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Experimental investigation of fan for personal protection equipment – influence of number of blades

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1. Introduction

The aim of research is development of new generation of powered air purifying respirators designed to filtrate contaminants in the form of gases, vapours and particles. These high performance units guarantee sufficient protection of the wearer even in heavy industrial environments, the chemical industry, laboratories and the pharmaceutical industry [4].

To help people while breathing through filter, a fan is used to propel air flowing in personal respiratory protection systems and units. Because, the reliability and efficiency are crucial for operation of these systems, our work is focused on improvement and optimization of a centrifugal fan used.

2. Methods

An example of the geometry of the impellers examined can be seen in Fig. 1. Two types of wheels were examined: with radial vanes with an inlet blade angle $\beta_1 = 90°$ and an exit blade angle $\beta_2 = 90°$, and backward curved vanes with various inlet and outlet angles. Around 15 variants with different numbers of various blades were investigated by experimental, numerical and theoretical methods. All wheels fort testing with diameter $d_2 = 60mm$ and width $b_2 = 4mm$ were produced by 3D printing technology [1].

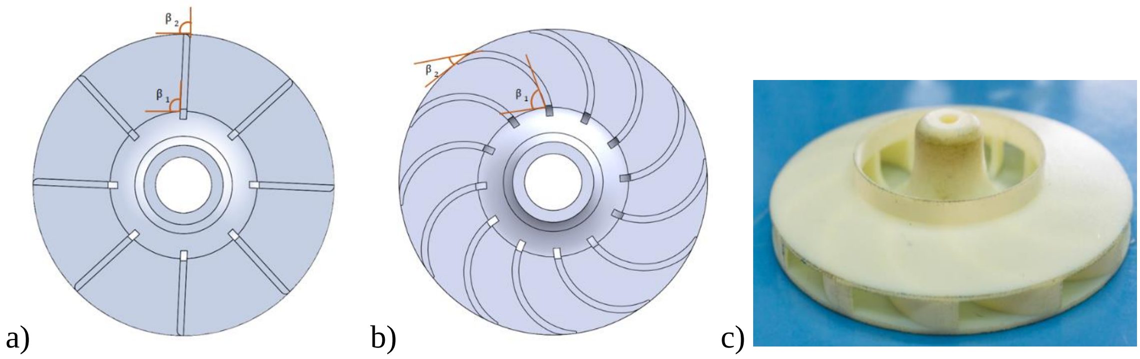


Fig. 1. Investigated wheels – a) radial blades, b) backward blades, c) a wheel manufactured by 3D printing technology

2.1 Theoretical Background

The theoretical increase of the total pressure Δp_{th} in a radial fan is described by the Euler equation

$$\Delta p_{th} = \rho(c_{2u}u_2 - c_{1u}u_1), \tag{1}$$

where c_u is a component of the total velocity in the direction of the peripheral velocity u, where indices 1 and 2 denote an input and an output point, respectively. As can be seen from the above relationship, it does not affect the number of blades in any way. However, the number of blades affects the individual losses that occur and which reduce the total achieved pressure Δp_{th} to the actual Δp. These losses include impeller inlet and outlet losses, directional input loss, pre-swirl loss or internal volumetric leakage. Among the most significant losses is the so-called inter blade circulation loss, which is caused by the finite number of blades z and the only one affects their number. The swirl loss between the blades is expressed by the formula

$$\Delta p_{blade} = \rho(u_2) r\omega, \tag{2}$$

where ω is the rotational speed of the impeller is r the radius of the imaginary circle between two blades, which can be expressed from the blades output angle β_2 as

$$r = \frac{\pi d_2 \sin\beta_2}{2z}, \tag{3}$$

in which d_2 is the impeller diameter and z is the number of blades. The resulting relationship for inter blade circulation loss is given by the relationship

$$\Delta p_{blade} = \rho u_2^2 \frac{\pi \sin\beta_2}{z}. \tag{4}$$

It is clear from the above relationship that loss by the finite number of blades is very significant and grows strongly with a small number of blades. Nevertheless, it should not be forgotten that with the increasing number of blades there are other losses, which, however, are often not taken into account: more blades cause a reduction in flow cross section and hence reduce flow volume and friction losses in the inter-bladder channel increase. The resulting power fan characteristic is shown in Fig. 2 on the left.

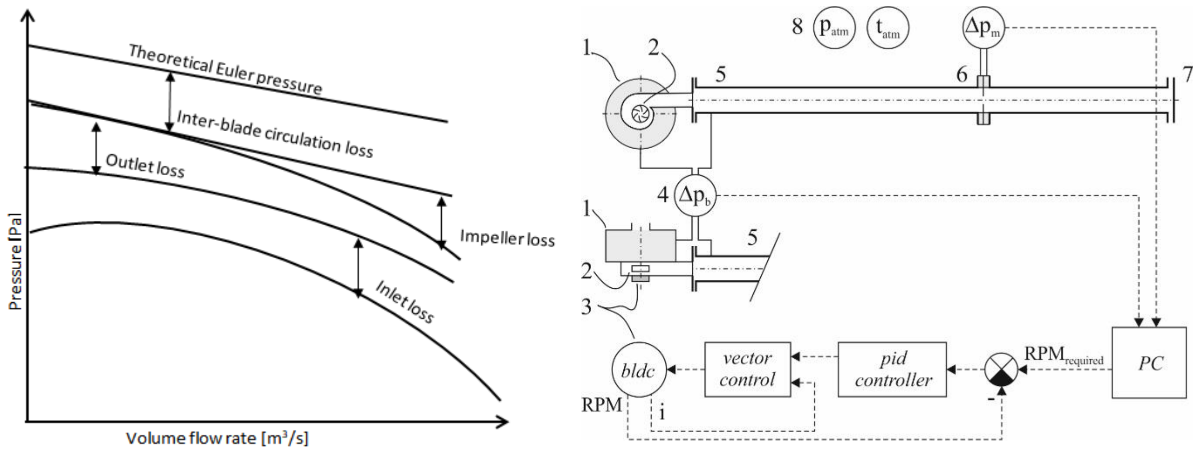


Fig. 2. (on the left) power curve of centrifugal fan, (on the right), testing stand: 1 – suction chamber with filter assembling, 2 – fan wheel, 3 – brushless DC motor, 4 – working pressure measuring (Δp_b), 5 – outflow tube, 6 – differential pressure Δp_m measuring for mass flow specification, 7 – chocking, 8 – measuring of atmospheric pressure and temperature

2.2 Experimental Investigation

The testing stand is visible in Fig. 2 on the right. The fan wheel (2) was propelled by electronically controlled brushless DC motor (3). To obtained power curves of a fan, rotations were specified directly and kept constant during measurements [1].

The air was sucked through suction chamber (1), which allowed assembling of filters, and was compressed and transported into the outflow tube (5). The back pressure and thus the working pressure Δp_b of the fan was controlled manually by chocking (7) at the tube exit and measured by differential pressure transducer. The mass flow rate was measured by orifice (6), where differential pressure Δp_m is measured.

3. Results

The curves obtained experimentally and predicted for the radial blade wheels are plotted in the diagram in Fig. 3 on the left. As can be seen from the results, the experimentally found deviations between the measured data for a different number of blades are almost negligible. With a small difference, the twelve-blade wheel, which exhibits a higher pressure, especially for higher flow rates, is optimal. The worst case is the 8-blade wheel, while the 16-blade wheel lies somewhere in between. In contrast, the results obtained theoretically differ considerably for a wheel with a different number of blades, see relation (4). The 8-blade wheel is the worst, while the 16-blade is the best. It is also evident that further increases in the number of blades will have less and less influence. Comparison of theoretically obtained and experimentally measured data shows the best match for a twelve blade wheel, while the results for the 8 and 16 blades differ considerably.

Similarly, the results for a wheel with 8 and 12 backward curved blades with blade angles $\beta_1 = 80°$ and $\beta_2 = 85°$ are shown in Fig. 3 on the right. Here too, the differences between the two wheels found experimentally are negligible and we can see good agreement with the theoretical calculation for the 12 blades, but the high mismatch for the 8-blade wheel.

Very similar results were obtained for backward curved blades with angles $\beta_1 = 60°$, $\beta_2 = 76°$ and also for angles $\beta_1 = 40°$, $\beta_2 = 68°$ (not presented in diagrams). Also with these wheels there is a relatively good match between the predicted and measured characteristics for the 12-blade wheel, the influence of the number of blades on the measured curves is negligible and the predicted curve for 8 blades is significantly underestimated.

The results of the research on the influence of the number of blades on a rear-angled low angle blade ($\beta_1 = 45°$, $\beta_2 = 30°$) are presented in Fig. 4, where we can observe the results of testing for 10, 12 and 14 blade wheels and numerical calculations for the wheels with 8 to 16 blades. Here, too, we see that the effect of the number of blades is minimal, but wheels with a lower number of blades seem to be advantageous for high flow rates, while a higher number of blades is more favourable for high back pressure. Nevertheless, the differences between the wheels are negligible.

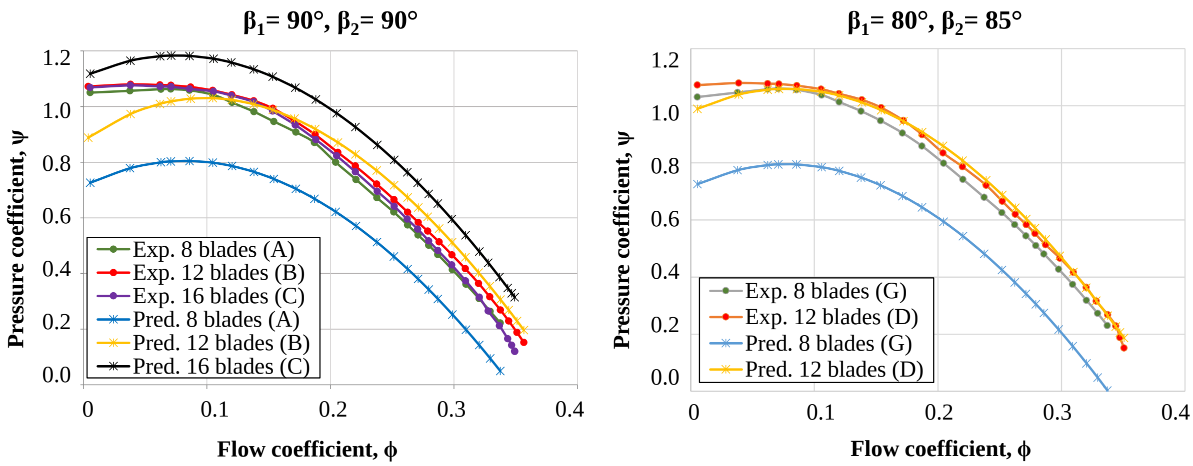
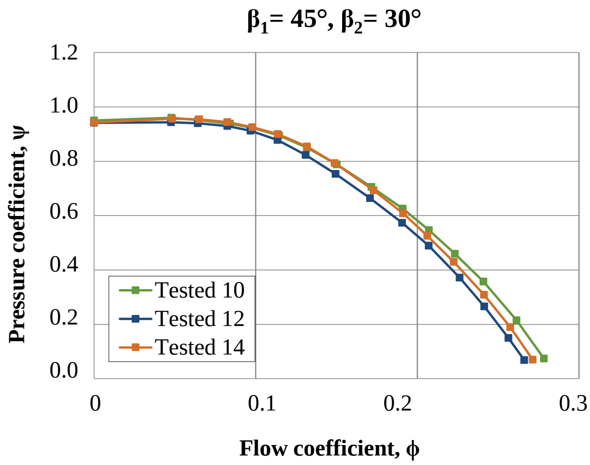


Fig. 3. Results for wheels with 8, 12 and 16 radial blades (on the left), results for wheels with 8 and 12 backward curved blades (on the right), $\beta_1 = 80°$, $\beta_2 = 85°$ [3]



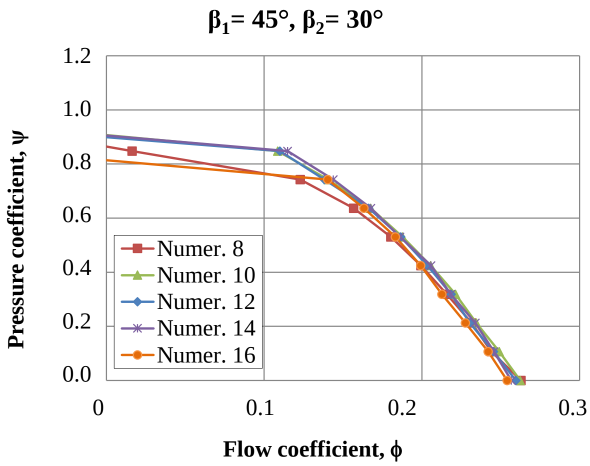


Fig. 4. Results for wheels with 8 to 16 backward blades with angles $\beta_1 = 45°$, $\beta_2 = 30°$ obtained experimentally (on the left) and numerically (on the right) [2]

4. Discussions

The results show that the influence of the number of blades on the characteristics of the fan is very small, sometimes almost negligible. The ideal number of blades appears to be 12 for the wheel under investigation, but neither the number 8 nor the 16 shows too much difference in the achieved values. The results show that theoretically determined influence of the number of blades on pressure loss due to inter blade circulation loss is considerably overestimated. Apparently this is due to the fact that in the calculations the number of blades is included only in this loss, which perceives the increase in the number of blades only positively and does not include accompanying influences – e.g. reduction of the characteristic dimension of the inter-blade channel.

5. Conclusions

Research into the influence of the number of blades on the characteristics of a radial fan has shown that the number of blades only slightly influences the performance of the fan. According to the test results, 12 blades seem to be optimal regardless of their shape. Numerical calculations show similar results. The predicted curves visibly overestimate the effect of inter blade circulation loss and do not count on additional losses at a higher number of blades. In order to optimize and predict the appropriate number of blades, the fan flow analysis model will need to be further modified.

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