A case study on exhaust fan – FEM analysis

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Abstract. This paper presents a case study for an exhaust fan rotor made from elements assembled through bolted joints. For this design of the rotor and normal operating conditions the fan achieve the field of resonance, conducting to the failure of rotor bearing assembly, and finally of the entire fan. The finite element method (FEM) is used to study the stress, strain and natural frequencies of the fan rotor. The FEM analysis proves that a rotor with welded construction eliminates the disadvantage of the resonance phenomenon occurrence in the range of the normal operating speed.

1. Introduction
Complex dynamic structures are a continuous challenge for the designers. In this case, a static and dynamic optimization by analytical model becomes very complex, a Finite Elements Analysis (FEM) being usually used.

The recent works recommend MSC/NASTRAN® for its capabilities to exactly predict the stress, strain and vibrations modes of fan blades [1-3].

This paper realizes a case study for an exhaust fan rotor made from elements assembled through bolted joints. In normal running conditions, the resonance phenomenon conducts to the destruction of the fan assembly in a prematurely period, as reported from practical applications in industry: in a first case the fan assembly failed in less than 60 hours, and in the second case in about 1 hour. The first visible defect is the bearing assembly failure (figure 1).

Figure 1. Bearing failure.
The resonance affected not only the bearings of the fan with bolted joints, but also its blades. The blades failed directly by breakage (figure 2a), or firstly by bending and after by breakage due to blade and fans house contact (figure 2b).

In comparison, a better solution is proposed, with the blades-hub construction of the fan realized by weld joints (figure 3b).

The elements of the fan are made in both cases from OL37 steel, their construction being detailed in figure 3 (a) for bolted joints construction and figure 3 (b) for the welded structure.

The studied fans possess 10 blades each of them. One of the fans has the blades connected to the hub by 20 screws M16 x 55 disposed in equal circular double rows (figure 3 a), and for the other fan the 10 blades are jointed to the hub by welding (figure 3 b). The dimensions of both types of fans are the same: outer diameter of ballades 1400 mm, outer diameter of hub 400 mm. The purpose of the paper is the FEM analysis of the two versions of the fan-hub design, with bolted and welded joints.

2. Results of the FEM Analysis by MSC/NASTRAN®

The FEM analysis of the exhaust fan must consider the running parameters of the fan: debit: 63000 m³/h; speed 1470 rpm; 620 mm H₂O pressure drop; running temperature 140-160 °C.

The two design of fans (figure 3), are modeled by MSC/Nastran® soft.

The next simplifying hypotheses are adopted in FEM analysis:
- The influence of the vibrations transmitted by groundwork was neglected.
- Only the blades are linear elastically deformable, the shaft and the hub being considered rigid.
The pressure distribution on blades is uniform and is computed for the maximum load and speed, the friction being neglected in the analysis.

The mesh was realized in Nastran in a quasi-uniform manner, indicating about 1000 uniform distributed imposed points on the contour of blades. In figure 4 (a) and (b) are represented the mesh of the fan with both welded and bolted blades and the uniform pressure distribution on blades, respectively.

![Image](a) ![Image](b)

Figure 4. Meshing and the pressure distribution of the fan with welded blades and bolted blades, (a) and (b), respectively.

### 2.1. Static strain analysis of the fans

In figure 5 (a) and (b) we have the FEM strain analysis due to the functioning vibrations of 25 Hz, for the fans with welded and bolted blades. The analysis is realized for the entire structure of the fan, but the results are presented for the only elements considered as linear elastic (the recessed blades).

![Image](a) ![Image](b)

Figure 5. Strain of the blades induced by the running vibrations around 25 Hz. (a) fan with welded blades; (b) fan with bolted blades; (c) detail of the welded blade; (d) detail of the bolted blade.
As seen in figure 5, the vibrations induce more static strain in welded blades than in the bolted blades.

For the bolted blades solution, the static analysis shows that the outer row of screws circularly placed at a diameter of 180 mm is more loaded than the inner second row of screws disposed about a circle of 110 mm diameter, the inner row of screws being almost unloaded.

For both types of fans, the static FEM analysis of the stress and strain does not reveal any problem, the maximum obtained stress being less than 70 MPa (Figure 6).

2.2. Dynamic FEM analysis of the fans

As no problems were detected from static strain and stress analysis of the both fan structures, a dynamic analysis is realized considering the variable load generated by variable running frequency.

The advantages of the fan with welded blades are drawn by a dynamic analysis. Rades [5] indicate as a proper parameter of analysis for aeronautical applications (blades, fans and turbofans) the structural damping or hysteretic damping. The structural damping, denoted by $G$, is the dissipated energy in a cycle of vibration, being directly proportional to the square value of the amplitude of displacement, but independent of angular frequency [5].

The natural frequencies of the structures are found by FEM analysis, on the frequency range 0... 25 Hz. For comparison, the results on structural damping obtained in Nastran for bolted and welded blades of the fans are represented versus natural frequencies (figure 7). The fan with welded blades assures better damping at high frequencies. Also, the maximum amplitude level of the structure is found three times smaller.

![Figure 6. Equivalent stress distribution on the blades for the welded fan induced by the running vibrations around 25 Hz.](image)

![Figure 7. Structural damping versus natural frequencies of the rotor.](image)
For the entire range of the running speed of the fan rotor (0…1 500 rpm), the corresponding frequency domain is 0…25 Hz. The fan with welded blades presents a limited number of natural frequencies, as the bolted rotor possess over 1000 natural frequencies and almost zero structural damping. The zero structural damping of bolted blades conducts to high amplitude displacements and possible resonance phenomenon on the corresponding natural frequencies. From our preliminary results, replacing the bolted joints of the blades with welded joints can by a solution to assure a better dynamic behavior and higher reliability of exhaust fans.

3. Conclusions
This paper realizes a case study for an exhaust fan rotor made from elements assembled through bolted joints. As reported from practical applications in industry, in normal running conditions the resonance phenomenon conducts to the destruction of the fan assembly in a prematurely period. In comparison, a better solution is proposed, with the blades-hub construction of the fan realized by welded joints. For both types of fans, the static MSC/Nastran ® FEM analysis of the stress and strain does not reveal any problem, the maximum obtained stress being less than 70 MPa. The advantages of the fan with welded blades are drawn by a dynamic analysis. The fan with welded blades presents a limited number of natural frequencies, as the bolted rotor possess over 1000 natural frequencies up to 25 Hz and almost zero structural damping. In fan rotor problems, the preliminary results show that replacing the bolted joints of the blades with welded joints can by a solution to assure a better dynamic behavior and higher reliability, a positive response being obtained from the industry.

4. References
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