COMPARATIVE STUDY OF CHARGING SYSTEM OF SPARK IGNITION ENGINE

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Abstract

The purpose of investigation was comparison of engine's output while equipped with different types of turbocharging systems. Engine used during research was Toyota's SI engine with displacement of 1296 cm^3. Intake and exhaust manifold were modified by introducing fixed and variable geometry turbocharger. The third system was electrically driven charger ensuring both constant and variable boost pressure. Regulatory parameters of fuel injection and ignition system weren't changed.

On the basis of carried out research , it was affirmed that there is a possibility of introducing charging system into the engine without changes of mentioned regulatory parameters. Proper choice concerning charging systems allows improving torque characteristic in wide range of engine's rotational speed. Electrically driven charger giving maximum boost pressure provides significant improvement in low engine's speed range, whereas in higher range it is not showing so much advantage. In medium engine's speed range the best result is given by variable geometry turbocharging system. In this application boost pressure had to be reduced to $0.25 \cdot 10^5$ [Pa] in order to provide stable engine's run in all conditions including variable engine's speed and whole range of throttle opening angle.

Keywords: *transport, combustion engines, charging system*

1. Introduction

Application of charging system in SI engine beside improvement of its performance, allows decreasing its displacement with no visible, negative influence on torque curve. Charging of SI engine requires not only modification in inlet and outlet system, but also reduction of compression ratio, due to higher exposure to knock. Important question is adaptation of fuel injection and ignition system. In case of race car's engines lack of exhaust gases 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.

When taking into consideration low and medium displacement engine, that type of technical solution is not suitable and leaves a space for different charging systems like electric charging [1,2]. Due to sensitivity of SI engine to knocking there is a need to limit boost pressure or modify engine control unit(ECU),with specific approach to engine's load, boost pressure, in-cylinder mixture temperature and quality of fuel. Modification of control unit can be done with adaptation of existing units of naturally aspirated engine or with brand new unit created on a test bed [3, 4, 5, 6, 7]. This paper shows attempt to introduce charging system into small displacement SI engine without any control unit modification. The goal of investigation was to verify outcome of this procedure.

2. The object of investigation

All tests were performed on Toyota Yaris engine with displacement of 1296 cm^3. Intake and exhaust manifold modification, including implementation of turbocharger and sensors was done for experimental purposes. The scope of experiments involved determination of engine's performance with different charging systems: turbocharging with variable turbine geometry, fixed turbine geometry and electric charging.Fig.1 presents fixed geometry turbocharging system's block diagram.

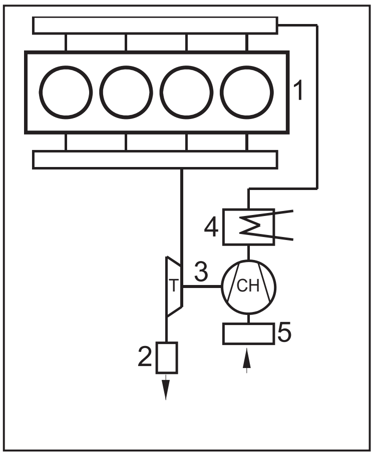

Fig. 1. Fixed geometry turbocharging system's block diagram, 1 – engine, 2 – catalytic converter, 3 – turbocharger, 4 – air cooler, 5 – air filter

Apart from using variable turbine geometry there is also a waste gate in exhaust manifold which improves maximum boost pressure's control, by redirecting exhaust gases flow. Fig. 2 presents variable geometry turbocharger system's block diagram.

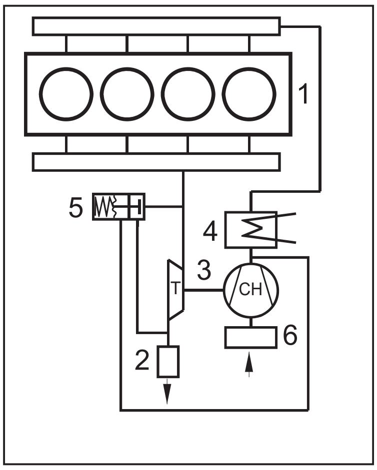

Fig. 2. Variable geometry turbocharging system's block diagram, 1 – engine, 2 – catalytic converter, 3 – turbocharger, 4 – air cooler, 5 – waste gate valve, 6 – air filter

Both of turbocharging systems use additional air cooler in intake system. In case of electrically driven charger changes consist of inlet with extension and charger mounting. Fig. 3 presents electrically driven charger's system.

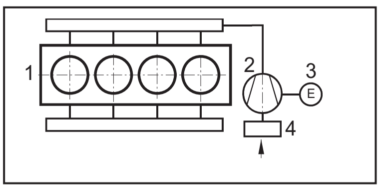

Fig. 3. Electrically driven charger system's block diagram, 1 – engine, 2 –charger, 3 – electric propulsion, 4 – air filter

3. Research results

All charging systems were tested with similar environmental conditions. Values of torque M_o, power N, fuel consumption G_e, air-flow mass m_{pd}, air temperature t_{pd}, intake manifold air pressure p_{pd}, CO, CO_2, HC emission and air to fuel ratio λ were measured during engine's test. Engine's coolant and turbine temperature, as well as ignition advance angle were constantly monitored during all tests. Significant torque curve improvement in wide range of engine's rotational speed can be observed when using variable geometry turbocharger (Fig. 4). For 75^o of throttle opening angle in medium and high engine's speed range (2200-4000 rpm) considerable power increase can be noticed (Fig. 5).

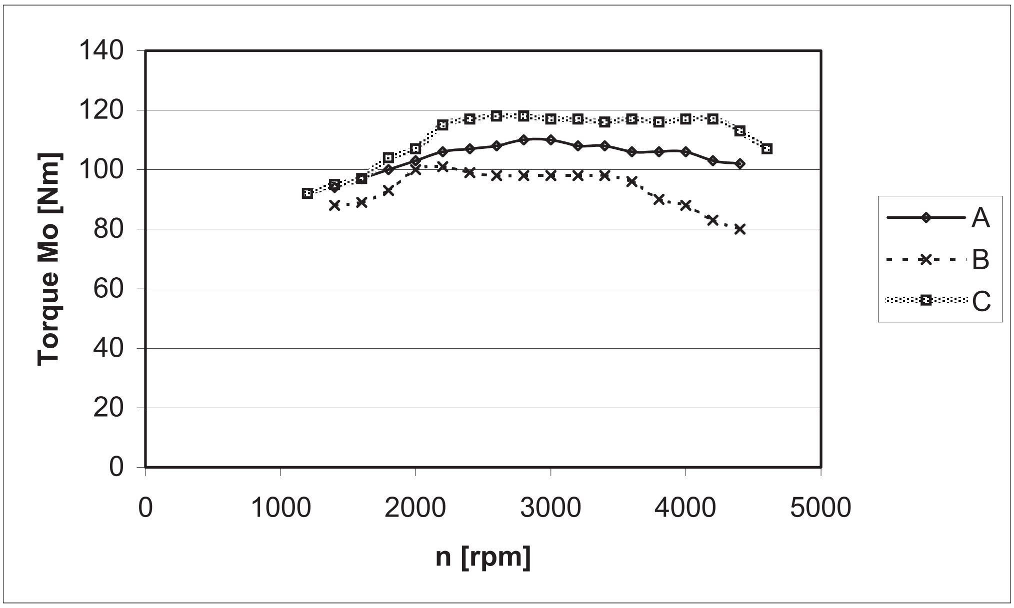

Fig. 4. Torque characteristic for 75^o of throttle opening angle, A –electrically driven charger, B –naturally aspirated engine, C – variable geometry turbocharger's system with waste gate

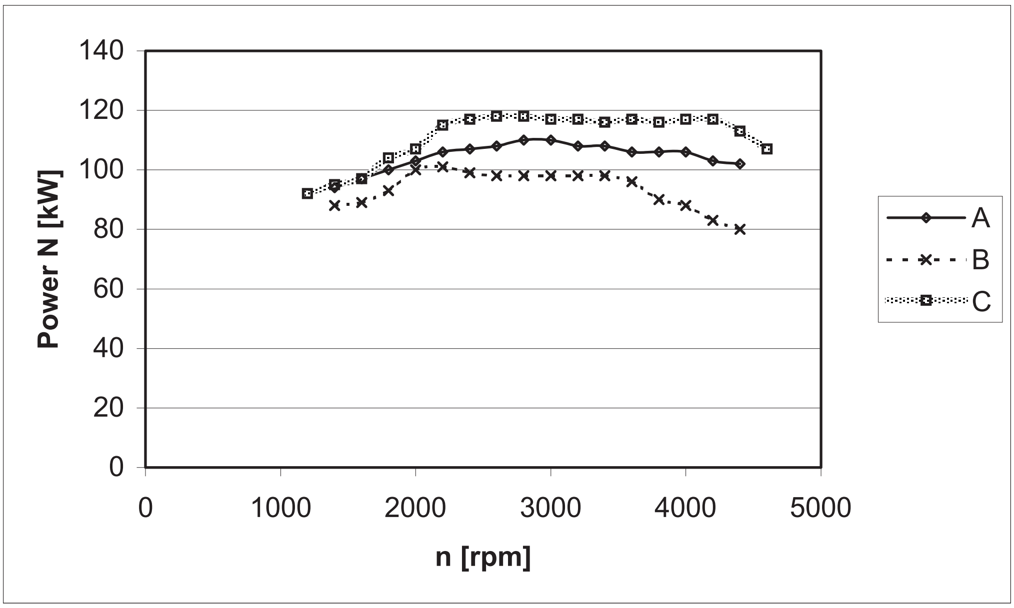

Fig. 5. Power characteristic for 75^o of throttle opening angle, A –electrically driven charger, B –naturally aspirated engine, C – variable geometry turbocharger's system with waste gate

When comparing turbocharging systems, fixed geometry is advantageous in case of small throttle opening angle while high engine' speed run (fig. 6).

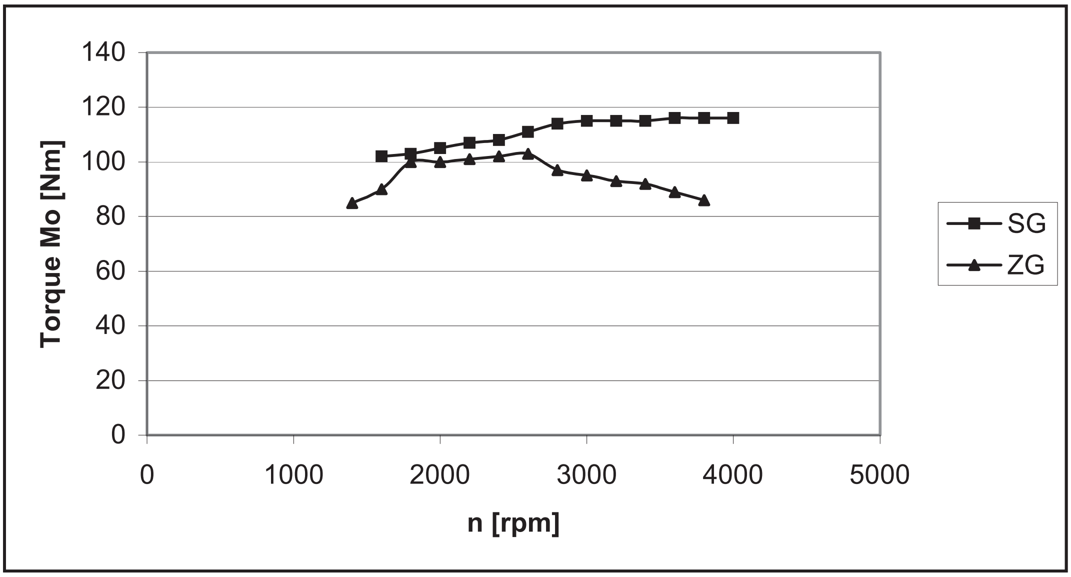

Fig. 6. Torque curve for 27^o throttle opening angle, SG – fixed geometry turbocharger's system, ZG –variable geometry turbocharger's system

One of the fixed geometry turbocharger inconveniences of the system is unstable engine's run while throttle opening angle being higher than 35^o and engine's rotational speed was exceeding 2600 rpm. This behaviour is connected with to high boost pressure causing sudden mixture leanness.

4. Research outcome analysis

Implementation of variable geometry turbocharger's system with waste gate valve responsible for limiting maximum boost pressure ensured torque increase and stable engine's run in a wide speed range with different throttle opening angles. I was possible to achieve without any additional change to regulatory parameters thanks to maximum boost pressure limitation to $0.25{\cdot}10^5$ Pa.
Use of electrically driven charger system with boost pressure value $0.05{\cdot}10^5$ Pa improved torque curve only in low engine's speed range and with almost full throttle opening. In high engine's speed range influence of low pressure charging on engine's performance was insignificant. For throttle opening angle values below 35^o, improvement in torque curve can be seen when exceeding 2000 rpm. In medium engine' speed range the best results, concerning shape of performance curve were obtained with application of variable geometry turbocharger. When analyzing engine's total efficiency (fig. 7) expressed by formula:

$$\eta_o = \frac{36 \cdot 10^5}{g_e W_d}, \qquad (1)$$

where:

W_d - fuel energy density [kJ/kg]

g_e - specific fuel consumption [g/kWh]

It can be observed, that in medium engine's speed range aim of increasing efficiency was not achieved due to higher fuel consumption.

Improvement of engine's total efficiency in low engine's speed range can be achieved with use of hybrid charging system, which combines advantages of turbocharging and electrically driven charger.

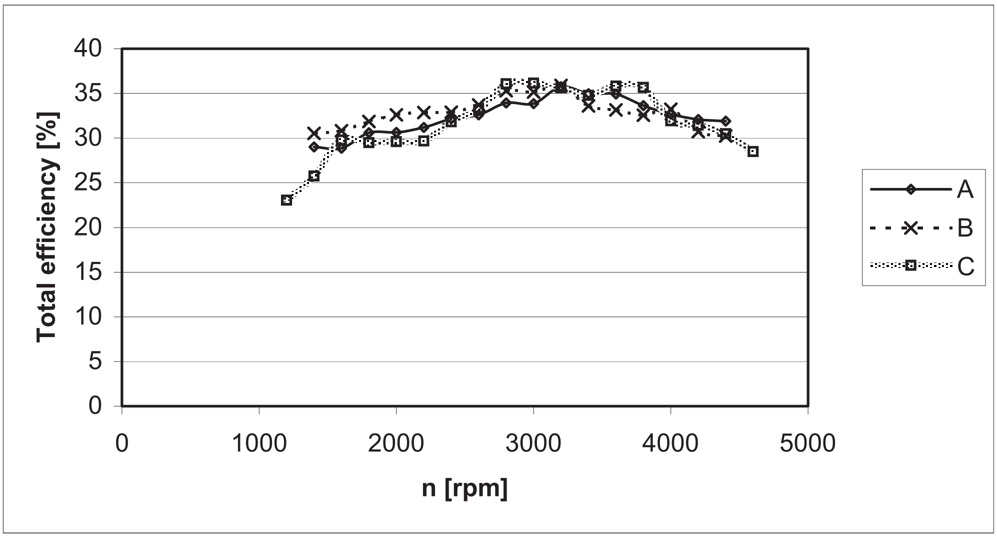

Fig. 7. Total efficiency characteristic for 75^o of throttle opening angle, A –electrically driven charger, B –naturally aspirated engine , C – variable geometry turbocharger's system with

5. Conclusions

Basing on research outcome it can be stated that satisfying results of engine's charging without any additional change in regulatory parameters can be achieved when using variable geometry turbocharger's system.

Further engine's performance improvement such as total efficiency and torque increase can be gained with combination of different charging systems.

References

[1] Pallotti, P., Torella, E., New, J., Criddle, M., Brown, J., *Application of an Electric Boosting System to a Small, Four-cylinder S. I. Engine*, SAE Technical Paper Series, 2003-32-0039.

[2] George, S., Morris, G., Dixon, J., Pearce, D., Heslop, G., *Optimal Boost Control for an Electrical Supercharging Application*, SAE Technical Paper Series, 2004-01-0523.

[3] Stotsky, A., Kolmanovsky, I., *Application of input estimation techniques to charge estimation and control in automotive engines*, Control Engineering Practice 10, pp. 1371-1383, 2002.

[4] Erikson, L., Nielsen, L., Brugard, J., Bergstrom, J., Pettersson, F., Andersson, P., *Modelling of a Turbocharged SI Engine,* Annual Reviews in Control, 26 (2002), pp. 129-137.

[5] Hafner, M., Schuler, M., Nelles, O., Isermann, R., Fast neural networks for diesel engine control design, Control Engineering Practice, 8, pp. 1211-1221, 2000.

[6] Isermann, R., Schaffnit, J., Sinsel, S., Hardware-in-the-loop simulation for the design and testing of engine-control system. Control Engineering Practice, 7, pp. 643-653, 1999.

[7] Frei, S. A., Guzzella, L., Onder, Ch. H., Nizzola, C., Improved dynamic performance of Turbocharged Si engine power trains using clutch actuation, Control Engineering Practice, 14 pp. 363-373, 2006.