ANALYSIS OF DIFFERENT SCHEMES FOR CONNECTING THE TURBOCHARGER TO INTERNAL COMBUSTION ENGINES

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Abstract: This report presents different schemes to connect the turbocharger internal combustion engines

Keywords: TURBOCHARGER, COMBUSTION ENGINE

1. Introduction

In recent years turbochargers for internal combustion engines (ICEs) with supercharging became the subject of mass production, which led to the unification and simplification of design decisions in several ways: increasing the liter and piston powers reducing the overall dimensions and weight, providing durability and reliability at high engine economy. As the piston engine are cyclical act and the relatively small number of cylinders, the energy of the gas can be utilized best by an appropriate connection between the cylinders and the turbine of the turbocharger (TC).

The turbochargers for vehicles are manufactured, or as stand-alone products or as components for a particular engine. In the first case most often TC is chosen for an engine based on experimental studies in laboratory conditions and in the latter (second) case, TC is designed and tested in parallel with the engine. Basic requirements to be brought to the TC are:

- Have a maximum efficiency;
- To ensure a high adaptability of the engine;
- Have a large motor-resource;
- Have small dimensions and width.

Classification of superchargers based on method of compression:
1. Dynamic supercharging.
2. Mechanical supercharging.
3. Exhaust-gas turbocharger.

2. Preconditions and means for resolving the problem

Dynamic supercharging be done without a compressor. Under this system, the pressure of working substance at the end of filling is increased by the use of dynamic pressure created by the inertia of the airflow in the intake manifold. Intensifier gas dynamic phenomena in the tube system is made as follows:

a) to select the optimum length and diameter of filler pipe;

b) loading cam profile is chosen so that the crossing section of the cartridge valve in the first half of the stroke to be negligible, resulting in the cylinder will get the highest dilution (0.03 ÷ 0.04 MPa) and when the piston is around the middle of its course, the valve opens and maximum air at high speed (up to 200 m/s) enters the cylinder. As a result of the dynamic pressure of the airflow pressure at the filling can reach 0.115 ÷ 0.120 MPa. The experimental data show that the power in this case can be increased by 20 ÷ 30%.

The use of dynamic supercharging in practice is limited, since a reduction of the speed of the engine significantly reduces the effect. Furthermore, the engine must be fitted with a large tube system.

Dynamic loading of the cylinder can be increased by using resonant events in the magazine line. For this purpose we create specific resonance chamber of tube system in the form of several variables volume.

Mechanical supercharging (Fig. 1) is carried out using a compressor that is driven by the engine through a gear, chain or other transmission, used part of the engine power (average of 5 ÷ 15%). The gear ratio between engine and compressor can be both fixed and variable.

In the mechanical drive compressor with constant gear ratio (n = const) the quantity of the air practically does not depend on engine load. In this case, when the engine load decreases, power consumed by the compressor for the submission of unnecessary amounts of air to reduce the mechanical efficiency of the engine. The variable gear (n ≠ const) creates conditions more favorable course of frequency characteristics and provides good economy and at partial load. The relatively small values of the pressure after the compressor p_k = 0.14 ÷ 0.16 MPa is very important of developing systems for mechanical super charging. The mechanical supercharging with pressure p_k greater than those no-mentioned values is irrational because the economy of the engine significantly reduced.

Fig.1. Scheme of engine mechanical supercharging

Exhaust Supercharging. This scheme is implemented using a compressor that is powered by gas turbine (Fig. 2). The gas turbine with compressor called turbo. Turbocharger unit is fully independent and has only a gas connection with the engine. To drive the compressor is used the heat of the exhaust gas, which reaches 30 ÷ 35% of the total quantity of heat brought into the engine.
The main advantage of turbine mechanical supercharging is that it does not spend part of the engine to drive the compressor. As a result, mechanical efficiency of gas exhaust engine supercharging will be higher than that of mechanical supercharging.

In exhaust supercharging air pressure after the compressor is replaced automatically depending on engine loading. Moreover, in exhaust supercharging engine torque to reduce speed falls rapidly, and it does not meet the requirements to transport engines. These negative aspects can be removed, but some complication of the installation.

Notwithstanding their shortcomings supercharging turbine is one of the most effective and promising means to increase engine power due to their compactness, simplicity of design and high efficiency of the turbocharger.

**Combined Supercharging.** This filling is characterized by compression of air in two different units. The one of the compressors are driven by the motor shaft and the other - from a exhaust gas turbine. Combination supercharging has special significance for two-stroke engines, which power the gas turbine at low load and low speed is usually insufficient to drive the compressor, consequently can not ensure the necessary quantity of air and air pressure for scavenging and charging the cylinder.

In the four-stroke engines this flaw does not exist because there are two auxiliary stroke, providing a change of working substance, and when the power turbine is insufficient (at low load engine).

The supercharging can be classified into two parameters: the pk value of the pressure or the degree of increase in power:

\[ \varphi_k = \frac{p_{ek}}{p_e} = \frac{N_{ek}}{N_e} \]

Depending on the pk and \( \varphi_k \) supercharging can be conditionally divided into normal, high and higher.

Under **normal** supercharging means such filling, where \( p_k \) does not exceed 0,14 MPa and \( \varphi_k \) reaches 1,5. When these values of \( p_k \) and \( \varphi_k \) is not necessary to cool the air after the compressor. Moreover, increasing the load on bearings and thermal state of heated parts is not essential, especially given that the details of modern engines have a stock of strength. The normal supercharging can be done with a compressor driven by the crankshaft of the engine or gas turbine.

Under **increased** supercharging means such filling, in which the pressure \( p_k \) is changing from 0,14 to 0,20 MPa and \( \varphi_k = 1,5 \div 2 \). In this case, cooling the air after the compressor, reducing the degree of compression, enhancement of details in the slider mechanism and increase the air to be desirable. Increased supercharging is done with

A compressor driven by exhaust gas turbine and in some cases by combined supercharging.

Under **high** supercharging means such filling, where \( p_k > 0,2 \) MPa and \( \varphi_k > 2 \). The cooling of the air after the compressor, reducing the degree of compression, gain of parts and increase the air to be indispensable. The high supercharging is via a compressor driven by exhaust gas turbine or by combined method.

**Schematics of a typical combined engines.** Supercharging place in the so-called. compound (turbo-piston) internal combustion engines.

The compound engines are a combination of three elements: a piston engine, a compressor and an exhaust gas turbine. In the piston engine is made fresh working substance, pre-thickened to a certain pressure \( p_k \) in the compressor and the energy of the gases that flow out of piston engine is used in gas turbine. There are a variety of schemes combining piston engine compressor and turbine, which can be divided into the following main groups.

The **compound engines with gas connection** is shown in the (Fig. 2). In these engines takes place discussed above usually supercharging turbine. This scheme is used in four-stroke engines. It is one of the most advanced and distributed schemes. Engines combined with just a gas connection are found widely in industry and transport, mainly due to their greater compactness, simplicity of construction and high efficiency.

The **compound engines with mechanical and hydraulic connection.** This group engines are two alternative schemes. In one scheme (Fig. 3a) compressor and turbine are mechanically connected individually with piston engines.

In the second scheme (Fig. 3b) turbine and compressor are combined into one unit - turbocharger, which is also mechanically coupled with the piston engine.
There are circuits and hydraulic connection (Fig. 4a,b). In this case the gear ratio between the shaft of the piston engine and turbocharger may vary depending on the filling of hydraulic clutch. Thereby creating conditions for changing the parameters and the quantity of fresh working substance that is filled by the compressor. When combined with mechanical motors and hydraulic connection when the power of the turbine is less than the compressor power \( N_t < N_c \) to ensure that pressure on supercharging \( p_c \), extra power is taken from the shaft of the piston engine. Then, when the turbine is greater than the compressor power \( N_t > N_c \) excess power the turbine is transmitted to the motor shaft, from which useful power is removed. Thus in compound engines with mechanical or hydraulic contact pressure supercharged \( p_c \) is independent of the power turbine. On the other hand, the energy of exhaust can be used in full, regardless of the pressure after the compressor \( p_c \).

**Fig. 4a.** Scheme combined with mechanical motors and hydraulic connection

**Fig. 4b.** Scheme of the compound engines with hydraulic connection

In mechanical connection engine and compressor work synchronously in all modes, resulting in a change of working substance flow and quality of the transitional arrangements. This is important especially for two-stroke engines, which is difficult to achieve normal charging of the cylinder with fresh working substance at partial loads. Moreover, the mechanical connection provides flexible working arrangements and a good starting performance of the engine.

Disadvantages of compound engines with mechanical or hydraulic link to the complexity of their construction and additional losses in the gear. Furthermore, those engines is difficult to obtain high efficiency in all operating modes.

To simplify design and increase the efficiency of the combined engine, in some cases, using several independent of each other turbines. As an example in Fig. 5 shows a scheme with two exhaust gas turbines.

The considered schemes with mechanical or hydraulic connection using both four and in two stroke engines.

**Fig. 5.** Scheme of the combined engine with two gas turbines

**Compound engines with a combined connection.**

These engines are made combined supercharging. The fresh working substance is compressed in two independent from one another compressor. One compressor is mechanically piston engine and the other (along with exhaust gas turbine combined into one unit - turbo) has a gas connection with a piston engine. The compression substance in compressors can be done simultaneously or sequentially.

**Fig. 6a.** Scheme combined with parallel compression engines

In the parallel compression (Fig. 6a) the one part of fresh working substance is compressed in a compressor and the other part - in the other. As a result, the size of compressors are relatively small. Regardless of that advantage this scheme has not found widespread mainly due to difficulties associated with coordination of the characteristics of the compressors, cooling and fresh working substance at high supercharging and complex structure of the tube system.

**Fig. 6b.** Scheme combined with sequentially compression engines

In successive compression of the fresh working substance are two alternative schemes. In one scheme (Fig. 6b) fresh working substance is compressed in
turbocharger initially, then the compressor which is driven by piston engines.

In the other scheme (Fig. 6c) back - the original compression takes place in the engine drives a compressor, and then in the turbocharger.

![Fig. 6c. Scheme combined with sequentially compression engines](Image)

This two-stage compression enables cooling of fresh working substance, and hence reducing power consumed by the compressor. To improve performance and economic performance of the combined engine, the rate of pressure rise in the compressor which is driven mechanically, must be minimum possible. Under equal conditions required total rate of pressure rise in both the compressor will occur with a lesser degree of pressure rise in the mechanically operated compressor when it is the second level of compression. It follows that the combined engine which works under the scheme in Fig. 6b other things being equal, would be more economical.

The main advantages of compound engines with a combined contact and consistent compression of the fresh working substance are: better starting performance and engine performance of the transitional arrangements and small loads, but also to different pressure values $p_k$ after the compressor. The significant deficiency in these schemes is the use of two compressors and complicated distribution system.

The combined schemes are mainly used in two-stroke engines, and also in four-stroke engines, where necessary high pressure rise, which can be ensured only in tier centrifugal turbo.

All schemes fed, which are discussed above are used in four-stroke engines.

![Fig. 7a. Scheme of the intermediate cooling - water-air](Image)

The effective engine power is directly proportional to the pressure and inversely proportional to the temperature. By increasing the pressure in piston machines, the temperature increased sharply. This reduces the coefficient of filling due to the reduced density of the intake air. Also increases the temperature load. For this, most manufacturers use turbo intercoolers placed on the air (so called. "Intercooler"), but the temperature should be reduced to some extent because many low-value rate of evaporation of fuel will be reduced sharply. The preferred temperatures are close to those of the walls of the tube system. Therefore, the best intercoolers are those of the water-air (Fig. 7a). They maintain a uniform temperature of the entraining air from those working in the air-air system (Fig. 7b) (especially at low temperatures), but are more expensive. The experimental data showed that cooling of the fresh mixture after the compressor $10{\degree}$C, the engine power is increased by $2 \div 2.5\%$. In this cooling reduces the temperature at the end of compression, combustion and expansion, and hence the average temperature of the operating cycle, leading to reduction of heat load.

3. Conclusion

The proposed design schemes are applied depending on the specific purpose of the engine.

4. Literature

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