The Implementation of Virtual Engineering to the Turbocharger Turbine Wheel Dynamic Stresses Analysis

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ABSTRACT

The article presents questions connected with the problems of turbocharger turbine wheel dynamic stresses modelling with utilization of CAD environment. The paper enclose some aspects of turbine wheel profile with regard of material, work condition and most frequent damages type which appears in case of faultily realized exploitation procedure of the charging device. The most popular methods of turbocharger selection for combustion engines were mention in the paper. The main part of the work includes the turbine wheel stress analysis and turbine wheel blades strain. The virtual analysis was conducted for three types of turbine wheel: cars, delivery truck and motor truck

INTRODUCTION

The turbocharger turbine wheel is the most important part of device assuring the compressor wheel shaft drive. Turbine rotor is directly exposed on corrosion hazard and temperature environmental hazard in results of combustion engine exhaust gases influence. While maximum engine load the turbocharger works in very hard mechanical conditions. The speed of rotation of the whirling unit exceed 180 000 rpm. For diesel engines the temperature of exhaust gases has value about 700 °C, but in case of combustion engines this value goes to 1000 °C.

The turbocharger turbine wheel is made from chromium-nickel-wolfram heat – treatable constructional steel, which has a chemical construction: 0,25%C, 0,4%Mn, 1,5%Cr, 4,2%Ni and 1%W [4]. The examples of turbocharger shaft with turbine and compressor rotors were introduced on figure 1.

Figure 1: turbocharger shaft with turbine and compressor rotors [own source]

During faultily realized exploitation procedure of the charging engine the turbine shaft is one of the most subjects on damages unit of device. In table 1 were introduced most frequently noticed damages with potential cause of the damage and the results of damage.

The turbocharger selection for combustion engines is chosen in two steps. The first step of selection is related with the requirement of the air by the engine.

TABLE 1: Turbocharger shaft damage [5, 7]

Type of damage	Cause of damage	Result of damage
The shaft overheat with running track damage	- the incorrect quantity of motor oil, - injector damage, - damage of lubrication system, - sudden engine stop.	-less engine power, - black exhaust smoke, - damaged bearings.
Broken turbocharger shaft	- broken-down air filter, - the "foreign matter" in suck in air, - turbine wheel overspeed.	- the noisy work, - the exhaust gas recirculation system damage, - blue exhaust smoke, - less engine power

This value is verified by relation below [5]:

$$V_0 = 35,4 \cdot 10^{-3} V_{ss} \pi \frac{1}{m} n \eta_v \varphi \frac{1}{\rho_p} \qquad [1]$$

where: V_{ss}- engine capacity, [dm³],m- polytropic compression exponent, n- engine rotation speed, [min⁻¹], η_v- level of cylinder filling, φ- scavenging factor, r_p- air density.

The second steep of device selection is strictly related to arrangement dynamic set. The proper dynamic properties and also rigorous requirements relating the issue of harmful substances in the exhaust gas caused that the manufacturers of vehicle engines reduced the fuel charge from injection's pump in relation to the lowered value of the thrust of charging. As an effect the turbocharger dynamics deteriorated, however the emission of dangerous substances was minimalized in combustion exhaust gases. The above mentioned idea confirms the fact, that the correct choice of charging devices for engine is the essential aspect, in spite of the proper static choice. Nowadays the most popular methods of turbocharger selection for engine motor is the graphics method, which

present the influence of the regulating parameters of engine during co-operation with the turbocharging device [5,7].

THE OPTIMIZATION OF THE TURBOCHARGER ROTORS NUMERIC MODELS

The simulating investigations with utilization of virtual engineering methods nowadays are the basis for behavior analysis of final object during its exploitation, that lets introduce changes already on the device constructing stage. These virtual tools also allow to execution of diagnostic investigations, resulting from obtained information of really exploited and damaged turbocharger aggregates [1,2,3,4]. For basic simulating investigations with use of the Autodesk Inventor 2015 environment belong the diagnostic investigations that include the turbine wheel stress analysis and turbine wheel blades strain analysis. These investigations verified the real strain and stress values formed in the result of the changing burden of the engine unit during its exploitation [3,4].

In this paper will be introduced accomplished investigations which make an analysis of stress and displacement of turbine wheel blades, which appears in result of mass forces connected with turbine wheel rotation. The analysis of this behaviour was made with utilization of virtual models in Autodesk Inventor 2015 environment. Many manufactures who construct and produce the turbocharger device do not reveal details connected with material and their mechanical properties. From this regard to virtual turbine rotor model the alloy Inconel 713C was put into analysis. The following properties characterize this alloy: Young's modulus $E = 2,05 \cdot 10^5$ MPa, coefficient of rigidity $G = 2,05 \cdot 10^5$ MPa, mass density $\rho = 8220$ kg/m^3, tensile strength $R_m = 1275$ MPa, yield stress $R_{0.2} = 829,5$ MPa [6].

The influence on the stress expansion for verified turbine wheel rotor has his shape and the size of the unit. From this matter the numeric models and virtual analysis was conducted for three types of turbine wheel: cars, delivery truck and motor truck. Created virtual models were introduced on figure 2.
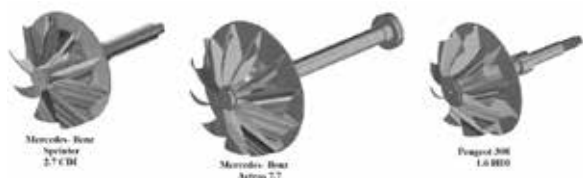

Figure 2: turbine wheel virtual models [7]
The stages of turbine wheel modelling were the same independently from the kind of the device rotor. The virtual analysis could be realized as it was introduce on figure 3.
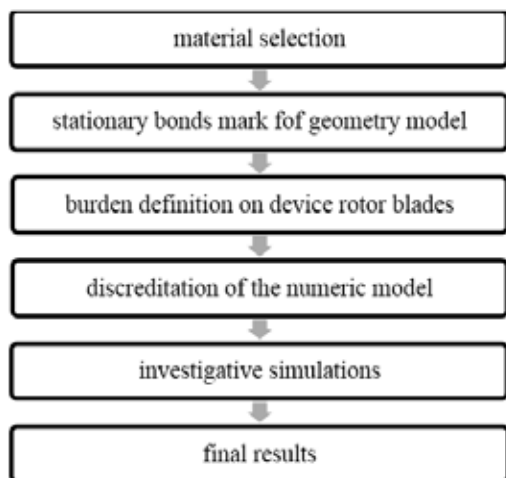

Figure 3: steps of virtual models analysis [7]

The durability analysis was realized for given speeds of rotor: 80000 rpm, 120000 rpm and 180000 rpm. The expansion of stresses was considered according to the Huber – Mises hypothesis. The chosen results of the analysis were introduced on figure 4.
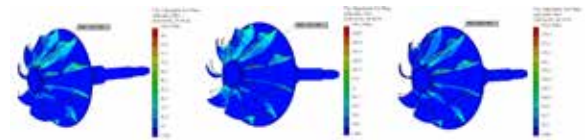

Figure 4: car turbine wheel expansion of stresses [own source]
As a result of simulation the critical places for rotor blades, where the value of maximum stresses appear were indicated. Sample of this result was introduced in figure 5. In results of formed stresses and mas strengths the blades of rotor undergo to displacement, which was introduce on figure 6. The verification of displacement for all types of turbine wheel was conducted for 120000 rpm.
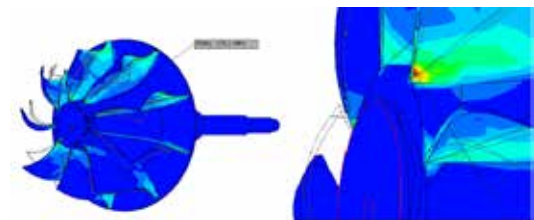

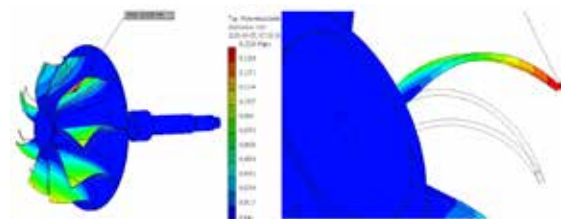**Figure 5: point of maximum stress in turbine wheel virtual model [7]**

Figure 6: displacement of turbine blade [7]
The comparison of received results during conducted investigations was introduced in table 2.

TABLE 2: Investigation results

Stress investigations			
	Vehicle type		
Rotation speed	Mercedes- Benz Actros	Mercedes- Benz Sprinter	Peugeot 308
80 000 min^{-1}	26,36 MPa	31,24 MPa	110,2 MPa
120 000 min^1	33,53 MPa	61,04 MPa	175,1 MPa
180 000 min^1	92,91 MPa	122,01 MPa	301,06 MPa
Displacement of rotor blades			
	Vehicle type		
Rotation speed	Mercedes- Benz Actros	Mercedes- Benz Sprinter	Peugeot 308
120 000 min^1	0,03567 mm	0,05639 mm	0,1526 mm

CASE STUDY
In the present study results in table 2 we could conclude that the expansion of stresses in the turbine rotor grows up as a result of mass strengths, together with the growth of the engine unit burdens.
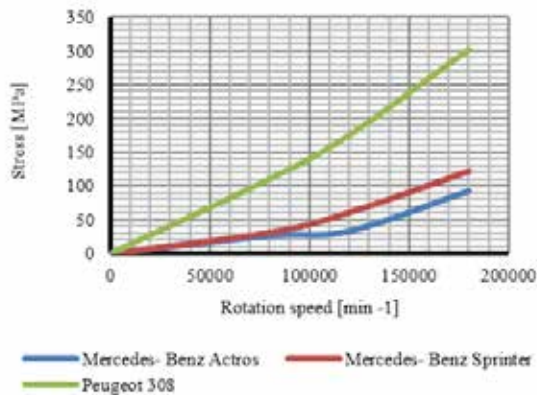
Figure 7: the dependence of stresses from the rotatory speed of the rotor

Figure 7 introduce he dependence of stresses from the rotatory speed of the rotor. The main reason for the results different values are the dimensions of analyzed rotors. The diameter of the turbine wheel of turbocharger for motor truck is about 35 larger mm than the dimension of the car turbine wheel. In the result of this difference, the stress appears on the rotor of the motor truck vehicle is small in the relation to different analysed numeric models.

CONCLUSIONS

Rotor of the turbine wheel as one of the basic units of turbocharger take an essential part in delivering the fresh air to the cylinder, near what he is subject on the working in extreme mechanical conditions. The significant assumption during investigations was proper mapping of the rotor blades shapes and the curvatures. In result we received for virtual analysis three types of turbine wheel: Peugeot 308, Mercedes- Benz Sprinter delivery truck and Mercedes- Benz Actross motor truck.

From regard of difficulty in the obtainment of the information relating materials used to the rotor building, we put into analysis the Inconel 713C alloy. The durability analysis was realized for given speeds of rotor: 80000 rpm, 120000 rpm and 180000 rpm. The expansion of stresses in turbine wheel rotor was three times bigger in motor truck than in the analysed car. The maximal values of stress was noticed for full load of combustion engine and they exceed of 300 MPa for motor truck, where the same values of engine load for Peogeot 308 turbine were noticed stresses value about 110 MPa. The conducted dynamic simulation also took into consideration dislocation of the rotor blades in relation to initial values. The nominal parameters of the turbine wheel work step out near the rotatory speed from range 110 000 to 130 000 rpm. From that reason the investigations were conducted in 120 000 rpm. The maximum value of blade displacement 0,1526 mm was estimated for car turbine wheel. The lowest value of rotor blade displacement was estimated for motor truck turbine wheel. In conclusion together with engine burdens the expansion of stresses grows up on the rotor blades but this value gets smaller with turbocharger dimension sizes growth.

Introduced in this paper investigations confirm that virtual tools used for modelling aided the investigative process of turbine selection on the construction stage in range of stresses analysis, displacement and final shape of turbocharger.

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