NEW HYBRID TURBOCHARGERS SOLUTIONS FOR SPECIAL MILITARY VEHICLES WITH INTERNAL COMBUSTION ENGINES

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Abstract: The internal combustion engines performance can be increase. The residual gases can be recovered through turbo charging systems because is an important reserve of exhaust gas energy, which can be capitalized. The turbo charging solution is one of the most popular technical solutions for increasing the energy performance of internal combustion engines. The solutions proposed for the theoretical and experimental research is the hybrid turbocharger. The hybrid turbocharger has a double function: to compress the fresh air and to generate electric energy for the vehicle. The compressed fresh air is compress by the rotor wheel of the compressor. The generator which produces the electrical energy is linearly coupled to the rotor on the compressor shaft outside zone. The electrical energy can be used for consumption of the military vehicles or can be stored in to the battery of the vehicle. The military vehicle must have a internal combustion engine or a hybrid engine equipped with a hybrid turbocharger. The article aim is to present the results of the hybrid turbocharger. The simulation was realised with the AMESim Software developed by Siemens. To simulate the exhaust gas energy was used a CIMAT test bed which can provides high pressure air.

Keywords: internal combustion engines, hybrid turbocharger, electric generator, military vehicles, AMESim Software

1. Introduction

In the past few years, the internal combustion engines have been developed, to increase, performance, pollution in relation to the costs [1]. More energy efficiency and less polluting processes is absolute essential for the internal combustion engines [2]. To improve the engine performance is required to improve also the turbocharger performance. A hybrid turbocharger was builted to demonstrate that the turbocharger coupled to a gear ratio and to an electrical generator is very efficient (figure 1).

Figure 1: Hybrid Turbocharger construction

To obtain high-speed rotation, the hybrid turbocharger is connected to a compressed air machine produced by CIMAT Balancing Machines. Figure 2 illustrates the CIMAT turbo test pro [3].

Figure 2: CIMAT Turbo Test Pro

The main aim of the CIMAT machine is to provide compressed air from 1 to 2 bars. The compressed air simulates the exhaust gases of the engine and it can deliver a high turbine speed. After this principle the connecting shaft between the compressor and the electric generator will rotate. I also mention that the electric generator is connected to the compressor side by a shaft. This application is mainly suitable for special military vehicles like military trucks or tanks.

Figure 3: Heavy-duty military truck produced in USA [4]

Higher the internal combustion engine capacity is, higher the efficiency of the hybrid turbocharger is.

Figure 4: PUMA tank produced in Germany [5]

Most internal combustion engines that equip tanks are supercharged engines. In figure 5 is showed a tank supercharger engine (800kW) produced in Germany by MTU which equip a Puma tank.

Figure 5: MTU turbocharged engine (800kW) for Puma tank produced in Germany [6]

Table 1 contains all the important components of the hybrid turbocharger: turbocharger components, gear ratio (1:10) and the 100W electrical generator. There is also represented the main symbols used by the simulation with AMESim software.

Tabel 1: The main component parts of turbocharger prototype such as: turbocharger, gear ratio and electrical genetator presented as components directly, but also as simulation parts of AMESim software

Nr. crt.	Main component part	Component part in AMESim software	Designation
1.			Electrical generator
2.			gear ratio/ 1:10
3.			Garrett turbocharger

2. Objective

The general objective of this experimental work is to show the great potential and performance of a hybrid turbocharger.

The experimental research of this paper was achieved with the CIMAT test bed which provides the compressed air for the turbocharger. The compressed air has the aim to simulate the engine exhaust gases. The CIMAT test bed can provide information about rotation, mass flow, inlet / outlet pressure, temperature parameters. The electrical part provided, using Siemens

PLC, information about electric current (Amper), voltage (Volt) and power (Watt).

In figure 4 is illustrates a general view of the hybrid turbocharger components with the AMESim software.

Figure 6: General view of the hybrid turbocharger components with the AMESim software

3. Methodology

The basic equations can be divided into two categories: for the mechanical part and for the electrical part. These equations are used for the mathematical simulation of the compressor.

3.1. Equations for the mechanical part

The equations for the mechanical part can be divided into two categories: compressor equations and turbine equations.

3.1.2 Compressor equation, speed/ flow rate

$$N_{cor} = \frac{N_{act}}{\sqrt{\frac{T_{up}}{T_{st}}}} \quad (1)$$

$$N_{red} = \frac{N_{act}}{\sqrt{T_{up}}} \quad (2)$$

$$\dot{m}_{cor} = \dot{m}_{red} \cdot \frac{\sqrt{\frac{T_{up}}{T_{st}}}}{\frac{P_{up}}{P_{st}}} \quad (3)$$

$$\dot{m}_{cor} = \dot{m}_{red} \cdot \frac{\sqrt{T_{up}}}{P_{up}} \quad (4)$$

$$PR = \frac{P_{out}}{P_{up}} A_o = \sqrt{\frac{T_{out}}{T_{up}} \left(\frac{1 + \frac{\gamma-1}{2} M_{out}^2}{1 + \frac{\gamma-1}{2} M_{up}^2} \right)} = \sqrt{\left[1 + \frac{\frac{\gamma-1}{2} PR^{\frac{2}{\gamma}} - 1}{\eta} \right]} \quad (5)$$

3.1.2. Turbine equations, speed/ flow rate

$$N_{red} = \frac{N_{act}}{\sqrt{\frac{T_{up}}{T_{st}}}} \quad (6)$$

$$N_{red} = \frac{N_{act}}{\sqrt{T_{up}}} \quad (7)$$

$$\dot{m}_{act} = \dot{m}_{red} \cdot \frac{\sqrt{\frac{T_{up}}{T_{st}}}}{\frac{P_{up}}{P_{st}}} \quad (8)$$

$$\dot{m}_{cor} = \dot{m}_{red} \cdot \frac{\sqrt{T_{up}}}{P_{up}} \quad (9)$$

$$P_{mec} = \omega_{turb} \cdot t_{turb} \quad (10)$$

3.2. Equations for the electrical part

The main alternator parameters of the electrical part system are: rotary velocity in [rev/min], temperature in [degC], current in [A], torque in [Nm], efficiency in [null] (i.e. no unit), losses in [W] (see Figure 5)

Figure 7: Alternator symbol with main parameters in AMESim Software

$$P_e = |U \cdot I| \quad (11)$$

$$I = \frac{U}{R} \quad (12)$$

[7]

where:

N_{cor} : speed corrected, m/s

N_{act} : speed actual, m/s

N_{red} : speed reduced, m/s

T_{up} : upstream temperature, K

T_{st} : standard temperature, K

P_{up} : upstream pressure, kPa

P_{st} : standard pressure, kPa

$\dot{m}_{cor}$: mass flow rate corrected, -

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- m_{red} : mass flow rate reduced,
- PR: compressor pressure ratio, -
- A_O : compressor sound speed ratio, -
- P_{up} : upstream absolute total pressure at port 3, barA
- P_{out} : downstream absolute total pressure at port 1, barA
- T_{up} : upstream temperature at port 3, K
- T_{out} : downstream temperature at port 1, K
- γ : specific heat ratio upstream gas mixture, -
- η : the isentropic efficiency, -
- P_{mec} : mechanical power, W
- ω_{turb} : turbine rotary speed, rad/s
- t_{turb} : turbine torque, Nm
- P: electrical power, W
- U: voltage, V
- I: current, A
- R: resistance, Ω
- rpm : rotations per minute

4. Results

The current intensity, the voltage and the resulting power are the main electrical parameters resulting from the hybrid turbocharger. The mechanical parameters of the hybrid turbocharger are: rotation, output pressure of the compressor and pressure ratio.

In figure 8 it is showed the current intensity, the voltage and the resulting power of the electrical motor from the experimental research in relation to time. The simulation research of the current intensity value range is from 0 to 5 Amper. The experimental research of the voltage value range is from 0 to 25 Volt. The experimental research of the power value range is from 0 to 100 Watt.

Figure 8: The current intensity, the voltage and the power from the experimental results in relation to time

In figure 9 it is showed the current intensity, the voltage and the resulting power of the electrical motor from the simulation research in relation to time. The simulation research of the current intensity value range is from 0 to 5 Amper. The simulation research of the voltage value range is from 0 to 25 Volt. The simulation research of the power value range is from 0 to 115 Watt.

Figure 9: The current intensity, the voltage and the power from the simulation results in relation to time

The speed rotor shaft of the turbocharger, the pressure ration, PR and the compressor outlet pressure are the main parameters of the experimental research on the mechanical side.

Figure 10 illustrates the speed rotor shaft [rpm] from the experimental research in relation to time, in a range is from 0 to 162400 rpm.

Figure 10: The speed rotor shaft in rotation per minute, rpm from the experimental results in relation to time

And figure 11 illustrates the simulations of the speed rotor shaft with the value range from 0 to 162400 rpm.

Figure 11: The speed rotor shaft in rotation per minute, rpm simulated with AMESim in relation to time

And figure 12 illustrates the experimental research of the pressure ratio, PR with the value range from 0 to 1.

Figure 12: The pressure ratio, PR from the experimental results in relation to time

And figure 13 illustrates the simulations of

the pressure ratio, PR with the value range from 0 to 1.

Figure 13: The pressure ratio, PR simulated with AMESim in relation to time

And figure 14 illustrates the experimental research of the the compressor outlet pressure with the value range from 0 to 1.6 bar.

Figure 14: The compressor outlet pressure from the experimental results in relation to time

And figure 15 illustrates the simulations research of the compressor outlet pressure with the value range from 0 to 1.5 bar.

Figure 15: The compressor outlet pressure simulated with AMESim.

6. Conclusions

The new hybrid turbocharger has three basic elements: the extended shaft which is

connected with the electricity generator, a gear that reduces the rotation of the turbocharger for the electrical generator. The main purpose of the hybrid turbocharger is to compress air but also to generate electricity for the electric engine of the vehicle or for consumption or to be stored in batteries to cover the full battery range [8]. This technical application is best suited for special military vehicles, where electricity autonomy is very necessary for communication systems.

Figure 16: Special Puma tank produced by Rheinmetall Defence Germany [9]

This technical application has many advantages like: compress air, generate electrical energy, easy maintenance, rigidifies the turbocharger shaft by construction eliminating tribological problems [10], [11].

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