Stress–strain behavior of discontinuous blades for axial mine fans

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Abstract. The study is aimed at designing of blades such that preserve strength at the tip speed not higher than 140 m/s. Because of high rotary speeds, cast blades lack the wanted strength. Thus, it is necessary to design light-weight blades to increase rotary velocity fans. Using the finite element method in ANSYS, strength calculations are performed for blades of varied cellular structures; the stress and strain patterns versus rotor speed are obtained. The cellular structure blades made of aluminium alloy AK7 allows 1.8 times increase in the rotor speed and delivery of an axial fan series VOD.

1. Introduction
High productivity mines need increasingly much air fed to underground openings using main mine fans. For instance, with increasing output of cutter–loaders and length of longwalls, methane release grows in the working area of the cutting machine as well as from broken coal on conveyor [1, 2]. Dilution of high methane concentration needs much more air than with operation of lower capacity machines. Thus, the problem of design and manufacturing of high-delivery main fans was and is of the high concern.

Mining industry in Russia widely uses axial main mine fans. Capacity of these fans mainly depends on the impeller diameter and rotor speed. Designers of main fan are set a task to engineer axial fans of higher capacity at the preserved sizes of the currently operating fans, i.e. 1.6–4.0 m. This objective is reached by speed up of the impeller rotation. In this case, it is required to improve strength both of impeller and its blades [3]. This paper discusses designs of impeller blades such that fulfill the strength condition at the tip velocity of blades not more than 140 m/s.

2. Methods and materials
The most popular axial mine fans in operation since the 1980s in Russia are the fan series VOD [4, 5]. The tip velocity of blades of these fans is 78.5 m/s. The blades are manufactured as weld-and-riveted cast assemblies. Such blades are heavy. As their tip velocity is increased, the inertial force considerably grows. This, in its turn, brings the requirement to reinforce the body of impeller, which increases the weight and inertia moment of the impeller [6]. Thus, in order to enhance delivery of fans by means of speeding up rotation, it is necessary to reduce weight of blades. For this reason, the blades are made of aluminium allows by casting. As a result, the tip velocity of such blades is increased to 100–105 m/s.

The table 1 describes characteristic of aluminium alloys suitable for manufacturing of blades [7, 8]. The ultimate stress limit largely depends on process conditions of casting and thermal treatment.
Table 1. Characteristics of materials of blades

| Description                        | Value                        |
|------------------------------------|------------------------------|
| Elasticity modulus $E$, Pa         | $69 \cdot 10^9$              |
| Poisson’s ratio $\mu$              | 0.27                         |
| Ultimate stress limit $\sigma_F$, MPa | 185–485 (subject to shipment) |
| Yield stress $\sigma_Y$, MPa       | 95–415 (subject to shipment)  |

The further acceleration of the impeller to 140–150 m/s needs stronger blades made of materials with $\sigma_Y > 300$ MPa, which makes the fan cost essentially higher. We propose to make cellular blades as shown in Figure 1.

Figure 1. Cellular structure blade.

Let us discuss efficiency of such blades in terms of its operation in a Kuzbass mine.

The required aerodynamic performance can be achieved by modernization of fans VOD-40 [9–11]. The modernization means replacement of two-stage rotor by single-stage rotor and use of a higher speed motor (Figure 2). With rotor replacement, a new impeller is designed with blades meant for specific aerodynamics of mine ventilation, which allows high efficiency of 0.8–0.9.

Figure 2. Fan VOD-40: (a) before modernization; (b) after modernization.

3. Results

We performed the stress–strain analysis of a cast blade made of aluminium alloy AK7 for fan VOD-40. The calculations were carried out in ANSYS [12–13] based on the finite element method [14–16].
We used 3D finite elements in the form of tetrahedron, with ten nodal points each having three degrees of freedom. Figure 3 shows the distribution of the von Mises stresses \([17, 18]\) in a blade, while Figure 4 offers the plot of the maximum stresses by von Mises versus the rotor speed.

**Figure 3.** Stress distribution in blade of fan VOD-40.

**Figure 4.** Maximum stresses in blade versus rotor speed: 1—stress–rotor speed curve; 2—stresses \(\sigma_F\); 3—stresses \(\sigma_T\); 4—allowable critical stresses; 5—allowable yield load.

The analysis shows that by the strength criterion, considering safety factor, the ultimate speed of the fan rotor with cast blades is 460 rpm. This is off the required speed of the modernized fan of 510 rpm, which ensures the desired aerodynamic performance of the fan.

Now, let us perform the stress–strain analysis of the blade of the cellular structure show in Figure 1. The calculations are carried out in ANSYS. Figure 5 demonstrates the distribution of the equivalent stresses by von Mises on the work and subsidiary surfaces of the blade. The stress distribution in the cellular structure blade is presented in Figure 6.
The stress–strain analysis yields that the new structure blade ensures the required factor of safety at the speeds up to \( n = 700 \text{ rpm} \) (146 m/s). Thus, the allowable tip speed of such blades is 1.8 times higher than the tip speed of the series-produced machine [5].

4. Conclusion
The cellular structure of blades made of aluminium alloy for impellers of axial fans series VOD allows the rotor speed to be increased 1.8 times. Accordingly, the fan delivery grows the same. This
achievement is feasible due to the considerable reduction in the blade weight and, consequently, the normal inertia force.

References

[1] Ordin AA and Timoshenko AM 2015 Reduction of coal bed methane release under high-rate advance of production face J. Min. Sci. Vol 51 No 4 pp 779–784
[2] Lebedev AV 1998 Major safety problems and their solution in coal mines in Russia Ugol No 9 pp 59–61
[3] Krasyuk AM and Russky EYu 2013 Stress–strain and frequency analysis of impellers of axial main mine fans GIAB No 8 pp 152–156
[4] Krasyuk AM and Lugin IV 2007 Investigation of the dynamics of air flows generated by the disturbing action of trains in the Metro J. Min. Sci. Vol 43 No 6 pp 655–661
[5] Krasyuk AM, Russky EYu and Popov NA 2012. Estimating strength of high-loaded impellers of large-size mine axial fans J. Min. Sci. Vol 48 No 2 pp 314–321 DOI 10.1134/S1062739148020128
[6] Krasyuk AM and Russky EYu 2012 RF Patent No 2484310 Axial fan impeller Byull. Izobret. No 16
[7] Botlon W 2011 Materials for Engineering 2nd Edition New York: Routledge
[8] Pisarenko GS, Yakovlev AP and Mateveev VV 1988 Handbook on Strength of Materials Kiev: Naukova dumka (in Russian)
[9] Babk GA, Bocharov KP, Volokhov AT et al 1982 Axial Mine Fans of Main Ventilation. Handbook Moscow: Nedra (in Russian)
[10] Krasyuk AM 2006 Ventilation in Subway Tunnels Novosibirsk: Nauka (in Russian)
[11] Russky EYu 2018 Analysis of dynamic parameters of mine fans IOP Conference Series: Earth and Environmental Sciences Vol 134 Conference 1 Article 012051
[12] Chigarev AV, Kravchuk AS ad Smalyuk AF 2004 ANSYS for Engineers: Reference Book Moscow: Mashinostroenie (in Russian)
[13] Paul A. Durbin and Gorazd Medic 2007 Fluid Dynamics with a Computational Perspective Cambridge University Press ISBN: 052185017
[14] Bazhenov VA 2005 Numerical Methods in Mechanics Moscow: Vysshaya shkola (in Russian)
[15] Bakhvalov NS, Zhidkov NP and Kobelkov GM 2003 Numerical Methods Moscow: nauka (in Russian)
[16] Krasyuk AM and Russky EYu 2013 Stress–strain analysis and vibration of twinblades of axial main mine fans GIAB No 6 pp 192–200
[17] Russky EYu, Lugin IV, Kosykh PV, Alferova EL and Kiyanitsa LA 2016 Research and engineering of aerodynamics and design parameters for axial fans with the various hub/tip diameter ratios 16th International Multidisciplinary Scientific Geoconference SGEM 2016 Bulgaria: Albena Vol II pp 727–734
[18] Kosykh PV, Krasyuk AM and Russky EYu 2018 Influence of adjustable electric drive on bending vibrations of mine fan rotor J. Fundament. Appl. Min. Sci. Vol 5 No 2 pp 255–260