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SIMULATION MODEL OF THE LIMIT LOADS ON TURBINE WHEEL OF TURBOCHARGER

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Abstract: *The objective of this article is to perform a numerical evaluation of the stress state and safety factor of a turbine wheel made of Ti-8Mn (annealed) under combined pressure, rotational, and thermal loading. Using SolidWorks Simulation, the analysis investigates the impact of high temperature on the mechanical behavior and structural integrity of the turbine wheel. The obtained results provide insight for optimizing geometry and material selection in high-temperature rotating components.*
Keywords: *internal combustion engine, turbocharger, turbine wheel simulation, stress.*

СИМУЛАЦИОНЕН МОДЕЛ НА ГРАНИЧНИТЕ НАТОВАРВАНИЯ НА ТУРБИННО КОЛЕЛО НА ТУРБОКОМПРЕСОР

ЙОРДАН СТОЯНОВ

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Резюме: *Целта на статията е да се извърши числен анализ на натоварванията и фактора на безопасност на турбинно колело от титаниева сплав Ti-8Mn (annealed) при комбинирано действие на налягане, въртене и висока температура. Чрез симулации в SolidWorks Simulation се изследва разпределението на напреженията и влиянието на термичното поле върху структурната устойчивост. Получените резултати целят да послужат за оптимизация на геометрията и избора на материал при високотемпературни ротиращи детайли.*
Ключови думи: *двигател с вътрешно горене, турбокомпресор, симулация на турбинно колело, стрес.*

1. Introduction

Along with growing interest in global environmental issues, regulations regarding emission gas and fuel economy of automobiles have been tightening year by year. An engine with a turbocharger, which feeds compressed air to the engine, can use smaller displacement than normal aspiration engines. Therefore turbochargers can reduce weight and friction loss of the engines, resulting in improvement of fuel efficiency and reduction of CO_2. In particular European automotive manufacturers have been increasingly employing smaller engines for improvement of fuel efficiency. Therefore use of turbochargers has been growing, which results in growth of the turbocharger market [2].

An automotive turbocharger uses exhaust gas to rotate the turbine, and then the compressor bladed wheel, the shaft of which is connected directly with the shaft of the turbine, is driven. A standard turbocharger uses a single scroll turbine. However, at lower engine speed, it cannot compress air supply sufficiently because exhaust gas flow is small and the boost pressure is low [1, 5].

Turbocharging turbines for internal combustion engines often work under pulsating flow conditions. It has long been recognized that the performance of these turbines can be quite different from that under steady flow conditions. Yet there is still a lack of understanding of the phenomena, and there is no simple method that can be used with confidence to predict the performance of the turbine under such conditions [4].

Engine developers move between the poles of fuel consumption, emissions and response behavior while keeping a focus on the applicable exhaust emission testing and consumption cycles. In current cycles the time-averaged engine operating range tends to concentrate on the part-load section. For future demands, such as Real Driving Emissions (RDE), the range considered will extend to the entire engine operating range. This is why discussion today is looking closer at technologies that can produce a positive effect on the entire engine operating range. With exhaust gas turbocharged SI engines, the focus is on avoiding full-load enrichment and minimizing throttling losses. The latter can be achieved in the broadest sense by means of downsizing, downspeeding and lean combustion processes. For this purpose and as a technology element now firmly established in engine development, the boosting system must be adapted to accommodate the changed engine boundary conditions. Single-stage boosting, made up of a rigid radial compressor and a rigid radial turbine with wastegate, is seen as a standard. In recent years aerodynamic measures have made it possible to increase throughput spread and efficiency of such radial machines [2].

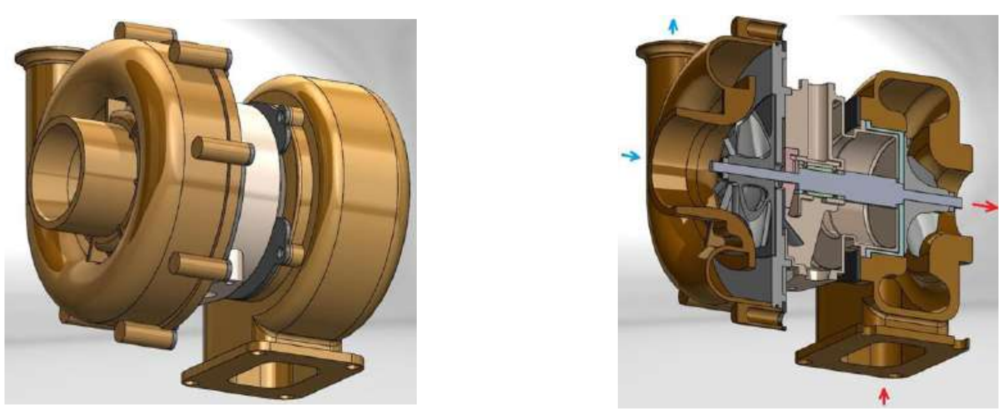
2. Material and methods

2.1. Modern Development Process

The modern development process integrates 1-D engine process simulation to an even greater extent into configuring an engine concept. This means that engine concepts undergo preliminary evaluation on the basis of simulation results, with transient engine behavior carrying greater weight in the evaluation process.
Transient engine behavior is understood to mean both an engine’s responsiveness (time to torque) as well as catalyst light-off, these being increasingly influenced by exhaust gas turbochargers.

Figure 1 shows the general path taken in a modern development process. The simulation results are examined to establish whether they reach target values, such as drivability at full load, fuel consumption and responsiveness. If applicable, promising parameters, such as the aerodynamic behavior of a turbocharger, are adjusted until they reach the target set.

These initially synthetic and iteratively obtained maps then provide the basis either for selecting an appropriate turbocharger or for configuring new rotors. A key aspect in this process is the advanced turbocharger model that is explained in more detail in the next section.



(a) (b)

Fig.1. *Common view and cross-section of a turbocharger*

2.2. Advanced Turbocharger Model

The advanced turbocharger model basically comprises the following elements:

- Aerodynamics of compressor and turbine on the basis of maps obtained from experiments
- Friction on the basis of a map obtained from experiments
- Heat flow and heat storage capability on the basis of semi-empirical Approaches [2, 3].

2.3. Geometries

A 3D model of a turbocharger, shown in Figure 1, was created in the SolidWorks design environment. A static analysis of the turbine wheel was performed in SolidWorks Simulation. Since the turbine and pump wheels are loaded differently due to the nature of their work, the object of analysis is the turbine wheel. The exhaust gases from the engine make their first contact from the engine outlet with the turbine wheel and transmit a large amount of heat and pressure, at which the turbine wheel rotates at a very high speed. The 3D model of the turbine wheel is shown in fig. 2 (a) and fig. 3 (a). The static analysis, including a mesh of nodes and elements of the created model, consisting of the total 253319 nodes and 159926 elements. The turbine wheel has parameters: Mass:0.131604 kg; Density:4,730.82 kg/m^3; Weight:1.28972 N: Overall dimensions: 0.08 mm by 0.034 mm. The turbine wheel has 8 blades with a blade thickness of 1 mm. Each blade has an area of 634 $mm^2$and a perimeter of 109 mm.

3. Result and discussions

3.1. Static analysis

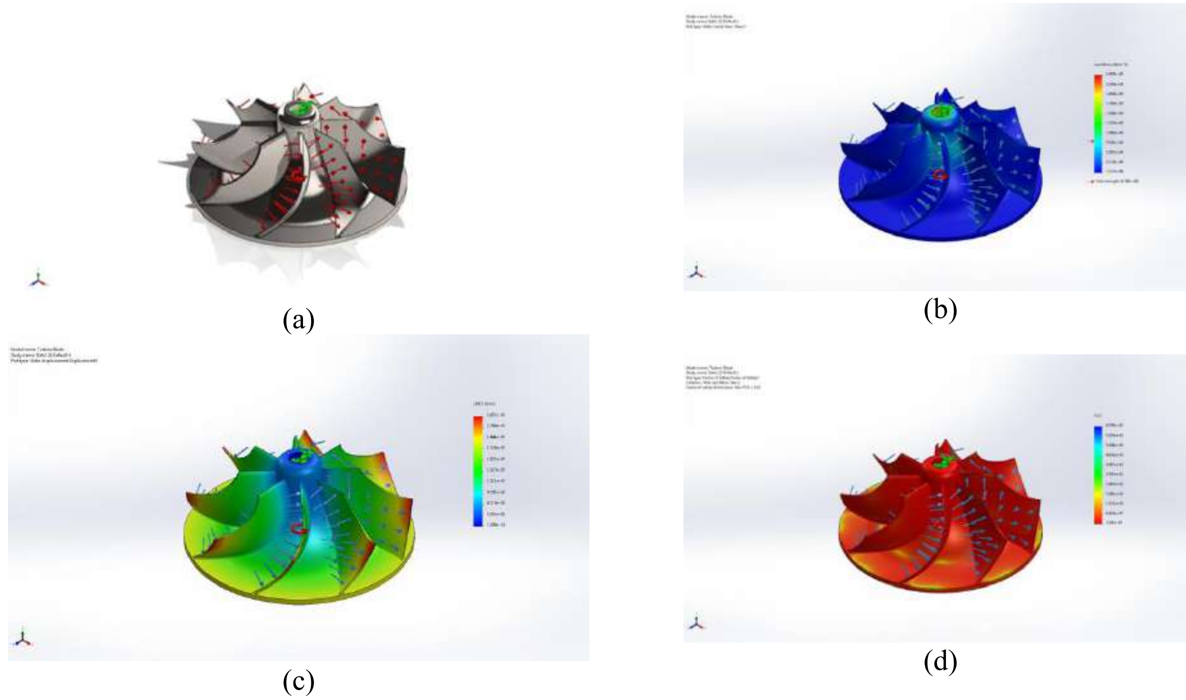
The material chosen for the manufacture of the turbine wheel must have strength properties that meet the temperature and static load and have a low volumetric mass. It was chosen Titanium Ti–8Mn is a titanium–manganese alloy (~8% Mn) offering a good balance of strength, ductility, and corrosion resistance, shown in table 1. The annealed condition provides a stable microstructure suitable for aerospace, biomedical, and high-performance mechanical applications. The material properties are shown in Table 1. The static analysis was performed in two versions: the first version included Pressure: 0.2 MPa; Centrifugal: 5.200 rad/s; Thermal: 500 $°C$, shown in fig 2, and second version included only Pressure: 0.2 MPa; Centrifugal: 5.200 rad/s, shown in fig. 3.

Thermal loading at 500 $°C$ causes a drastic reduction in FOS from ~2.7 to ~0.32, primarily due to constrained expansion and reduced yield strength at elevated temperature. Under the given geometry and material properties, the Ti–8Mn turbine wheel is not structurally safe for continuous operation above ~350 $°C$ at 5200 rad/s.

Increasing the thickness of the blades can increase the FOS, but will be critical for the centrifugal load, as the centrifugal forces will increase exponentially. Another solution is to find a lighter material to use for the turbine wheel or a material that has better properties.

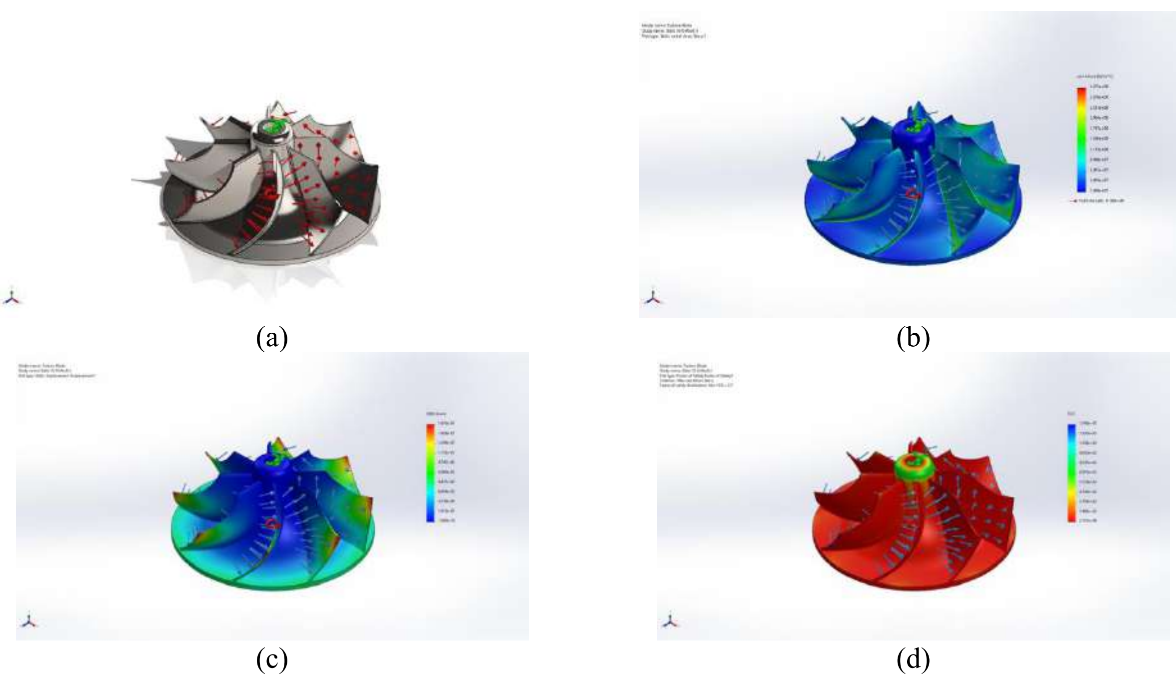
Table 1. *Material properties of Titanium Ti–8Mn (Annealed)*

Property	Value	Units	Description
Yield Strength	8.1×10^8	N/m^2 (Pa)	810 MPa
Ultimate Tensile Strength	9×10^8	N/m^2 (Pa)	900 MPa
Compressive Strength	8.75×10^8	N/m^2 (Pa)	875 MPa
Elastic Modulus (Young's Modulus, E)	1.15×10^{11}	N/m^2 (Pa)	115 GPa
Mass Density (ρ)	4,730	kg/m^3	Typical for titanium alloys
Shear Modulus (G)	4.9×10^{10}	N/m^2 (Pa)	49 GPa
Coefficient of Thermal Expansion (α)	8.6×10^{-6}	$1/K$	Moderate thermal expansion typical for titanium
Heat Treatment	Annealed	–	Improves ductility and reduces residual stresses



(a) (b) (c) (d)

***Fig .2**. Turbine wheel: (a) 3D model; (b) stress; (c) displasement; (d) FOS = 0.32.*



(a) (b) (c) (d)

***Fig. 3.** Turbine wheel: (a) 3D model; (b) stress; (c) displasement; (d) FOS = 2.7.*

Conclusions

The numerical analysis of the titanium turbine wheel demonstrates that thermal loading at 500 °C critically affects the overall stress distribution and structural integrity. When thermal effects are included, the factor of safety decreases from approximately 2.7 to below 0.3, indicating that the Ti-8Mn alloy is unsuitable for high-temperature operation at the specified rotational speed. The primary cause is the constrained thermal expansion and the resulting stress concentration in the blade root region. Ensuring reliable performance requires realistic thermal boundary conditions, allowance for axial expansion, or the use of a high-temperature Ni-based super alloy.

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