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CHARGING SYSTEM OF SPARK IGNITION ENGINE WITH TWO CHARGERS

SYSTEM DOŁADOWANIA SILNIKA O ZAPŁONIE ISKROWYM Z DWIEMA SPRĘŻARKAMI

A b s t r a c t

The purpose of the investigation was the application of two chargers systems in spark ignition engine and determining chargers' work parameters depending on throttle opening and engine's rotation speed. The system with small turbocharger or electrically driven charger and larger variable geometry turbocharger in parallel and series connection was examined. The engine used during the investigation was 1300 ccm displacement SI engine with modified intake and exhaust manifolds. Intake and exhaust manifold modification including only the implementation of chargers and sensors was done for experimental purposes. Specific values of maximum boost pressure were obtained by introducing a waste gate valve system with appropriate characteristics. The application of two chargers system as modification of naturally aspirated spark ignition engine allows to improve the torque flexibility rate.

Keywords: *spark ignition engine, supercharging system, turbocharger*

S t r e s z c z e n i e

Celem przeprowadzonych badań było określenie możliwości zastosowania systemu doładowania z dwiema sprężarkami w silniku o zapłonie iskrowym oraz określenie parametrów pracy w zależności od obciążenia, stopnia otwarcia przepustnicy i prędkości obrotowej. Badano system doładowania z główną turbosprężarką z turbina ze zmienną geometrią oraz dodatkową małą sprężarką. Jako mniejszą sprężarkę zastosowano turbosprężarkę ze stałą geometrią oraz sprężarkę napędzaną elektrycznie. Do badań zastosowano silnik o pojemności skokowej 1300 cm^3 ze zmodyfikowanymi układami dolotowym i wylotowym. Ciśnienie doładowania było regulowane systemem z zaworami obejściowymi o dobranej charakterystyce. Zastosowanie systemu doładowania z dwiema sprężarkami pozwoliło na poprawę przebiegi momentu obrotowego w szerokim zakresie prędkości obrotowej.

Słowa kluczowe: *silnik spalinowy o zapłonie iskrowym, system doładowania, turbosprężarka*

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1. Introduction

Threats of environmental pollution require the reduction of energy consumption and generation of pollutants in transport. The development of a new environmentally friendly generation of internal combustion engines is essential. Supercharging is one of the most promising approaches to reduces the fuel consumption of spark ignition engines. Applications of charging system in spark ignition engines beside improvement of its performance, allows to decrease its displacement with no visible, negative influence on torque curve. Charging of SI engine requires modification in inlet and outlet system and adaptation of fuel injection and ignition system. An important question is the necessity of reduction of compression ratio, due to higher exposure to knock [4].

In case of race car's engines with turbocharger system lack of exhaust gasses mass flow in low engine's speed range is compensated with considerable increment of torque and power in high speed range. Furthermore high power of this type of engine allows implementation of supercharging system with mechanically driven compressor and turbocharger. When taking into consideration low and medium displacement engine, the type of technical solution is not suitable and leaves a space for different charging system like two turbochargers and turbocharger with electrically driven charger.

With the turbocharged SI engines, the higher charge pressure results in higher ultimate compression temperatures. This increases the risk of autoignition and of knocking. In part-load operation, the mass flow of turbocharged SI engines is throttled, and a bypass must be used around the compressor. Due to sensitivity of SI engine to knocking, there is a need to limit boost pressure or modify engine control unit with specific approach to engine's load, boost pressure, in-cylinder mixture and quality of fuel.

The purpose of the investigation was the application of systems with two chargers, two turbochargers and turbocharger with electrically driven charger.

2. The engine and experimental setup

The object of the experimental tests was an engine with modified intake end exhaust manifolds. The intake and exhaust manifold modification including only implementation of turbochargers and sensors was done for experimental purposes. The naturally aspirated engine (1300 ccm) without decreasing compression ratio (11 : 1) was used. The engine was tested with three supercharging systems, two turbochargers in parallel connection and turbocharger with electrically driven charger in parallel and series connection.

The basic data for main turbocharger was determined from compressor pressure ratio [1, 2, 3]. Compressor pressure ratio can by defined by the equation

$$\frac{p_2}{p_1} = \left[1 + \frac{\dot{m}_T}{\dot{m}_V} \cdot C_1 \cdot \frac{T_3}{T_1} \cdot \eta_{TL} \cdot \left(1 - \frac{p_4}{p_3} \right)^{\frac{k_3 - 1}{k_3}} \right]^{3,5} \tag{1}$$

where:

p_1 – compressor upstream pressure,

p_2 – compressor downstream pressure,

p_3 – turbine upstream pressure,
p_4 – turbine downstream pressure,
T_1 – compressor upstream temperature,
T_3 – turbine upstream temperature,
k_3 – isentropic exponent of the exhaust gas,
$\dot{m}_T$ – turbine mass flow,
$\dot{m}_V$ – comressor mass flow,
C_1 – constant,
η_{TL} – group efficiency.

In the system with two turbochargers, small and main variable geometry turbocharger, values of maximum boost pressure was controlled by the system with two waste gate valves and check valve (Fig. 1). In order to achieve a sufficient charge pressure at low engine speed, a small turbine was chosen with small neck cross section (32 mm).

The work of turbochargers depended on pressure in the intake manifold. In low and medium engine speed range, at low load of engine, only the small turbocharger (2) was used. At medium load of engine, in medium and higher engine speed range the waste gate (4) directed exhaust gas to the larger turbine (3). The air flow in the intake manifold was controlled by plate check valves (8, 9). To limit the associate component load, the charge pressure was controlled to a constant value by allowing the excess exhaust gas enthalpy stream to bypass the turbine (waste gate 5). At higher load of engine in high engine speed range, the work of turbocharger with the variable turbine geometry (3) was supported by a small turbocharger (2). The additional air cooler was used in the intake system (7).

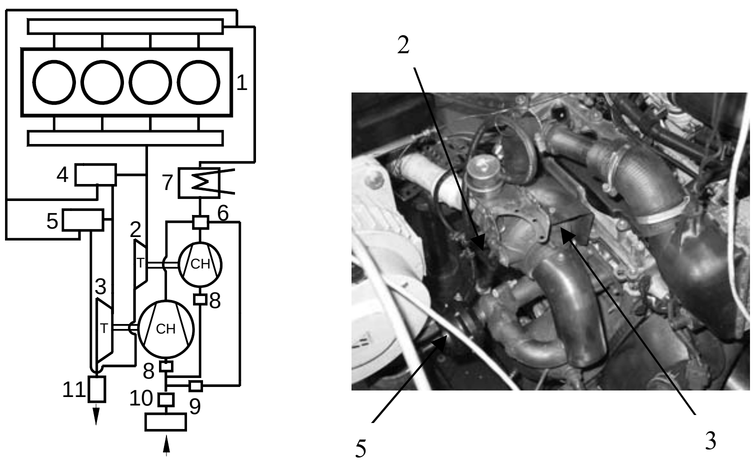

Fig. 1. Scheme of system with two turbochargers: 1 – spark ignition engine, 2 – small turbocharger, 3 – variable geometry turbocharger, 4, 5 – waste gate valve, 6 – control valve, 7 – intercooler, 8, 9 – check valve, 10 – air mass sensor, 11 – catalytic converter, 12 – air filter

Rys. 1. Schemat systemu z dwiema turbosprężarkami: 1 – silnik o zapłonie iskrowym, 2 – mała turbosprężarka, 3 – turbosprężarka z turbiną o zmiennej geometrii, 4, 5 – zawory upustowe, 6 – zawór sterujący, 7 – chłodnica powietrza doładowującego, 8, 9 – zawory kontrolne, 10 – czujnik przepływu masy powietrza, 11 – katalizator, 12 – filtr powietrza

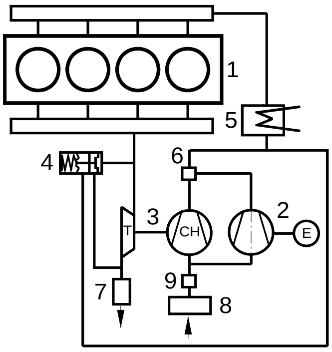

Fig. 2. Scheme of system with turbocharger and electrically driven charger (parallel connection): 1 – spark ignition engine, 2 – e-charger, 3 – variable geometry turbocharger, 4 – waste gate valve, 5 – intercooler, 6 – control valve, 8 – check valve, 7 – catalytic converter, 8 – air filter, 9 – air mass sensor

Rys. 2. Schemat systemu z turbosprężarką i sprężarką napędzaną silnikiem elektrycznym (układ równoległy): 1 – silnik o zapłonie iskrowym, 2 – sprężarka napędzana silnikiem elektrycznym, 3 – turbosprężarka z turbiną o zmiennej geometrii, 4, – zawór upustowy, 5 – chłodnica powietrza doładowującego, 6 – zawór upustowy, 7 – katalizator, 8 – filtr powietrza, 9 – czujnik przepływu masy powietrza

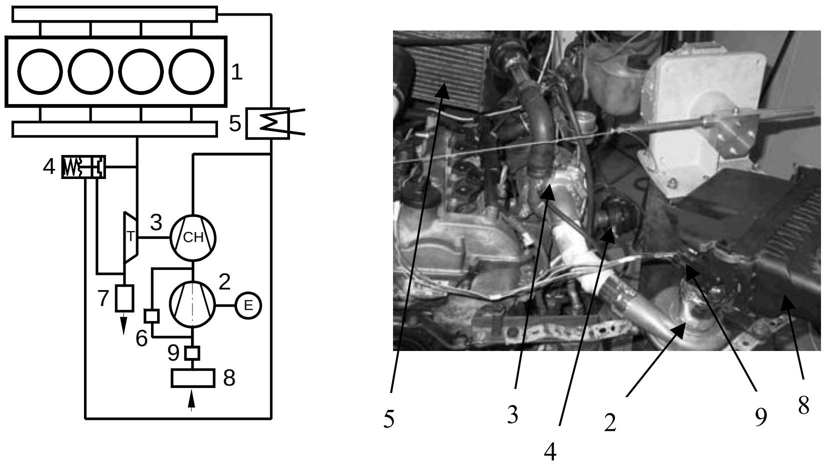

Fig. 3. Scheme of system with turbocharger and electrically driven charger (series connection): 1 – spark ignition engine, 2 – e-charger, 3 – variable geometry turbocharger, 4 – waste gate valve, 5 – intercooler, 6 – control valve, 8 – check valve, 7 – catalytic converter, 8 – air filter, 9 – air mass sensor

Rys. 3. Schemat systemu z turbosprężarką i sprężarką napędzaną silnikiem elektrycznym (układ szeregowy): 1 – silnik o zapłonie iskrowym, 2 – sprężarka napędzana silnikiem elektrycznym, 3 – turbosprężarka z turbiną o zmiennej geometrii, 4, – zawór upustowy, 5 – chłodnica powietrza doładowującego, 6 – zawór upustowy, 7 – katalizator, 8 – filtr powietrza, 9 – czujnik przepływu masy powietrza

In the system with turbocharger and electrically driven charger (e-charger) (Fig. 2), in low medium engine speed range, at low load of engine, only the electrically driven charger (2) was used. At medium load of engine, in medium and higher engine speed range the variable geometry turbocharger was used.

In the system with series connection (Fig. 3) the bypass with control valve (6) around e-charger was used.

All tests were carried out at similar environmental conditions. The room with a test stand was air-conditioned which provided the right ambient temperature in the range of 293–298 K. The application of cooling air system enabled to maintain the work temperature of the examined charging system below 973 K. The temperature was measured by pyrometer which was mounted on the housing of the turbine. It was possible to keep the temperature of the cooling liquid within the range of 340–365 K because water-cooled heat exchanger was applied in the cooling system of the engine. Scheme of the engine test apparatus and measuring system is shown in Fig. 4.

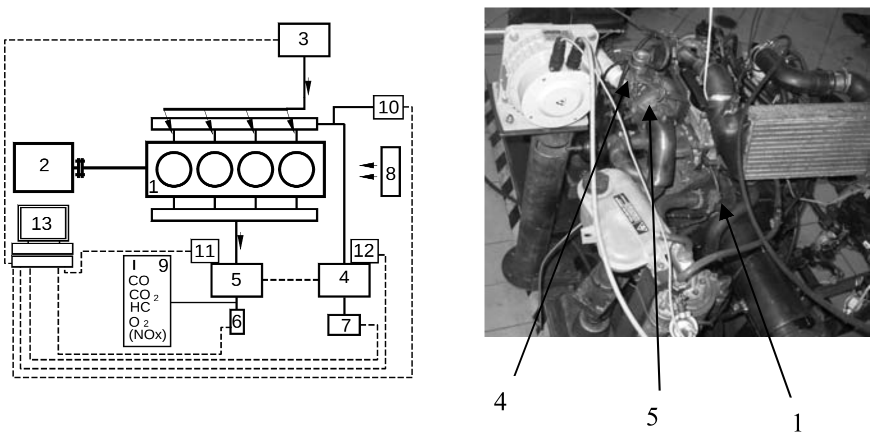

Fig. 4. Scheme of experimental apparatus: 1 – spark ignition engine with turbocharger system, 2 – dynamometer, 3 – fuel distribution system with measuring equipment, 4 – intake manifold with compressors of turbochargers, 5 – exhaust manifold with turbines of turbochargers, 6 – exhaust gas temperature 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

Rys. 4. Schemat stanowiska badawczego: 1 – silnik o zapłonie iskrowym z układem doładowania, 2 – hamulec silnikowy, 3 – system pomiarowy zużycia paliwa, 4, – układ dolotowy ze sprężarkami, 5 – układ wylotowy z turbinami turbosprężarek, 6 – czujnik pomiarowy temperatury gazów spalinowych, 7 – czujnik pomiarowy temperatury powietrza dolotowego, 8 – wentylator nadmuchowy, 9 – analizator spalin, 10 – czujnik pomiaru ciśnienia w kolektorze dolotowym, 11 – czujnik pomiaru ciśnienia w kolektorze wylotowym, 12 – czujnik pomiaru temperatury w kolektorze dolotowym, 13 – urządzenie do kontroli i akwizycji danych

The test was equipped with a 100 kW eddy current dynamometer, controlled by the electronic system. The turbochargers of the test engine consisted of a radial turbine and centrifugal compressor. As it was shown in Fig. 4, the experimental apparatus was composed of the test engine, a dynamometer, control system of fuel, intake air and exhaust gas. 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 were measured during engine's test. Engine's coolant and turbine temperature, as well as ignition advance angle and fuel injection time were constantly monitored during all tests.

3. Research results

A test grid covering from 1000 to 6000 rpm, and from 25%, 50%, 75% and 100% throttle opening values was designed. Boost pressure had to be reduced to 0,35 bar in order to provide stable engine's run in all conditions including variable engine speed and the whole range of throttle opening angle with restricted fuel consumption. Results of the tests have been shown in Fig. 5. The results of the tests of engine with two chargers was compared with the results of tests of naturally aspirated engine and the engine with one turbocharger with variable geometry turbine [5].

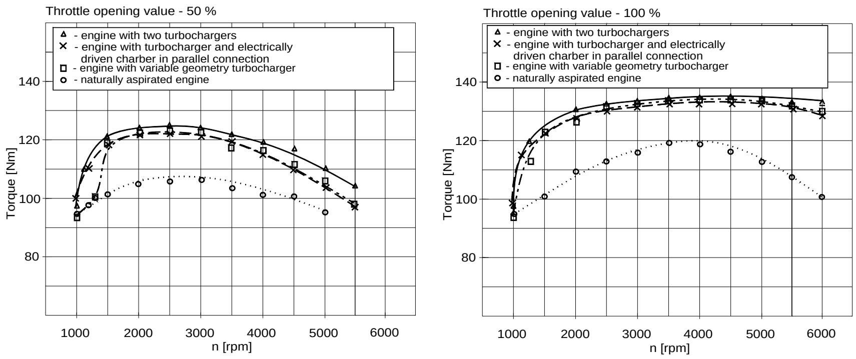

Fig. 5. Results of tests of engine with two charger systems, torque curve

Rys. 5. Przebieg zmian momentu obrotowego dla systemu z dwiema sprężarkami

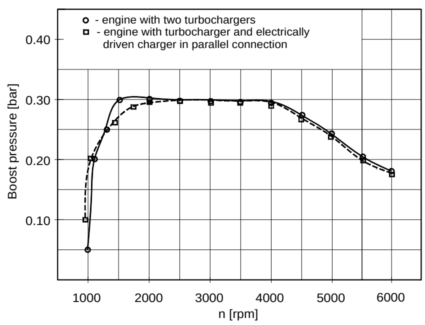

Fig. 6. Boost pressure curve

Rys. 6. Przebieg zmian ciśnienia doładowania

Both systems with additional small turbocharger or e-charger allowed to increase significantly the torque value in low and medium speed range for throttle opening values below 50%. The system with e-charger allowed to increase boost pressure between 900–1200 rpm speed range with parallel to the reduction boost pressure in 1200–2000 rpm speed range in comparison with the system with two turbochargers (Fig. 6).

The effective efficiency in medium engine's speed range was much better for medium throttle opening values (50–70%) (Fig. 7). Effective efficiency (η_e) of engine was calculated by formula

$$\eta_0 = \frac{1}{g_e \cdot W_p}$$

where:

g_e – effective specific fuel consumption,
W_p – net calorific value of the fuel.

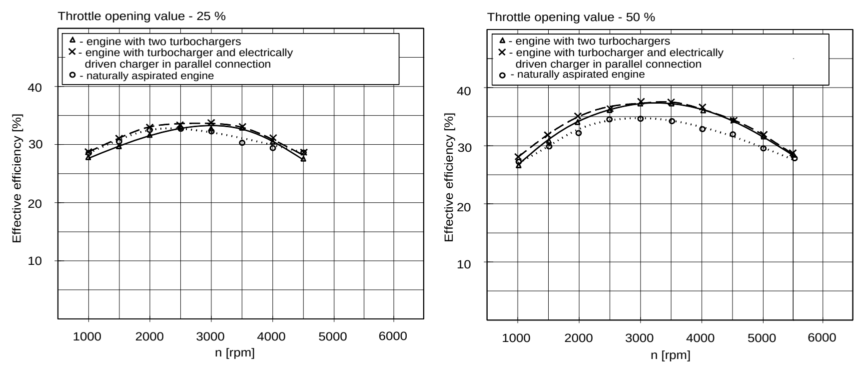

Fig. 7. Effective efficiency characteristics

Rys. 7. Przebieg zmian sprawności ogólnej

4. Conclusions

The application of two chargers system as modification of naturally aspirated spark ignition engine allows to improve torque flexibility rate. There is a possibility to apply the charging system with two chargers, with boost pressure control system, in already existing, naturally aspirated engine without decreasing compression ratio and modifying engine's control system.

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 allows to use higher values of boost pressure within the range of mean values of the engine load. Pneumatic-mechanical controlling of the air streams from both compressors can be replaced by an electronically controlled system which makes it possible to reach better parameters of engine performance in transient states.

W tekstach obcojęzycznych Redakcja dokonała tylko standardowej adiustacji, zachowując ich oryginalną wersję.

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