NEW TECHNICAL SOLUTION FOR HYBRID TURBOCHARGERS

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ABSTRACT—Internal combustion engines have an efficiency of operating which can be exploit to increase its performance. Part of the residual gases can be recovered through the technical solutions such as turbocharging. The turbocharging solution is one of the most popular technical solutions for increasing the energy performance of internal combustion engines. For the turbocharging process it is used a turbocharger. The turbocharger can contribute also with new technical solutions to increase the energy performance of the internal combustion engines. One of the solutions proposed for the theoretical and experimental research is the hybrid turbocharger, which has a double function, namely to compress the fresh air for the internal combustion engine, and to generate electric energy for the electric engine of the vehicle both for consumption other to be stored in batteries. This article aims is to present the result of the experimental research of the hybrid turbocharger, simulate and validate the new solutions for increasing the energy performance of internal combustion engines through hybrid turbochargers using a coupled electric generator. The simulations will be made using the AMESim Software developed by Siemens to demonstrate the efficiency of the new solutions such as a hybrid turbocharger through calculations. The tests will be carried out with the test bed CIMAT. CIMAT test bed is a machine which provides high pressure air which simulate the combustion gases of an engine. The purpose of the CIMAT test bed is to rotate the hybrid turbocharger turbine and also the compressor wheel. More technical information about the hybrid turbocharger test will be presented in the article and also constructive details. Based on the technical information and input data in the first phase it will be made an application for the simulation and validation of the prototype to demonstrate the great potential of the turbocharger to produce also green energy.

KEY WORDS: internal combustion engines, hybrid turbocharger, electric generator, green energy, AMESim Software

NOMENCLATURE

\( N_{cor} \): 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 absolute total pressure at port 3, bar
\( P_{st} \): standard pressure, kPa
\( m_{cor} \): mass flow rate corrected, -
\( m_{red} \): mass flow rate reduced, -
\( PR \): compressor pressure ratio, -

\( A_{SC} \): compressor sound speed ratio, -
\( P_{up} \): upstream absolute total pressure at port 3, bar
\( P_{st} \): downstream absolute total pressure at port 1, bar
\( T_{up} \): upstream temperature at port 3, K
\( T_{st} \): downstream temperature at port 1, K
\( \gamma \): specific heat ratio upstream gas mixture, -
\( \eta \): the isentropic efficiency, -
\( P_{mech} \): mechanical power, W
\( \omega_{turb} \): turbine rotary speed, rad/s
\( t_{turb} \): turbine torque, Nm
\( P \): electrical power, W
\( U \): voltage, V
\( I \): current, A
\( R \): resistance, \( \Omega \)

SUBSCRIPTS
1. INTRODUCTION

The internal combustion engines have developed in the last years and also the expectations like performance, pollution in balance with the costs, therefore the research area expanded also. (Mithun D. et al., 2017) More energy efficiency and less polluting processes are required in the internal combustion engines sector. The compression-ignition engines are used in generating electricity, marine and transportation and the Otto engine for transportation use but in both cases the processes can be improved and made enable to higher pressure ratios and also to generate electricity in sufficient operating conditions. (Heim K., et al., 2016). One of the ways to improve the engine performance is to improve the turbocharger performance. To demonstrate that the turbocharger has a great capability of improvement it was built a hybrid turbocharger, namely a turbocharger coupled to a gear ratio and to a electrical generator. (figure 1)

![Figure 1. Hybrid Turbocharger real construction](image1)

Figure 1. Hybrid Turbocharger real construction

To obtain the high speed turations the hybrid turbocharger is connected to a compress air machine produce by CIMAT Balancing Machines.

![Figure 2. CIMAT Turbo Test Pro](image2)

The CIMAT machine has the main aim to provide compressed air to the ranking of 1 to 2 bars. The compressed air simulates the exhaust gases of the engine and it can deliver a high turbine speed which rotates the connecting shaft between the compressor and the electric generator. I also mention that the electric generator is connected to the compressor side by a shaft. In figure 2 it can be seen the CIMAT Turbo Test Pro. (figure 2) In figure 3 it can be seen how the hybrid turbocharger is whit the CIMAT machine connected. The CIMAT machine can provide information of the turbocharger boost pressure ratio test real life spin test, turbocharger rotational speed measurement, turbocharger air loss test, position sensor test, compressor section performance test.

![Figure 3. The hybrid turbocharger connected to compressed air of the CIMAT Turbo Test Pro](image3)

In tabel 1 are detailed all important components of the hybrid turbocharger such as: turbocharger components, gear ratio (1:10) and the electrical...
generator of 100W also with 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 generator presented as components directly, but also as simulation parts of AMESim software.

| nr. | 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 paper is to demonstrate that the turbocharger has very great performance improvement. But to demonstrate this aspect, it must also be presented the simulation and validation results of the hybrid turbocharger prototype. The experimental work test will simulate the hybrid turbocharger on the CIMAT test bed which provides the compriate aer for the turbocharger with the aim to simulate the engine exhaust gases. The results will be collected for the mechanical part using CIMAT machine that will supply, the rotation, mass flow, inlet / outlet pressure, temperature parameters and for the electrical part using Siemens PLC and InfoU software which will deliver information about electrical current (Amper), voltage (Volt) and power (Watt). In figure 4 it can be seen the general view of the hybrid turbocharger with the main components of the simulation system.

Figure 4. General view of the hybrid turbocharger components with the AMESim software

3. METHODOLOGY

The basics equations used for the mathematical simulation of the compressor, turbine and alternator can be expressed into two categories namely for the mechanical part and for the electrical part.

3.1. Equations for the mechanical part

To take into account the real engine operating conditions the rotary speed and the mass flow rate values are corrected or reduced.

3.1.2 Compressor equation, speed/ flow rate

\[
N_{cor} = \frac{N_{act}}{\sqrt{\frac{T_{up}}{T_{st}}}}
\]

\[
N_{red} = \frac{N_{act}}{\sqrt{T_{up}}}
\]

\[
m_{cor} = m_{red} \cdot \frac{\sqrt{T_{up}}}{P_{st}}
\]

\[
m_{cor} = m_{red} \cdot \frac{\sqrt{T_{up}}}{P_{st}}
\]
\[ PR = \frac{P_{out}}{P_{up}} = \sqrt{\frac{T_{out}}{T_{up}} \left( \frac{1 + \frac{\gamma - 1}{2} M_{out}^2}{1 + \frac{\gamma - 1}{2} M_{up}^2} \right)} \]

3.1.2. Turbine equations, speed/flow rate

\[ N_{red} = \frac{N_{act}}{\sqrt{T_{up}}} \]

\[ m_{act} = m_{red} \cdot \frac{T_{up}}{T_{st}} \cdot \frac{P_{up}}{P_{st}} \]

\[ m_{cor} = m_{red} \cdot \sqrt{T_{up}} \cdot \frac{P_{up}}{P_{st}} \]

\[ P_{mec} = \omega_{turb} \cdot t_{turb} \]

3.2. Equations for the electrical part

The main alternator parameter 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 5. Alternator symbol and main parameters in AMESim Software](image)

\[ P_e = |U \cdot I| \]

\[ I = \frac{U}{R} \]

(LMS AMESim, Ameshelp Library)

4. RESULTS

The results will show the electrical parameters resulting from the turbocharger rotation, namely: the current intensity, the voltage and the resulting power. This is the green energy produced by the turbocharger at a constant speed of 162400 revolutions per minute, with a resulting pressure of about 1 bar.

In figure 6 it is showed the resulting voltage of the electrical motor from the experimental research in relation to time. The experimental research value range is from 0 to 25 Volt. And in figure 7 it is showed the resulting voltage from the AMESim simulation in relation to time with the simulation range value from 0 to 23 Volt.

![Figure 6. The voltage from the experimental results in relation to time](image)

In figure 8 it is showed the resulting current intensity of the electrical motor from the experimental research relation to time. The experimental research value rage is from 0 to 5 Amper. And in figure 9 it is showed the resulting current intensity from the AMESim simulation in relation to time with the simulation rage value from 0 to 5 Amper.

![Figure 7. The resulting voltage from the AMESim simulation in relation to time](image)
Figure 8: The resulting current intensity in relation to time.

Figure 9: The resulting current intensity in relation to time from the AMESim simulation.

Figure 10: The electrical power in relation to time from the experimental research.

In figure 10 it is showed the resulting electrical power of the electrical motor from the experimental research relation to time. The experimental research value rage is from 0 to 100 Watt. And in figure 11 it is showed the resulting electrical power from the AMESim simulation in relation to time with the simulation rage value from 0 to 115 Watt.

Figure 11: The resulting electrical power in relation to time from the AMESim simulation.

About the experimental research on the mechanical side stood following parameters, namely: speed rotor shaft of the turbocharger, the pressure ration, PR and the compressor outlet pressure.

In figure 12 it is showed the speed rotor shaft in rotation per minute from the experimental research relation to time. The experimental research value rage is from 0 to 162400 rpm. And in figure 13 it is showed the speed rotor shaft in rotation per minute, rpm simulated with AMESim in relation to time with the simulation rage value from 0 to 162400 rpm.

Figure 12: The speed rotor shaft in rotation per minute, rpm from the experimental results in relation to time.
Figure 13: The speed rotor shaft in rotation per minute, rpm simulated with AMESim in relation to time

In figure 14 it is showed the pressure ratio, PR from the experimental research in relation to time. The experimental research value rage is from 0 to 1. And in figure 15 it is showed the pressure ratio, PR simulated with AMESim in relation to time with the simulation rage value from 0 to 1.

![Figure 14: The pressure ratio, PR from the experimental results in relation to time](image1)

![Figure 15: The pressure ratio, PR simulated with AMESim in relation to time](image2)

Figure 14: The pressure ratio, PR from the experimental results in relation to time

Figure 15: The pressure ratio, PR simulated with AMESim in relation to time

In figure 16 it is showed the compressor outlet pressure from the experimental work in relation to time. The experimental work value rage is from 0 to 1.6 bar. And in figure 17 it is showed the compressor outlet pressure simulated with AMESim in relation to time with the simulation rage value from 0 to 1.6 bar.

![Figure 16: The compressor outlet pressure from the experimental results in relation to time](image3)

![Figure 17: The compressor outlet pressure simulated with AMESim](image4)

Figure 16: The compressor outlet pressure from the experimental results in relation to time

Figure 17: The compressor outlet pressure simulated with AMESim

5. CONCLUSIONS

The new turbo compound systems for the automotive industry for internal combustion engine to recover energy has three basic elements: the extended shaft to accommodate the electrical energy generator at the blower end, a gear that reduce the rotation of the turbocharger and a cooling system for the generator witch is optional.

Observing the values obtained through the experimental part and the simulation part it can be stated that the turbocharger has a great potential for development and to obtain ecological electric energy for the vehicle. The hybrid turbocharger can be used at hybrid engines but also for the classic solution of the internal combustion engines.

Parallel sequential turbocharging systems can be generate namely to able to operate in different modes, to generate electric energy for the electric engine of the vehicle both for consumption and to be stored in batteries to cover the full battery range. (Galindo J., et al., 2009)

The main advantages of the new hybrid turbocharger are: consume the green electrical energy and storage in the main battery of the vehicle, also redirect to peripheral...
computer consumers and to compress air for the engine. (Perrot N., et al., 2017), (Chiriac R., et al., 2017)

6. DECLARATIONS

6.1. Availability of data and materials
Not applicable

6.2. Competing interests
Not applicable

6.3. Funding
Not applicable

6.4. Authors' contributions
All the paper scientific information, especially the simulation of the turbocharger with the AMESim software and the experimental data of the turbocharger obtained with the CIMAT test bed!

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