J. Marine. Sci. Appl. (2008) 7:111-115
DOI: 110.1007/s11804-008-7026-8

Turbocharging the DA465 gasoline engine

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Abstract: In order to improve performance of the DA465Q gasoline engine, a substantial amount of research was done to optimize its turbocharging system. The research led to the GT12 turbocharger being selected and its turbocharging parameters being settled. Based on these tests, rational matching was worked out for respective components of the turbocharging system. Results show that this turbocharger allows the engine to easily meet the proposed requirements for power and economic performance, giving insight into further performance improvements for gasoline engines.
Keywords: turbocharging; gasoline engine; turbocharging system; turbocharger
CLC number: TK411.8 **Document code:** A **Article ID:** 1671-9433(2008)02-0111-05

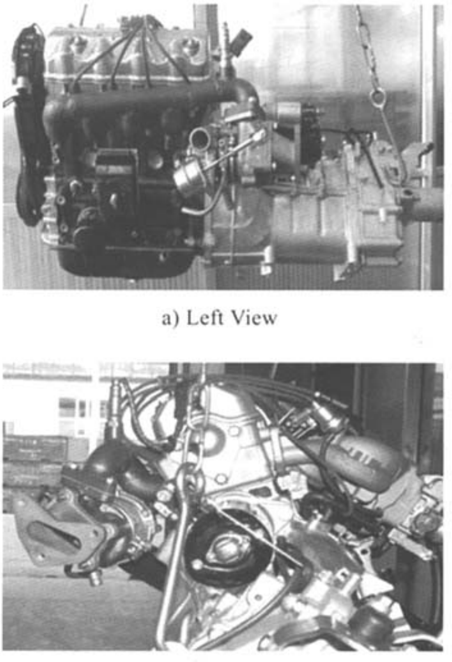
1 Introduction

Since 1978, the turbocharging technology had started to be applied in gasoline engine in foreign countries, which was soon on its path of rapid development and perfection[1,2], but its research and application in China relatively lagged behind. At the end of 1980s, domestic universities, such as Tsinghua University, Xi'an Jiaotong University, worked together with gasoline engine producers to conduct the turbocharging research on 492Q. Affected by detonation and limited by thermal load, the engine failed to achieve its turbocharging goal and its performance was also far from being ideal.

Compared with turbocharged diesel engine, turbocharged gasoline engine holds a particularly advantageous position in its application upon small gasoline engines. In recent years, as the emission rules are tightened up and the international energy situation is growing tense, research on turbocharging technology is much needed to help people control emission, improve power output, increase engine power density, recover the highland power, and so on. Thus, the research may well help saving energy, protecting the environment and improving the engine performance [3-5]. The turbocharging system serving DA465Q has been explored and developed, aiming to effectively improve its power performance and economic performance, and thus to give an insight into the improvement of the performance of the gasoline engine.

2 Setup parameters of turbocharging system

The chief parameters before and after being turbocharged of DA465Q are presented in Table 1, and the arrangements of turbocharger upon engine are shown in Fig.1.



a) Left View

b) Front View

Fig.1 Arrangements of turbocharger upon engine

Received date: 2007-04-20.
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Table 1 The comparisons of chief parameters

Model	Parameters	Original	Turbocharged
1	Engine mode	DA465Q	DA465Q/T
2	Number of cylinders	4	4
3	Bore/mm	65.5	65.5
4	Stroke/mm	72	72
5	Nominal motor power/kW	35.5	>50
6	Maximum torque/N·m	74	>110
7	Displacement/mL	970	970
8	Compression Ratio	8.8	8.0
9	Characteristic minimum oil consumption/ g·(kW·h)$^{-1}$	275	≤275
10	Idling speed/r·m^{-1}	850	850
11	Ignition order	1-3-4-2	1-3-4-2
12	Oil supply	Inlet interjection	Inlet interjection
13	Omission requirement	EUII	EUII
14	Number of single-cylinder intake valves	1	1
15	Number of single-cylinder exhaust valves	1	1
16	Fuel grade	93#	93#
17	Charger-air inter cooling	—	Yes
18	Way of turbocharging	—	Constant pressure

It is indispensable to solve the matching problem for achieving good performance of turbocharged engine, that is, to coordinate the work of turbocharger and engine To ensure the good matching and to reach the standard set for all specifications, first of all, parameters of supercharging are to be settled, which will serve as the important basis for the design and choice of suitable supercharger.

2.1 Air flow

$$G_c = \frac{N_e g_e \alpha \eta_s}{3600} L_0, \tag{1}$$

where G_c is the air flow needed by the engine (kg/s); N_e is the engine power (kW); α is the excessive air coefficient, which might be increased by 10%~30% for the purpose of lowering the heat load, the exhaust temperature and increasing the torque coefficient; η_s is the coefficient of scavenging; g_e is the fuel consumption rate, and g/(kW·h) can be reduced by 5%~10% after the engine is turbocharged. In order to meet the requirement of the maximum power output and maximum torque, calculations should be done under the external characteristic.

2.2 Compressor pressure ratio

$$\pi_c = \left(\frac{\rho_c}{\rho_0}\right)^{\frac{1}{1-\frac{0.286}{\eta_n}}}.$$

In real measurement,

$$\pi_c = \frac{P_c + P_0}{P_0 - P_{c1}}, \tag{2}$$

where ρ_c is the compressor delivery air density; ρ_0 is the needed inter cooling charger air density; η_n is the compressor polytropic efficiency; P_c is the compressor delivery pressure; P_{c1} is the compressor intake pressure.

2.3 Compressor efficiency

$$\eta_c = \frac{(273 + t_{c1})(\pi_c^{0.286} - 1)}{t_c - t_{c1}}, \tag{3}$$

where t_{c1} is the compressor intake temperature (℃); t_c is the compressor exit temperature(℃).

2.4 Set up the turbocharging parameters of DA 465Q engine

2.4.1 The raw data of the design

$D = 65.5$ mm, $S = 72$ mm, $V_h = 970$ mL. For the original engine, N_e is 35.5 kW/5 000 r/min; after being turbocharged, N_e≥50 kW/5 000r/min.

2.4.2 Choice of the point of design

To ensure good torque characteristics, the point of design is chosen as n=4 000 r/min, P_0=100 kPa, t_o=30, N_e=46.9 kW, G_e≤275 g/(kW·h).

2.4.3 To set the turbocharging parameters

Excessive air coefficient a=1; volumetric coefficient η_v=0.98; coefficient of scavenging η_s=1.0; scavenging excessive air coefficient $\phi_s = \eta_v \eta_s = 1$. Now, the engine power is enriched, and thus L_0 is 13.0. The air needed by the turbocharged engine is

$$G_e = \frac{N_e g_e \alpha \eta_s L_0}{3600} \times 10^{-3} = \frac{46.9 \times 275 \times 1.0 \times 1.0 \times 13.0}{3600 \times 1000} = 0.0465 \text{ kg/s}. \tag{4}$$

The air flow of the applied turbocharger is 0.046 5 kg/s.

The charger air density is

$$\rho_c = \frac{120G_e}{nV_h\eta_v\eta_s}\times10^{-3} = \frac{120\times0.0465}{4000\times0.97\times0.98\times1.0}\times10^{-3} = 1.466\ \text{kg/m}^3. \qquad (5)$$

When $\Delta P = 5\,000$ Pa, the compressor inlet air pressure is

$$P_a = P_0 - \Delta P = 100\,000 - 5\,000 = 95\,000\text{Pa} \qquad (6)$$

ΔP means the compressed pressure of the compressor inlet.

The inlet air density of compressor is

$$\rho_a = \frac{P_a}{RT_a} = \frac{95\,000}{287\times303} = 1.092\,4\ \text{kg/m}^3. \qquad (7)$$

The compressor pressure ratio is

$$\pi_c = \left(\frac{\rho_c}{\rho_a}\right)^{\frac{1}{1-\frac{\lambda}{\eta_n}}} = \left(\frac{1.466}{1.092\,4}\right)^{\frac{1}{1-\frac{0.286}{0.76}}} = 1.420\,9^{1.603} = 1.601, \qquad (8)$$

where η_n is the compressor polytropic efficiency, and η_n=0.76,

$$\lambda = \frac{k-1}{k} = \frac{1.4-1}{1.4} = 0.286. \qquad (9)$$

Thus the compressor design parameter are π_c=1.60, G_c=0.465 kg/s.

3 Turbocharging matching

3.1 The matching between engine and compressor

Compressor is aiming to reach the designed pressure ratio, and high efficiency as well. The higher the efficiency of the compressor is, the lower the temperature is under the same pressure, the denser the derived pressure air density is, and therefore the better the turbocharging effects are.

The conditions of the tests about the compressor performance are as follows:The lubrication oil inlet pressure is 0.2~0.4MPa; the lubrication oil inlet temperature is 45~85℃; the lubrication oil outlet temperature is 120℃; and the turbine inlet temperature <750℃.

Compressor GT12 performance characteristic curve is shown in Fig.2, which tells that the compressor possesses wide high-efficiency circle, that the air flow range is wide when the efficiency is higher than 75%, and that the surge line and the flow range are moving moderately to the left, to the area of less air flow, so as to increase the matching compressor's surge margin.

By comparing the operating curve of engine with the characteristic curve of compressor, the matching features can be shown clearly. The working range when DA465Q matches GT12 is presented in Fig.3.

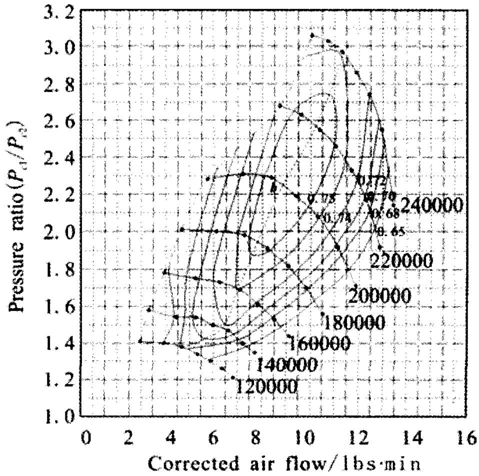

Fig.2 Characteristic map of the GT12 compressor

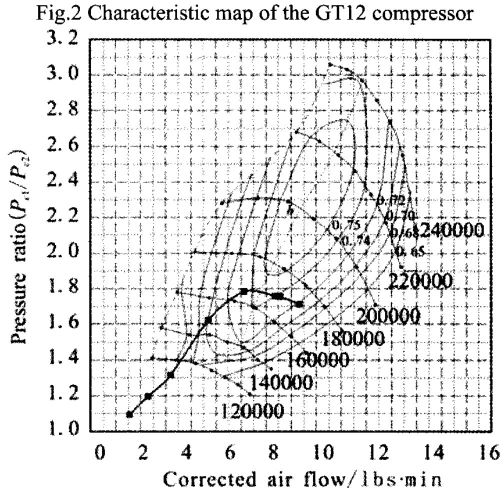

Fig. 3 Matching operating curves of the turbocharging engine

The above diagram shows that the curve has already reached the 72% efficiency area and left more than 10% safety margin from the surge border and the curve trend is fine. But limited by the small engine displacement, the compressor cannot reach the best efficiency area. When the engine is at low speed (lower than 2 000r/min), the engine volumetric efficiency is affected, but the engine can still work normally during the whole operation process.

3.2 The matching between engine and turbine

During the whole operation process, turbine possesses high efficiency. Experiments show that the turbine flow capacity delicately influences the matching, and therefore the matching of engine and turbine chiefly depends on the choice of turbine flow capacity. The method is to mark the location of the engine operation line on the turbine flow characteristic line, which is presented in Fig.4.

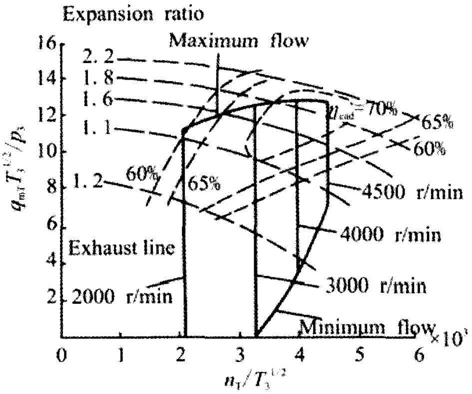

Fig.4 Characteristic matching of gasoline engine and turbine

As to vehicle engine, markers and maximum torque operation condition should also be marked on the diagram, since there are some cases when the turbine flow capacity at the marker is suitable to the maximum torque point, but it might be too small for the marker, so the adaptation and modulation are necessary.

In Fig.4, when the engine is under full load, the contour rotational curve turns into a vertical line. That's because under that operational condition, out of the influence of force of inertia, turbine is almost running at the same speed though there is still the exhaust pulse. And with the exhaust pulse, the turbine flow varies, so the maximum and minimum of the flow are marked out on the diagram.

3.3 The matching between compressor and turbine

3.3.1 Conditions to achieve balance for compressor and turbine

1) Same speed.

2) Continuous flow: for a turbocharger that operates alone, when the passage is leak-proof, the gas quality should be the sum-up of the compressor flow and the fuel flow.

3) Balanced power output: as the turbocharger is working steadily, the turbine power output should be equivalent to the sum-up of the compressor exhaust power and the mechanical loss.

3.3.2 The relation between compressor impellor diameter and turbine diameter

In reality, the compressor impellor diameter D_c and the turbine diameter D_T are often disproportionate, which can be easily deduced from the power balance relation:

$$\frac{D_c}{D_T} = \frac{1}{\frac{u}{c_0}} = \sqrt{\frac{\eta_T}{2\mu}}, \tag{10}$$

where u/c_0 is the turbine impellor velocity; η_T is the turbine efficiency; μ is the compressor compeller slip factor.

3.4 The matching between engine and turbocharger

From the overall turbocharger efficiency, an equation can be derived:

$$\pi_c^{0.286} - 1 = 1.12\eta_{Tc}\frac{T_T}{T_0}(1 - \frac{1}{\pi_T^{0.284}}), \tag{11}$$

$$J = \eta_{Tc}\frac{T_T}{T_0}. \tag{12}$$

When J is fixed, there is a value for $\pi_T(P_c)$. The curve diagram can be used to illustrate that the range of turbine inlet exhaust temperature is limited. Thus the higher the value of η_{TC} is, the lower the values of π_c and π_T are, in other words, the higher the inlet-exhaust pressure differential ΔP_{C-T} is, the better the scavenging. According to Fig.5, when J<1, it does not work for scavenging to adopt standard pressure system because $P_C < P_T$. Thus there is a minimum demand: when t_T=500~600℃, the lowest value of η_{T_C} is 0.40~0.46 (the higher the π_c, the higher the required lowest value of η_{Tc}).

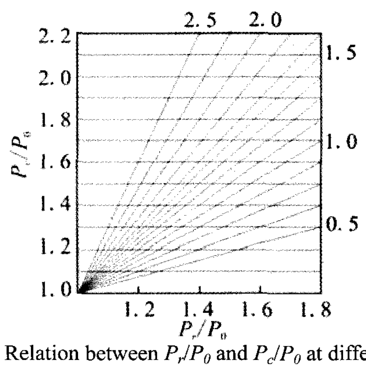

Fig. 5 Relation between P_r/P_0 and P_c/P_0 at different J

The matching tests of turbocharger and engine are done. The conditions of tests are: engine inlet oil temperature is (80±3)℃; cooler water inlet temperature is (75±5)℃; turbine inlet exhaust temperature ≤800℃; main gallery oil pressure ≥0.3 Mpa; turbocharger oil pressure ≥0.25 MPa;

maximum combustion pressure ≤8 MPa.

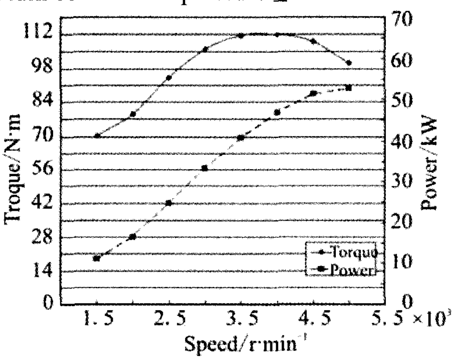

Fig. 6 Curves of power output and torque after matching

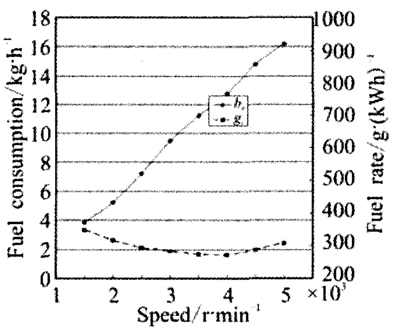

Fig. 7 Fuel consumption curves after matching

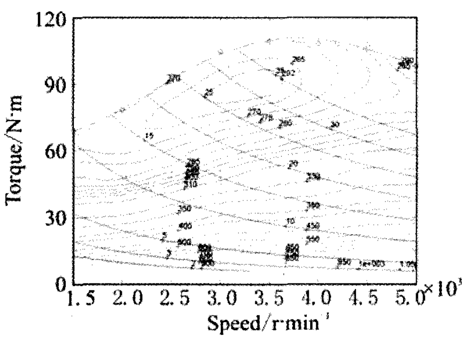

Fig.8 Characteristic performance curves after matching

As shown in Figs.6~8, after being matched with supercharger GT12, engine DA465Q takes on a new look with better performance, which has achieved the designed power and economic performance, enjoys large area of low oil consumption on the characteristic performance curve, and thus helps avoiding the occurrence of high oil consumption when engine is within the range of low load.

4 Conclusions

1) Matching GT 12 with DA465Q can help the engine achieve better power and economic performance.

2) The operation range of engine is closer to compressor's high efficiency area and there is still a large surge margin from the compressor surge line. Although compressor cannot work out its full efficiency, it can still ensure the well operation of engine and supercharger.

3) The exhaust temperature is within limits in the engine operation process.

4) The turbocharger is not working with full load within the range of engine operation, so turbocharger speed n_{TC} won't exceed the maximum and the values of P_c and $P_{\max}$ won't be too high.

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