THE STUDY ON THE EFFECTS OF DIFFERENT OPENING RANGES OF WASTE-GATE ON IMPROVING THE WORK PARAMETERS OF SPARK IGNITION ENGINE

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Abstract

The experimental study was conducted to investigate the effects of different opening ranges of waste gate of a turbocharged medium displacement spark ignition engine on improving work parameters such as exhaust emission, torque characteristics and fuel consumption. The object of the experimental tests was an engine with modified intake and exhaust manifolds. The intake and exhaust manifold modification included only implementation of turbocharger with the variable geometry turbine. The values of boost pressure were controlled by the system with waste gate valves with a changeable characteristic and a control valve. Work parameters of waste-gate valves have been selected experimentally. Boost pressure had to be reduced to 1.3 and to 1.5 bar in the range of medium values of throttle opening.

The system with waste-gate allowed to increase significantly the torque value at low engine speed range as well as to reduce the boost pressure at high engine speed range for throttle opening values above 50%. In total range engine work, emission of particular exhaust gas components did not exceed the values of the emission suitable for normally aspirated engine. It provided the stable engine's running in all conditions including variable engine speed and in the whole range of throttle opening angle with restricted fuel consumption. The application of changeable characteristics in the waste gate valve which reduces the charging pressure by controlling characteristics variable of the valve depending on the engine work parameters was controlled by electronic system. The controlled system allows improving parameters of engine performance in wide range of engine's rotation speed.

Keywords: *spark ignition engine, turbocharger*

1. Introduction

The increasing amount of car transportation units and shortcomings of energy resources as well as environmental pollution threatening require the reduction of energy consumption and generation of pollutants in transport. The maximum value to be expected in the next few years for CO_2 emission for vehicles and the increasing demand for more driving comfort represent new challenges for the automobile industry. One approach to a solution is the reduction of the displacement engine. This method is often referred to using the term "downsizing" and requires the engine to be turbocharged in order to meet the requirements for performance and torque. Downsizing and supercharging is one of the most promising approaches to reduce the fuel consumption of SI engines [1, 2]. The goals of development in terms of the thermodynamics and operating response of future passenger car SI engines can be summarized as follows: increase in the power density of the engine, highest possible maximum torque at low engine speeds across the widest possible range of speed, improvement of the driving response in transient operating phases. The application of turbocharging system enabled to obtain the suitable value and curve of torque in all engine speed ranges [3]. One of the possibilities to control value of boost pressure is controlling the turbine upstream. The waste-gate system enables to control work parameters of the engine and exhaust emission.

The results of investigations [4] indicated that the inlet manifold pressure of turbocharger is very effective in improving the exhaust emission. Decreasing the opening range of waste-gate which results in increasing the inlet manifold pressure allows improving the exhaust soot emission at specific opening range of waste-gate in a compression engine.

2. The purpose and methods of investigation

The experimental study was conducted to investigate the effects of different opening ranges of waste gate of a turbocharged medium displacement spark ignition engine on improving work parameters such as exhaust emission, torque characteristic and fuel consumption. The examination of possibilities of torque value changes by controlling and changing the value of boost pressure was the main aim of the investigations.

The values of boost pressure were controlled by a system with waste gate valves with changeable characteristic and a control valve. Work parameters of waste-gate valves have been selected experimentally. Boost pressure had to be reduced to 1.3 and to 1.5 bar in the range of medium values of throttle opening.

The basic data for turbocharger system was calculated applying GT-Power application. The turbo speed and pressure ratio were calculated by the software, and then the efficiency and mass flows were looked up in the turbine and compressor maps respectively [5].

The turbine and compressor power are calculated from:

$$P = \dot{m}\left(h_{in} - h_{out}\right), \tag{1}$$

where the inlet enthalpy is calculated from the upstream gas condition and the downstream enthalpies are:

$$h_{out,turbine} = h_{in} - \Delta h_{s,T}\eta_s , \tag{2}$$

$$h_{out,compressor} = h_{in} + \frac{\Delta h_{s,C}}{\eta_s}, \tag{3}$$

The enthalpy change is calculated from formulas for turbine and compressor, which are:

$$\Delta h_{s,C} = c_p T_{0,in}\left(\left(P_{0,out}\big/P_{0,in}\right)^{(\gamma-1)/\gamma} - 1\right), \tag{4}$$

$$\Delta h_{s,T} = c_p T_{0,in}\left(1 - \left(P_{0,out}\big/P_{0,in}\right)^{(\gamma-1)/\gamma}\right), \tag{5}$$

where c_p and $T_{0,in}$ are for the machine inlet conditions.

The turbo speed is calculated from the torque (im-) balance between compressor and turbine:

$$\Delta\omega = \frac{\Delta t}{J_{rotor}}\left(\tau_{turbine} - \tau_{compressor} - \tau_{friction}\right). \tag{6}$$

where:

Dw - change in shaft speed per timestep,

Dt - calculation timestep,

J_{rotor} - turbo rotor moment of inertia,

t - torque.

The pressure ratios are determined from the pressure in the adjacent subvolumes immediately upstream and immediately downstream of the compressor and turbine.

3. Experimental setup

The object of the experimental tests was an engine with modified intake and exhaust manifolds. The intake and exhaust manifold modification, including only implementation of turbocharger and sensors, was made for experimental purposes. The naturally aspirated engine (1300 cm) without decreasing compression ratio (11:1) was used. The turbocharger with a turbine with variable geometry and with additional waste-gate system was tested. The values of maximum boost pressure were controlled by the system with waste-gate valves and with changeable characteristics and a control valve (Fig. 1). Upstream flow for the turbine was controlled by pressure in a manifold.

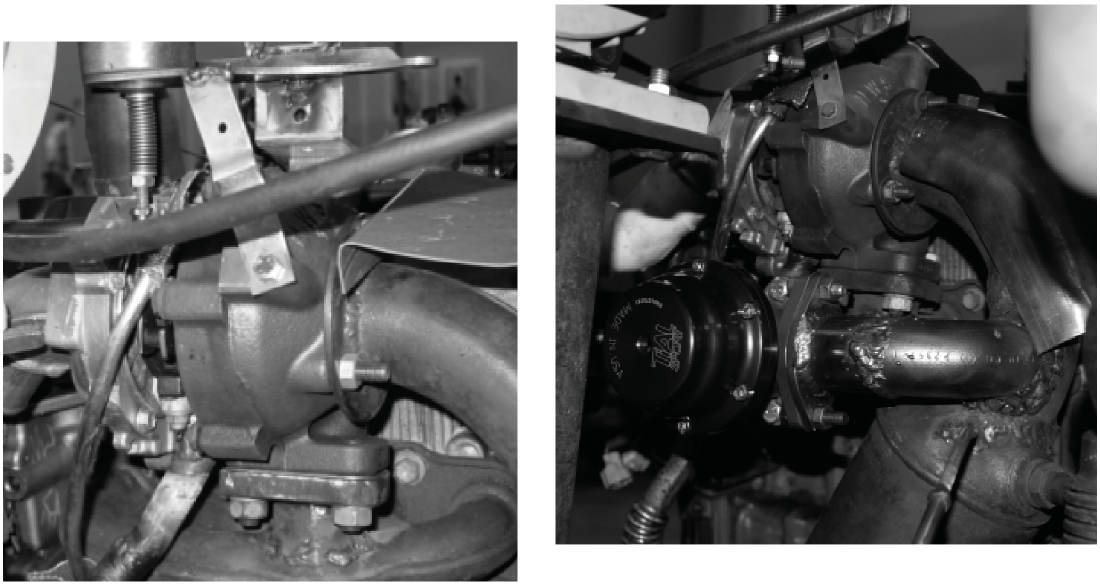

Fig. 1. The experimental engine with turbocharger and turbocharger with waste-gate valve

Different types of pneumatic waste-gate systems, a valve with fixed value of opening pressure and a waste-gate with changeable characteristic have been tested. The value of opening pressure in the first system depended on the type of actuator's main spring and its length. The changeable characteristic in the second type of waste-gate system was obtained using the device which controlled the range of the opening of the valve. Springs with different characteristics in the waste-gate valve in both systems have been tested (Fig. 2). Springs with different forces and length were applied. The maximum deflection of the springs was changeable.

The test was equipped with a 100 kW eddy current dynamometer, controlled by the electronic system. As it has been shown in Fig. 3, the experimental apparatus consisted of the test engine, the dynamometer, the control system of fuel, intake air and exhaust gases. The values of torque, power, admitted mass of fuel per unit of time, air-flow mass, air temperature, intake manifold air pressure, exhaust gas temperature, emission of CO, CO_2, HC, NO_x, and air-fuel ratio (λ) were measured during the tests of the engine. The engine's coolant and turbine temperature, as well as the advance angle of ignition and fuel injection time were constantly monitored during all tests.

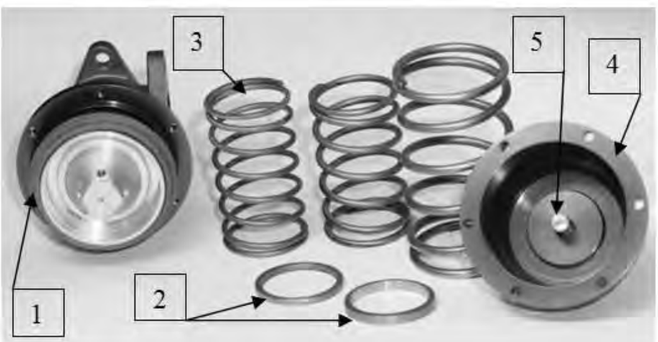

Fig. 2. The elements of waste gate 1 - membrane, 2 - space washer, 3 - springs, 4 - casing, 5 –bumper

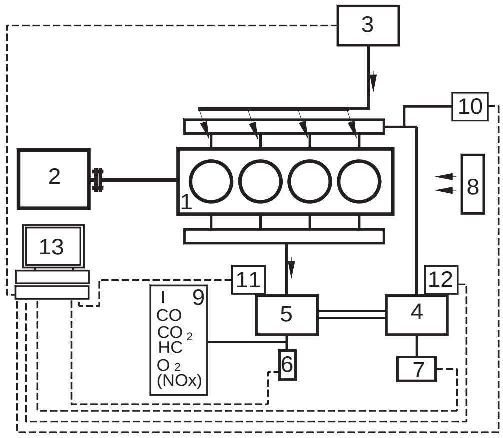

Fig. 3. The experimental work stand 1 - spark ignition engine with turbocharger system, 2 - dynamometer, 3 - fuel distribution system with measuring equipment, 4 - intake manifold with compressors of turbochargers, 5 - exhaust manifold with turbines of turbochargers, 6 - exhaust gas temperature sensor, 7 - air mass and temperature measurement equipment, 8 - cooling fan, 9 - exhaust emission measuring equipment, 10 - intake manifold pressure sensor, 11 - exhaust manifold temperature and pressure sensors, 12 - intake manifold temperature sensor, 13 - signal controller and data analyzer

4. Results and discussion

A test grid covering the range of rotation speed from 1000 to 6000 rpm, and from 25%, 50%, 75% and 100% throttle opening values was designed. The results of the tests have been shown in Fig. 4 and 5.

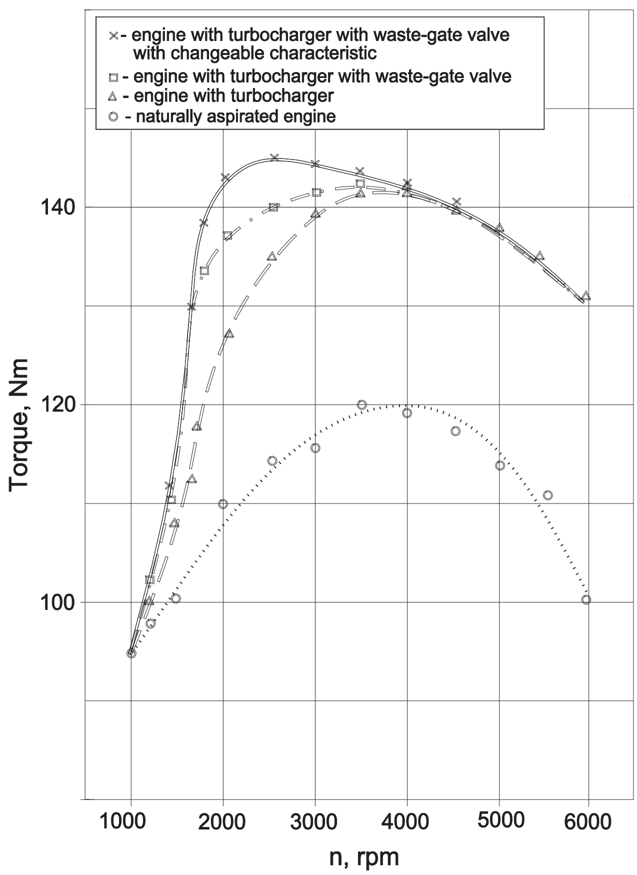

Fig. 4. Results of test of engine with different waste-gate systems, torque curve (max. boost pressure 1.5 bar) – 100% throttle opening

For the system with fixed value of maximum pressure the boost pressure, had to be reduced to 0.4 bar in the range of medium and higher values of throttle opening. At higher values of the engine speed, boost pressure has been reduced for higher values of throttle opening. It provided the a stable engine's running in all conditions including variable engine speed and the whole range of throttle opening angles with restricted fuel consumption. For the system with changeable characteristic, the value of boost pressure was changed from 1.3 bar for the low speed range and low values of throttle opening to 0.8 bar for the full throttle opening. In the second case, the value of boost pressure was changed from 1.5 to 1.0 bar. In that case it was necessary to change injectors and the control system which dosed the. The test results of the engine with changeable waste-gate characteristic were compared with the results of tests of engine with fixed value of maximum boost pressure. The system with waste-gate with changeable characteristic enabled to obtain higher value of boost pressure at low engine speed and at low throttle opening value. It allowed improving torque characteristic in a wide range of engine rotation speed and throttling opening value.

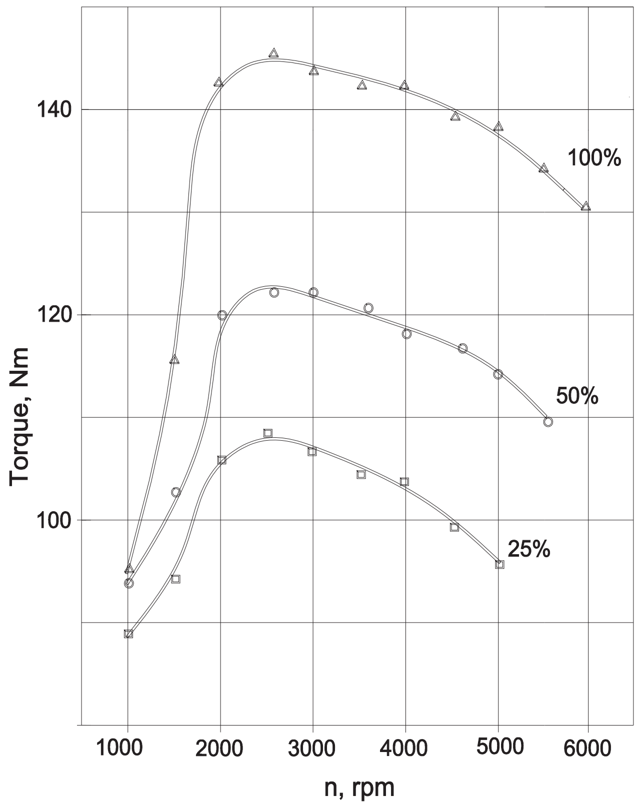

Fig. 6. Results of tests of engine with waste-gate system wit changeable characteristic, for different value of throttle opening (max. boost pressure 1.5 bar) - torque curves

5. Conclusion

The application of turbocharging system with a turbocharger of variable geometry turbine was quite satisfactory. A waste-gate with changeable characteristic enabled to use higher values of boost pressure within the range of mean values of the engine load. The ratio of the opening of the waste-gate valve depended on the charging pressure and other engine work parameters such as throttle opening value and engine speed. The application of waste-gate with changeable characteristic enabled to avoid a combustion knocking by higher values of the engine load. There is a possibility to apply the charging system with one or two charges, with boost pressure control system, in the already existing, naturally aspired engine without decreasing compression ratio and modifying the engine's control system.

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