It is also observed that the geometry of a tornado is similar to a funnel as shown in Fig. 1. That is, the diameter of the tornado is smallest near the ground surface. On the other hand, tornado is also able to generate a huge vacuum suction force to lift cars and even houses on the ground into the air. In this paper, a brand new design to generate the vacuum effect is proposed. The basic idea is to imitate the geometry of a tornado. Such a novel design is totally different from the traditional vacuum generator which is based on the Bernoulli's equation. In details, traditional vacuum generator utilizes nozzles to produce the airflow jet. The pressure will significantly decrease if the velocity of airflow jet increases. One typical structure is shown in Fig. 2. However, such a technique is quite old though it is still accepted by engineers nowadays. One significant feature of this study is the utilization of CFD-simulation to find the most suitable structure and dimension for a novel tornado-like vacuum generator. An experimental test rig is also constructed to verify the design. In the following, the design using the CFD-simulations will firstly be outlined.

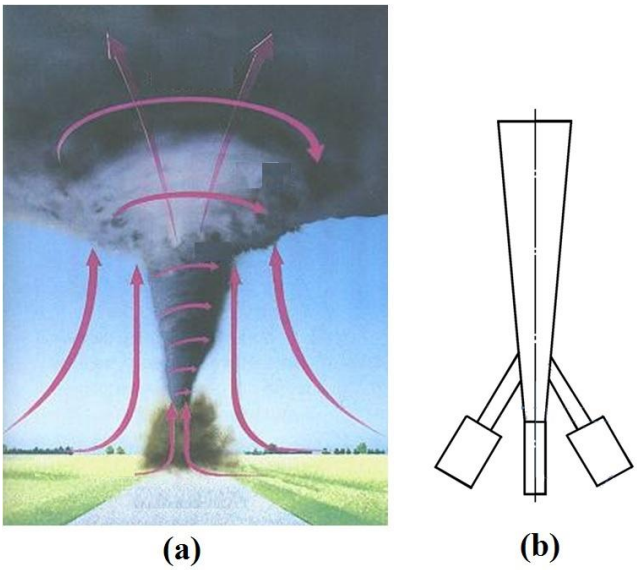


FIGURE 1. (a) A tornado, (b) Funnel shape structure to imitate a tornado.

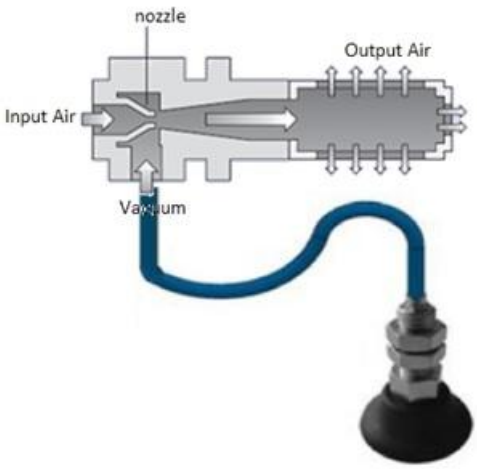


FIGURE 2. Typical structure of traditional vacuum generator.

DESIGN BY CFD-SIMULATIONS

Figure 3 shows the most important design parameters for the CFD simulations, which include the number of eccentric inlet ports, the diameter of the inlet restrictor (φ_r), the diameter of the vacuum pressure port (φ_v), the inclined angle of inlet port (α), the expansion angle of the tornado-like funnel (β) and the height of vortex flow (H). In addition, only one parameter is adjusted at a time while the rest parameters are kept unchanged. Thus, after numerous CFD simulations, a most suitable design configuration for the tornado-like vacuum generator can be determined as shown in Fig. 4. It is observed that two eccentric inlet ports at both sides and one vacuum pressure port at the bottom are constructed. The former is used to generate the vortex flow. From previous literatures [1-4], it was already proved that the vortex flow can be used to develop non-contact pneumatic suction pads. In this paper, however, the flow path of the vortex is guided to move upwards to establish a flow field which is very similar to a tornado. Table 1 summarizes the corresponding values of design parameters. In details, two inlet ports with restrictor diameter φ_r = 1.0 mm, the vacuum pressure port diameter φ_v = 2.0 mm, inclined inlet angle $\alpha = 15^o$, funnel expansion angle $\beta = 5^o$ and the height of vortex flow H = 35 mm are found to be the most suitable structure and dimensions. Figure 5 depicts an example of pressure distribution of the most suitable design using CFD simulation. It is observed that the negative pressure, which is generally called the vacuum pressure, occurs at the vacuum pressure port. The real picture of the developed prototype is shown in Fig. 6. Moreover, to verify this design, a test rig will be established and a series of experiments will be conducted in the following sections.

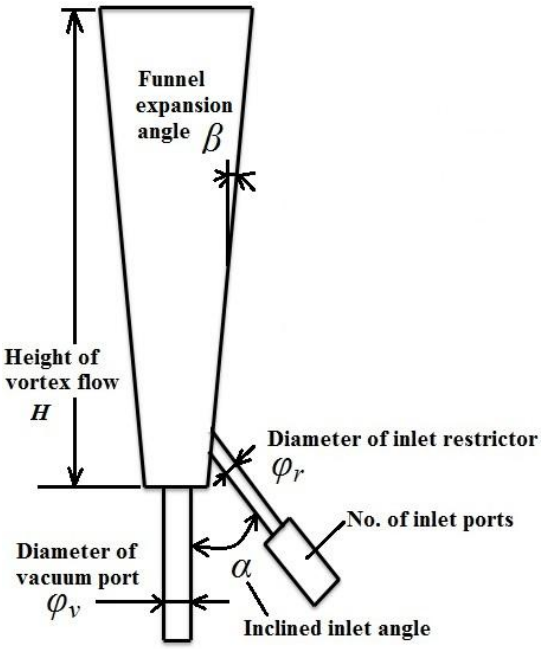


FIGURE 3. Most important design parameters for the CFD simulations.

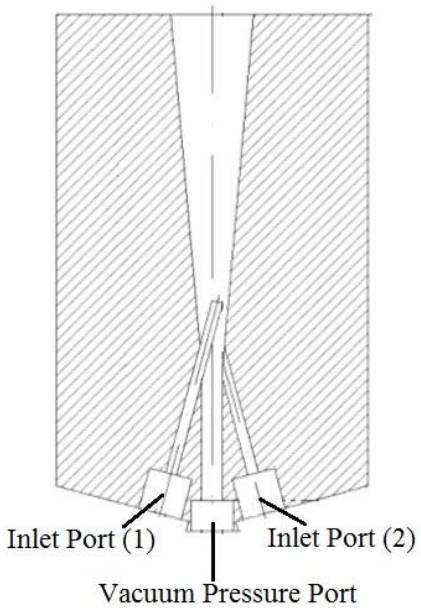


FIGURE 4. Most suitable design configuration for the tornado-like vacuum generator.

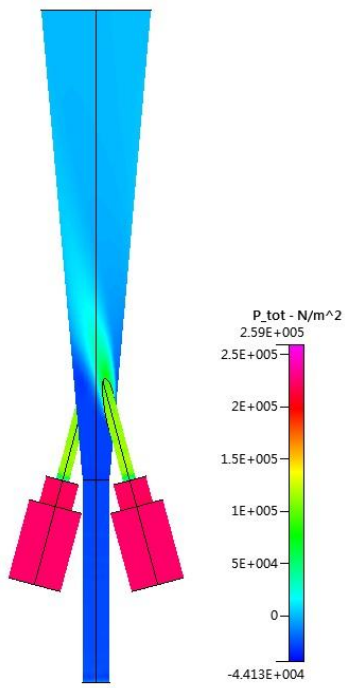


FIGURE 5. An example of pressure distribution of the most suitable design using CFD simulation.

TABLE 1. Values for the most suitable design parameters.

Parameter	Value
No. of inlet port	2
Inclined inlet angle α	15°
Funnel expansion angle β	5°
Diameter of inlet restrictor φ_r	1.0 mm
Diameter of vacuum port φ_v	2.0 mm
Height of vortex flow H	35 mm

FIGURE 6. Real Picture of the developed prototype.

EXPERIMENTAL TEST RIG

To test the performance of the developed vacuum generator based on tornado-like vortex flow, a test rig is constructed and its scheme is shown in Fig. 7. The inlet pressure to the vacuum generator can be adjusted from 0.5 to 10 bar by manually adjusting the pressure reducing valve (No. 4). Besides, a vacuum gauge (No. 10) is utilized to measure the generated vacuum pressure and a flow-rate meter (No. 8) is used to record the consumed volumetric airflow-rate.

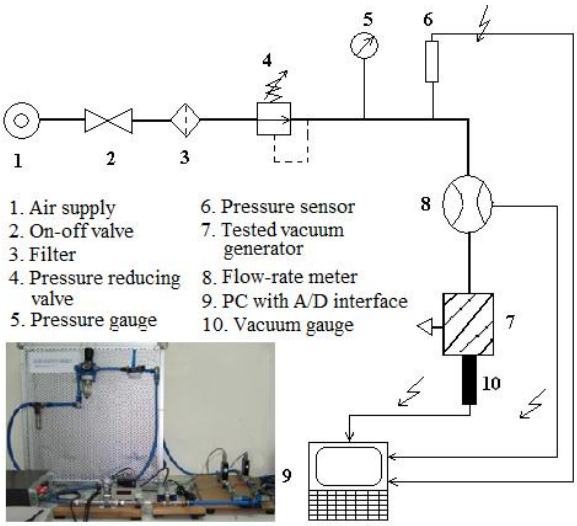
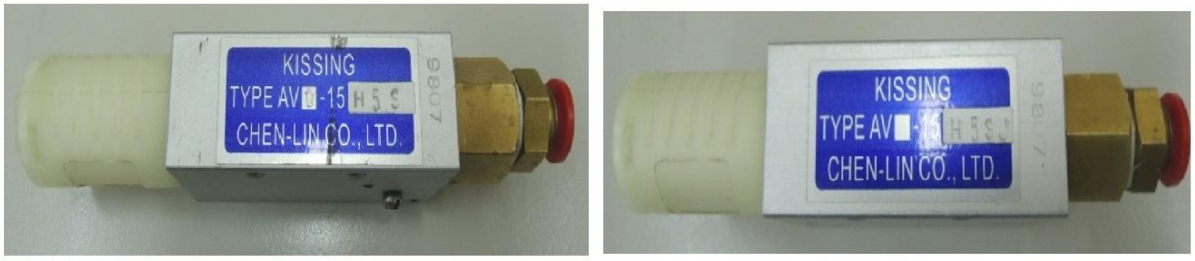


FIGURE 7. Scheme of the test rig.

TEST RESULT AND DISCUSSION

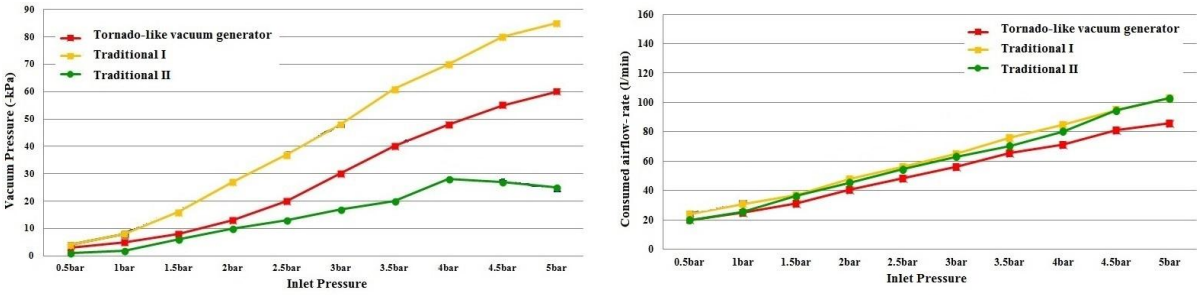
First of all, two traditional nozzle-type vacuum generators with type number AVD-15H5S (denoted as Traditional-I) and AV-15H5SJ (denoted as Traditional-II) are chosen as shown in Fig. 8. The generated vacuum pressure and the consumed volumetric airflow-rate are two indices for comparing the performance. The former is obviously the key performance, and the latter represents the degree of energy efficiency. Generally speaking, the absolute value of generated vacuum pressure is higher corresponding to a larger inlet pressure. However, the consumed volumetric airflow-rate will also be higher meaning that more power is needed. From the viewpoint of generated vacuum pressure, as shown in Fig. 9 (a), the performance of the proposed new vacuum generator is better than Traditional-II, but worse than Traditional-I. Moreover, form the viewpoint of energy efficiency or consumed volumetric airflow-rate as shown in Fig. 9 (b), the proposed new vacuum generator is the best among three tested vacuum generators. It is worth mentioning that even though the proposed new vacuum generator is

not the best regarding the key performance, the absolute value of vacuum pressure of 60 kPa at the inlet pressure of 5 bar is good enough for real industrial applications.



(a) **(b)**

FIGURE 8. Two traditional nozzle-type vacuum generators chosen for comparison, (a) Traditional-I; (b) Traditional-II.



(a) **(b)**

FIGURE 9. (a) Comparison of generated vacuum pressure, (b) Comparison of consumed airflow-rate.

CONCLUSION

In this paper, both simulation and experimental studies prove that the new tornado-like vacuum generator can generate acceptably large vacuum pressure while the consumed volumetric airflow-rate is kept at a low level. However, it is still possible to do more research and apply other optimal design criterion in this area to further improve the performance in the future. Nevertheless, it can already be concluded that the currently developed vacuum generator based on tornado-like vortex flow is not only a successful new idea but also a potential alternative for future vacuum generator design. It is expected that such a novel tornado-like vacuum generator can find some potential applications in the real industry.

ACKNOWLEDGMENTS

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