OPTIMALIZATION OF FUNCTIONAL PROPERTIES OF RADIAL FANS

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The article describes the process of optimizing the design of functional parts of radial fans. The main goal was to improve their performance characteristics. The proposed methodology was experimental measurements and the testing station had been built. After processing the results of the experiment the best fan construction option was chosen with optimum performance characteristics.

KEYWORDS

fan, optimization, experimental tests, airflow, performance characteristics, delivery pressure

1 INTRODUCTION

An essential factor in assessing the quality of buildings is the state of its internal environment, ie. internal microclimate and its creation through the ventilation systems. To ensure optimum internal microclimate of buildings of different types is therefore fundamental choice of ventilation equipment for ventilation or air conditioning. Design and operation of these devices requires the application of new knowledge, ensuring their high operational reliability and decreasing energy consumption.

Part of any forced ventilation system is the fan - a rotary blade machine which is used to transport air. The article describes the design optimization process of functional parts of the radial fan RVE-P 630, which is being manufactured by Ekotechna s.r.o. Presov. The aim was to improve the performance characteristics of this type of industrial fans. To achieve this goal two tasks were set:

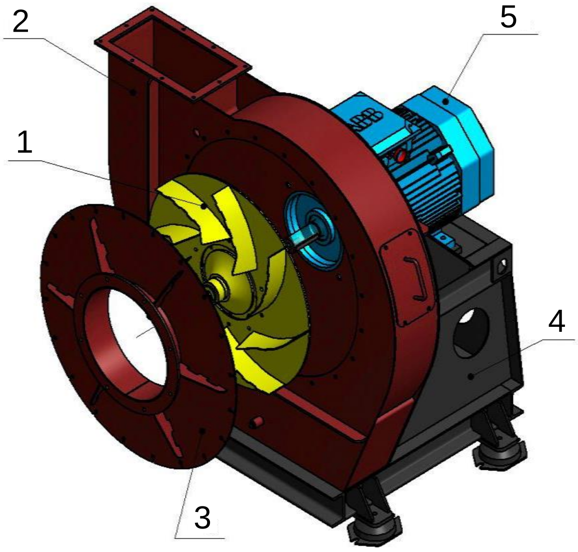
- Proposals for appropriate structural adjustments of the blades of the fan wheel RVE-P 630 with respect to achieving the highest possible air velocity and volumetric air flow.
- Draft methodology for measuring the performance characteristics of different types of industrial fans.

2 INDUSTRIAL USE AND TECHNICAL CHARACTERISTIC OF THE FAN TYPE RVE - P

Fans RVE - P are radial high-pressured industrial fans powerd directly by electric motors. The impeller is mounted directly on the motor shaft. These fans have also control equipment that can be connected. There are two design types of these fans, either classic or armored, in which the impeller and spiral conver are reinforced for example by resistant steel. Power transfer and vibration are minimized by dynamic balancing of impellers [Ekotechna 2017].

Fans RVE - P are used primarily in the engineering industry, normally for filtration or dust removal in power plants, heating plants, cement plants, lime works, quarries, filtration equipments and many other industrial applications. Fans with a standard design installed directly on the shaft transport clean or slightly polluted air without abrasive particles at a temperature in the range -20 ° C to 70 ° C, or if connected to the clutch the temperature range is changed to 20 ° C to 250 ° C. For transporting air with abrasive the armored version of the fan is used. These fans are not built for the transport of explosive, toxic and hazardous mixtures [Ekotechna 2017].

The main parts of the fan RVE-P are shown in Fig. 1.



1 FAN WHEEL
2 FAN CHAMBER,
3 FRONT COVER - INTAKE APERTURE
4 MOUNT
5 ELEKTRIC MOTOR

Figure 1. Model of the fan created in Autodesk Inventor Professional

2.1 Technical Parameters of Fan

The main parameters of fans are overall traffic pressure, airflow and power consumption. Airflow Q determines the amount of air (usually with the air density ρ = 1.2 kg.m^{-3}), which is the ventilator able to transport. Total delivery pressure of fan Δp_d characterizes the fundamental characteristic of the fan to ensure the flow of air in a piping network. Total delivery pressure covers the pressure loss of the piping system including losses in dynamic pressure discharge [Gebauer 2005].

Fan power P is given by the product of the air volumetric flow Q and the overall transport pressure Δp_d.

$$P = \Delta p_d \cdot Q \quad [\mathrm{W}] \tag{1}$$

Fan power consumption P_P is the ratio of fan power P and the overall effectiveness η_o, which is defined as the ratio between performance and power consumption of the fan.

$$P_P = \frac{P}{\eta_o} = \frac{\Delta p_d \cdot Q}{\eta_o} \quad [\mathrm{W}] \tag{2}$$

Δp_d - overall transport pressure of fan [Pa]
Q - airflow [m^3/s]
η_o - overall efficiency of the fan [-]

For fans energy evaluation the Specific Fan Power Input SFP is used. It is given by the ratio of the electric power input of fan P_P in the air distribution systems and the air flow Q for the proposed load (total transport pressure):

$$SFP = \frac{P_P}{Q} = \frac{\Delta p_d}{\eta_o} \quad \left[\mathrm{W \cdot s/m^3}\right] \tag{3}$$

2.2 Performance characteristics of fans

Properties of fans are deifned by their performance characteristics:

- Pressured characteristics - $\Delta p_d = f(Q)$
- Power consumption characteristics - $P_p = f(Q)$
- Efficiency characteristics – $\eta_o = f(Q)$

Performance characteristics specified by the manufacturer in fan catalog are determined standardly for the ideal air density (ρ = 1,2 kg/m^3).

2.3 Fan testing

The characteristics of the real fans are determined experimentally. The measurement procedure is defined regarding STN standard EN ISO 5801 *„Industrial fans - Performance testing using standardized airways.“*, STN 12 30 61 *„Air engineering. Fans. Rules for measurement“* and STN ISO 10780 *“Stationary source emissions. Measurement of velocity and volume flowrate of gas streams in ducts*.“

The fan is usually connected by discharge port to measuring track and the pressure and airflow are being measured. For the testing of the fan type RVE-P, we chose the ability to connect the fan suction port on the measuring track. The reason was the fact that about 90% of fan installations, Which are manufactured and delivered by the company Ekotechna s.r.o., is working on the principle of suction.

Fan power consumption is measured either mechanically by dynamometer, or more offten by electric wattmeter. The process of measurement starts by outlet opening on measuring track where relevant parameters are being measured. Then the opening is gradually closing.

Pressure and air flow are usually measured using various types of flowmeters. In this case was used the Prandtl tube, which uses changes in kinetic energy of the flowing fluid to pressure. It is suitable for measuring high speed fluid flows. Instantaneous velocity of a flowing fluid is determined at the point of immersion tube, and requires laminar and uniform flow. Tube is composed of a cylindrical probe with a rounded face and a support tube which extends across the measuring cross-section (Fig. 2). In the head of the cylindrical probe with diameter d is the inlet opening. Fluid flowing through this hole is routed to the differential nanometer, which is used for measurement of the total pressure p_c of flowing fluid. Along the perimeter of the cylinder at a distance 3d are sampling holes for static pressure p_s measurements. The holes are placed at the point where the value of dynamic pressure reaches zero.

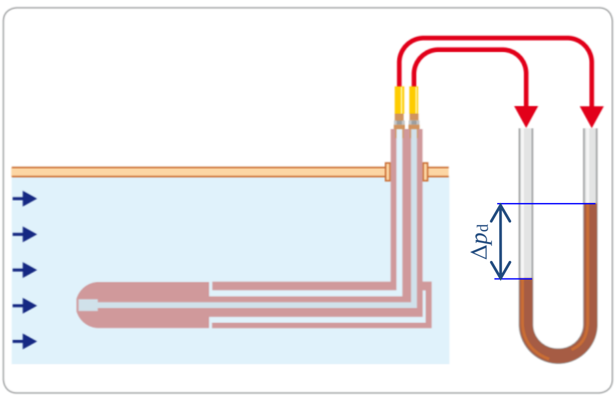
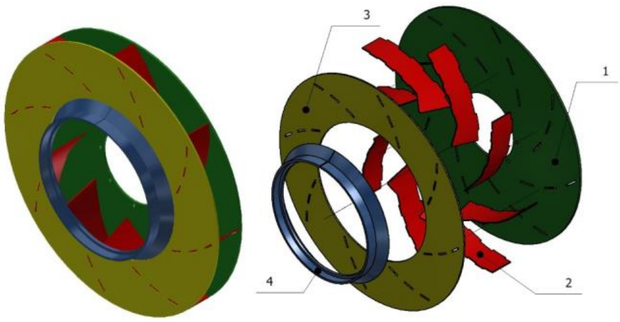


Figure 2. Measuring the speed of fluid flow using Prandtl tube

3 DRAFT OF CONSTRUCTIONAL ADJUSTMENT OF THE IMPELLER

In the design optimization adjustments we assumed that the greatest influence on the performance characteristics of the fan is the design of the impeller [Pavlenko 2016b], respectively the shape and position of the blades (2 and Fig. 3) of the wheel.



1 BACK PLATE WHEEL
2 BLADES
3 FRONT PLATE WHEEL
4 SUCTION PORT

Figure 3. The basic parts of the impeller fan RVE-P

The shape and dimensions of the main parts of the impeller remained unchanged (1,2,3,4 in Fig. 3). For the type of fan it was proposed eight alternative combinations of changes of blades inclination and blades tilt of the impeller - Table 1.

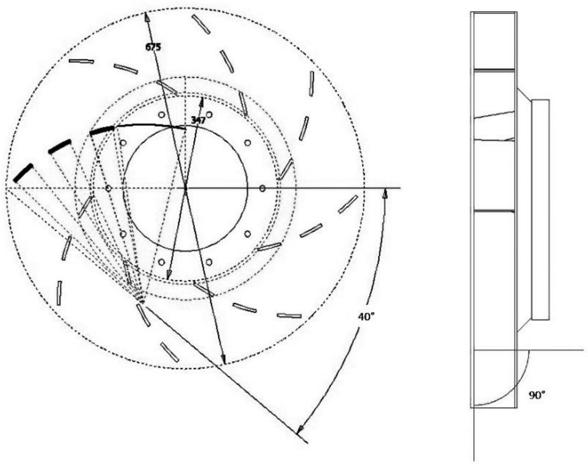


Figure 4. The initial state: the inclination of 40 ° and 0 ° tilt of blades in the impeller.

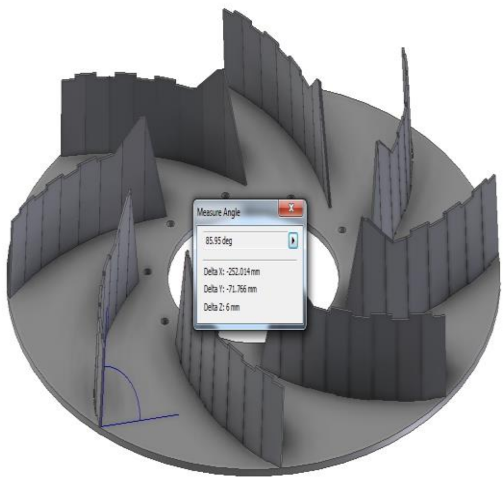


Figure 5. Impeller. 5 ° tilt

Fan type:	RVE-P 630
Type of impeller:	5N.
Change of blades tilt, Fig. 5	0°, 5°, 10°, 15°
Change of blades inclination	30°, 35°, 40°, 45°, 50°

Table 1. Draft of constructional adjustment of imepller

4 DESIGN AND PRODUCTION OF PROTOTYPES OF FAN WHEEL

The CAD system Autodesk Inventor Professional was used to model each part and a digital model of the fan in its the original construction design. Modifying the inclination angle and tilt of the blades of the impeller, as proposed in Table 1 there were created 8 alternative design solutions of fan RVE-P 630 impeller.

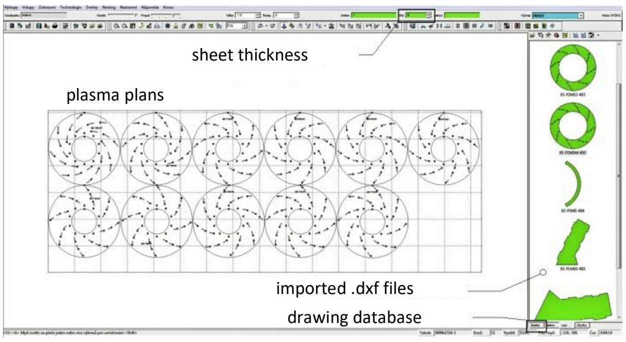


Figure 6. Plasma plans creation

Figure 7. Plasma cutting

All components of the impeller were indexed in modeling process as a Sheet Metal (plates). Therefore it was aslo possible to generate the 3D models in an unfolded shape. The particular faces of unfolded parts and flat components were exported to .dxf format, which were imported into the Wrykrys application.

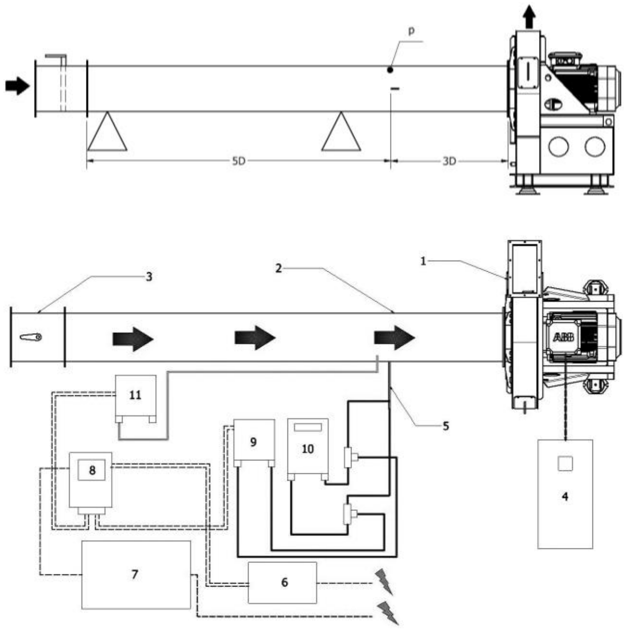
Wrykrys is CAD / CAM software for technological preparation of production for plasma cutting CNC machines, it ensures the accuracy and quality. Plasma plans were craeted (Fig. 6), the technical documentation of plasma plans was created (Fig. 7) and the CNC program. After the components burn out, forming and welding all alternatives of impeller were assembled.

5 EXPERIMENTAL MEASUREMENTS

Functional analysis of RVE fan-P 630 was carried out according to a pre-established plan of measurement on the test station with the appropriate measuring and diagnostic equipment - Fig. 8. Measuring track, measurement procedure and processing of the experimental measurements results were designed and realised in accordance with valid standards [STN ISO 10780].

Fan type:	RVE-P 630
Type of impeller:	**5N.**
Manner of Measurement:	Measurement scheme – Fig. 8
Calculated quantities:	Velocity, Airflow.
Measured quantities:	Temperature, Humidity, Differential Pressure, Static Pressure, Noise, Power Consumption, Load.
Measurements at speed of:	975 rpm, 1475 rpm, 2950 rpm

Table 2. Measurement plan



1 Industrial fan RVE –P 630
2 Measuring pipeline
3 Throttle Flap
4 Frequency converter
5 Prandtl tube
6 Power point
7 Computer
8 Data Logger
9 N - pressure sensor
10 Secondary pressure controller
11 Primary pressure controller
▬▬ Rubber tubes
– – – – – – Electric wiring and cables

Figure 8. Measurement scheme

The measuring instruments and diagnostic equipment:

- ST-8820 - 4 v 1 Multifunctional meter of environment
- Electric source MLS424.1
- N - pressure sensor
- Prandtl tube
- Data Logger
- Vibrationmeter N30

Measurement procedure:

1. Preparation the workplace (installation of measuring track), preparation of measurement and diagnostic instruments.
2. Preparation of the test impeller (assembly and welding blades, mounting the wheel to the hub).
3. Installation of the impeller to the shaft of the fan.
4. Analysis of the vibrational state of the wheel using Vibrometer.
5. Dynamic balancing of the impeller when the vibration exceeded the tolerance value.
6. Installation of the test pipe on the suction side of the fan.

Figure 9 Measuring track for experimental tests on fans [Wittner 2015]

7. The check of the measurement and diagnostic equipment, technical preparation for writing data, the definition of control parameters of Data logger (two-channel recorder).
8. Launch of Data logger (two-channel recorder) and with the help of a frequency converter the start of electric motor to the desired speed for the particular alternative measurement.
9. Measurement of physical parameters (Table 2) by means of measurement and diagnostic devices according to the design plan.
10. Backup of measurement data suitable for analysis and further processing to the storage medium.
11. Removal of the test pipe – Fig. 10. Replacement impeller for other alternative. Repeating the measurement procedure.

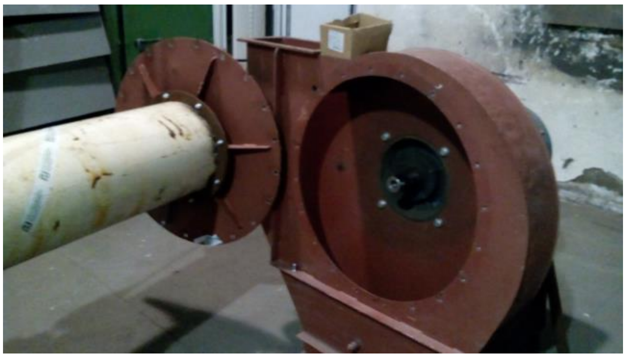


Figure 10: Removing and Replacing Fan Wheel [Wittner 2015]

Eight series of measurements was executed (8 alternatives Fan Wheel). After mounting each impeller of fan has gradually undergone a tests at three different electric motor speeds (Table 2).

The measurement was followed by the start of the electric motor at 975 rpm and fully closed throttle flap. The flap was gradually opening approximately every 20-30 seconds of 10 degrees, to release the air flow. Subsequently, the motor speed increased to 1475 rpm, respectively. to 2950 rpm and then the process with the throttle flap was repeated.

From the measured data the air flow was calculated:

1. Calculation of air density ρ based on measurement conditions as [STN ISO 10780]:

$$\rho = \frac{p \cdot M}{R \cdot T} \quad \left[\mathrm{kg} \cdot \mathrm{m}^{-3}\right] \tag{4}$$

p – atmospheric pressure [Pa]

M - molar mass [kg·mol^{-1}]

R - universal gas constant [J·mol^{-1}·K^{-1}]

T - temperature [K]

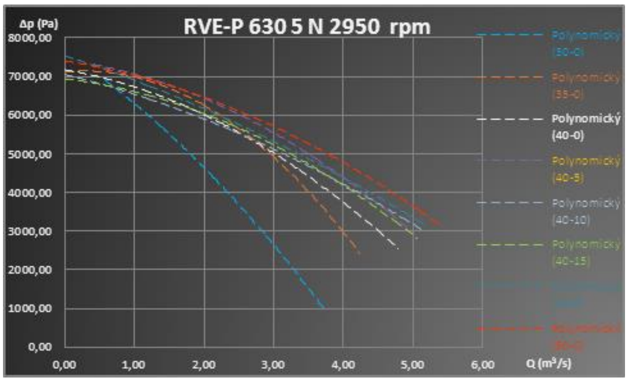


Figure 11. Pressure characteristic - 2950 rpm

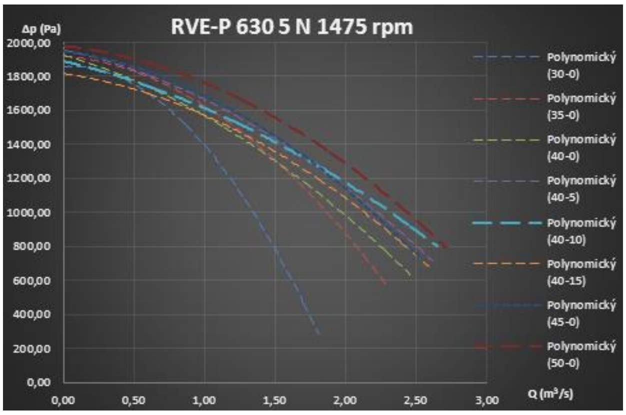


Figure 12. Pressure characteristic - 1470 rpm

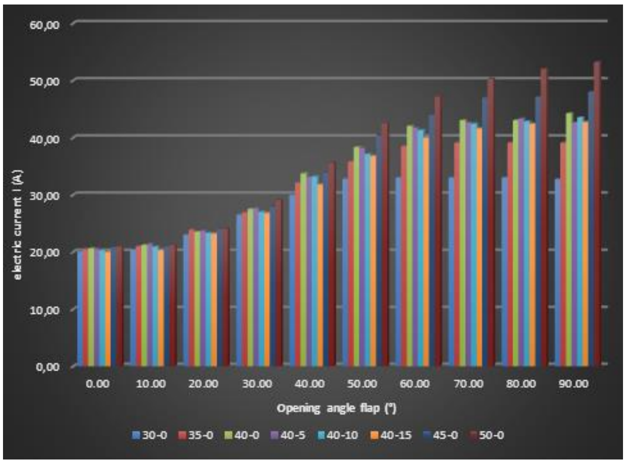


Figure 13. Power consumption at 2950 rpm

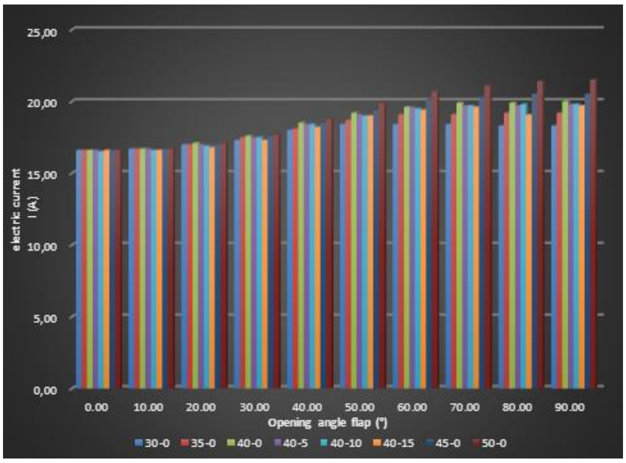


Figure 14. Power consumption at 1475 rpm

2. The calculation of the flow velocity v based on measured values of differential pressure $\Delta p_d = (p_t - p_s)$:

$$v = \sqrt{\frac{2 \cdot \Delta p_d}{\rho}} \quad [\mathrm{m \cdot s^{-1}}] \qquad (5)$$

Δp_d – differential pressure [Pa]
p_t – total pressure [Pa]
p_s – static pressure [Pa]

3. Calculation of volumetric airflow Q regarding the flow velocity and cross-section of the measurement pipeline S:

$$Q = v \cdot S \quad [\mathrm{m^3 \cdot s^{-1}}] \qquad (6)$$

Measured and calculated values were being processed in the form of graphs (Fig. 11 - 14).

6 DISCUSSION

In Figure 11, there are the fan pressure characteristics for particullar design alternatives. As the most favorable in terms of volumetric airflow the structural design of wheel blade with tilt of 50 degrees was recommended. With this angle of the blades the maximum flowrate has been reached, but this was reflected in the high power consuption and the electric motor load. Considering the electric power consuption, simply for optimal and efficient operation is most suitable design of the impeller of the fan blades with the 45° inclination. The measured values also shows that tilt of the blades has an impact on power characteristics. Impact of blades tilt is not as significant as the impact of the blades inclination. The best results were reached with the impeller with blades 10° tilt.

Table 3. The final optimization recommendation

Fan type:	**RVE-P 630.**
Type of the impeller:	5N.
Optimization of inclination of the blades:	30°, 35°, 40°, **45°**, 50°.
Optimization of the blades tilt:	0°, 5°, **10°**, 15°.
Power consuption at maximum power of the electric motor (2950 rpm – 50 Hz)	**48** A

7 CONCLUSIONS

Experimental tests of radial fans were conducted at the request of the manufacturer, the company Ekotechna Ltd. Prešov. There was a condition that tests on fans will be carried out in the environment near to real operation. The testing station and the methodology for measuring and evaluating the performance characteristics of fans had been designed. The accuracy of experimental design was verified and confirmed by the example of optimization of the functional properties of the radial ventilator RVE L-630. The result was the optimum draft design of the impeller of the industrial fan, where it was achieved the most favorable ratio of volumetric flow and the energy consumption. Based on the processing methodology for the measurement and gained knowledge and experience, the company can use diagnostics fan for maintenance, repair, inspection and servicing of own products or to offer the service to other manufacturers of various types of fans.

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