A Study on the Improving Diesel Performance by Means of Cyclic Synchronizing Power and the Geometrical Features of Turbocharging Systems

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디젤 기관과 터보차저 싸이클 동기화에 의한 디젤기관의 성능 개선에 관한 연구

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요 약

터보 노즐에 유동하는 가스 에너지의 변화와 그위상의 조정에 의하여 디젤엔진의 성능 개선 가능성을 검토 하였다. 그리고 디젤기관의 각실린더와 터빈 노즐 면적과 가스의 유동에 대한 동기화를 실시함으로써 엔진 성능 또한 개선할 수 있었다.

SYMBOLS AND ABBREBIATIONS

G_{ij} : gas flow rate
H_{ij} : specific gas flow energy
H_{th} : inlet gas flow energy
N_{TS} : power of standard power
N_T : power of turbine power
μ_{ij} : net power of gas power
η_{ij} : internal efficiency of turbine
ψ_1 : an ending part of an exhaust
ψ_2 : scavenging and filling cylinders of diesel
ψ_3 : begining free part of an exhaust

1. INTRODUCTION

The increase in power and the improvement of fuel economy and the speed torque characteristics pose very important study for the development of diesel engines. All the known turbocharging systems have essential limitations. The systems empoly constant gas pressure, before the turbine suffer major power losses in their damping reservoirs. The systems will have an unsteady pulsating gas pressure flow, before the turbine lose a lot of power factors in the turbine itself. These two methods of turbocharging themselves suffer a major power losses for turbocharged to internal combustion engines.

Diesels engine are usually operated in steady conditions evidence a constant gas pressure before the turbine, and demonstrate maximum turbine efficiency. And the engine also can be operate in unsteady conditions with a pulsating gas pressure in inlet of the turbine, and produce in low efficiency of the turbine, but they can have higher efficiency more than diesels in a constant gas pressure inlet of the turbine. Diesels engine will have a constant gas pressure, which is placed between the cylinders and the turbine, before the turbine demonstrate big losses of power in the damping reservoir. Diesels will have pulsating gas pressure, before the turbine have big losses of power in the turbine.

2. EXPERIMENTAL SET UP

Using six-cylinder diesels with an electric generator of the type 6 FC 18/22 and with a turbocharger TCR-14, we estimated the power by measuring current and voltage, and pressure; by a tension device, and temperature; and by means of a thermocoupler. And fuel consumption was by means of its measuring capacity respectively.

3. GENERAL ANALYSIS AND DISCUSSION

There is a contradiction in the joint cyclic to operate cylinders and operate the turbine simultaneously. In the exhaust system, the pulsating gas flow requires a decrease in the fluctuation of the gas pressure - especially a decrease in the fluctuation amplitude of the gas pressure and the energy of the gas flow of the internal combustion engines exhausted in phases. A decrease in the amplitude of changing the exhaust gas pressure relative to the turn angle of the diesel crank shaft increases the efficiency of the turbine. For a more perfect transformation of the exhaust gas power into mechanical energy of the turbine, it is necessary to redistribute the gas passage area of the turbine nozzle assembly according to the phases of exhaust. The redistribution of the gas passage area of the turbine nozzle and the redistribution of the gas flow power decrease the surplus of mass and energy at the begining phase of opening the exhaust valve. This phase is known as the preliminary free subphase part of the exhaust. This redistribution decreases the mass and energy of the gas flow at the compulsory exhaust subphase and at the scavenging subphase. This minimization of the power losses in the exhaust system consists in the dividing, redistribution and summing up of the flow power at the subphases of the diesel exhausted, that is an increase turbine power. The increase of turbine power is achieved by the improvement of the conditions of the overall turbine operation. This effect can be seen from this equation which compares the redistribution power of the turbine NT to the power of a standard operating turbine

$$N_{TS} = \sum_{\phi_1} G_{ij}\mu_{ij}\eta_{ij} + \sum_{\phi_2} G_{ij}\mu_{ij}\eta_{ij} + \sum_{\phi_3} G_{ij}\mu_{ij}\eta_{ij} \tag{1}$$

$$N_T = \sum_{T} G_{ij}\mu_{ij}\eta_{ij} \tag{2}$$

The gas flow before the turbine with a constant nozzle passage area pressure changes according to the changes of the turn crankshaft angle, because during one phase of the exhaust, the mass flow rate is also changed. In the beginning subphase of opening the exhaust cylinder valve, the mass flow rate through the turbine is increased from a minimum to a maximum valve opening. This subphase is called the preliminary free subphase of the exhaust. The pressure decreases when the weight flow rate through the opened valve is decreased. The name of this subphase is the second half of the free subphase and the compulsory exhaust subphase, where the minimum pressure is settling, and when the cylinders are being scavenged and filled. The synchronization of power and the geometric features of the turbocharging system is carried out by means of a joint maximization of the weight flow rate with the maximum passage area of the nozzle assembly and by joining the minimum passage area of the nozzle assembly. This combination should be carried out according to the crank angle. To change the passage area in the turbine case, an auxiliary shaft with one or two disks is put in place. The disks are made with a frame on the edges. The disks should be placed in the case perpendicularly to the middle line of the nozzle assembly. The shaft is then joined with the engine crankshaft by mechanical or other transmission. The disks and the crankshaft should then turn simultaneously. The window of the disks should open the nozzle assembly entirely, when the maximum weight flow rate comes into the turbine. The disks should remain in the minimum part of the nozzle assembly opened, when the minimum gas flow rate enters the turbine. An increase in the turbine efficiency is achieved by using only one disk, two disks will increase the efficiency much more. One disk provides one step of synchronization; two disks will provides two steps of synchronization. A staged synchronization of the passage area of the nozzle assembly provides an approximate conformity of the turbine permit capacity with the weight flow rate from the cylinders at the varies phases of the exhaust. Increasing the turbine' s power allows a shortening of the free exhaust subphase, and allows decreasing losses of energy and yielding the possibility of openings the exhaust valve later to prevent the cylinder' s admission and exhaust valves from the gas returning. In units of two - stroke and four - stroke engines, the numerical values for the pressure are obtained according to the staged changes of the passage area of the nozzle assembly. An approximate increase of the passage area by 20% decreases the flow pressure (10 - 15%); a decrease of the passage area by 20 - 35% in the scavenging subphase increases the gas flow pressure(15 - 60%) before the turbine. The precise value of the pressure is defined in several constructions and regimes. Although the peculiarities of operating a standard pulsating turbine in the exhaust system of a diesel have been described in technical literature, which is description of a synchronized turbine operation. A change of the permit capacity of the turbine has an essential influence on its operation. The losses in energy are redistributed between the nozzle assembly and the blade wheel. When the gas flow rate and the passage area of the nozzle assembly are decreased, the value of the reaction of the turbine is also decreased. A decrease of the passage area of the nozzle exit increases the gas flow velocity from the nozzle losing energy in the blade wheel, and gas flow outlet from the turbine. When a part of the nozzle assembly is closed, a partial admission appears. The partial admission increases ventilational losses in the turbine. But those losses are smaller than the increase in the peripheral power.

The average value of synchronized turbine power is bigger than in an ordinary turbine.

$$N_{th} = \frac{1}{\phi_i - \phi} \sum_{i=1}^{\phi} \sum_{j=1}^{m} G_{ij} H_{ij} \eta_{ij} H_{th} = G_{ij} H_{ij} \eta_{ij} \qquad (3)$$

The duration of the low - speed regime of the turbine is increased, because its peripherial losses are decreased. In general, the power of the turbine is increased, because in a phase of maximum pressure the turbine' s permit capacity is increased and in the scavenging phase the gas flow specific energy is increased. The increase in the turbine' s internal power increases the internal efficiency of the diesel. The turbocharger forces fresh air into the cylinders, while the nozzle assembly passage area is decreasing. In this case, the power of the turbine and the air pressure is increased compared with the ordinary case. Even though the velocity of the air flow is decreasing, the characteristic values for scavenging and filling provide favorable conditions for the operating of the engine, because the density of the air flow is increased. In the compulsory exhaust scavenging and filling subphase, the hydraulic losses are decreased compared with ordinary cases. Increasing the turbine efficiency also increases the indicated efficiency of the internal combustion engine, because the subsequent expansion ratio is also increased. In the subphase, the pressure before the turbine defines the ratio of the pressure in the admission receiver and cylinders. In all operating regimes of the diesel, these ratios provide the necessaries.

Coefficient of filling etav is the coefficient of excess scavenged air and the coefficient of scavenging. The increases of pressure behind the exhaust valve at the subphase of the partially closed of turbine nozzle assembly decreases the period of ignition lag, because the temperature of the compression is increased. Reducing the energy for turbocharged gas exchange in the engine increases the indicator values : the indicator pressure pi and the indicator efficiency. The operating cycle of the diesel is greater than an ordinary diesel cycle. The improvement of the values of turbocharging results in reducing the exhaust gas temperature, as the subsequent expansion ratio and current density of the admitted air are increased. The indicator efficiency is increased without increasing the pressure terminal combustion (pz), as the values of mechanical and thermal stress are improved, that is the coefficient of the exess air is improved.

This gives an opportunity to except losses of a charge, and to provide high coefficient filling; because at the compulsory exhaust subphase and scavenging subphase the gas flow velocity and air flow velocity are smaller in comparison with an ordinary exhaust system.

To achieve this, the turbine nozzle area is accorded with the gas flow rate during one cycle of the exhaust from the cylinder. In the moment, when the mass flow in front of the turbine reaches its maximum, the turbine nozzle area reaches its maximum too; likewise, when the mass flow in front of the turbine reduces to its minimum, the turbine nozzle area reduces to its minimum too.

This accord of the mass flow with the nozzle area in the one cycle of the exhaust allows the decrease of losses of gas power for the air supply of the diesels. It is achieved by a synchronizing device connected to the crankshaft, which opens or closes a part of the turbine nozzle assembly.

The synchronized working of the diesel turbocharging system allows the possibility of improving the performance of the diesel in conditions of variable load, as shown in Fig.1 and Fig.2. Shaft 12 is connected by mechnical transimission 10 with gas distributive shaft4, and

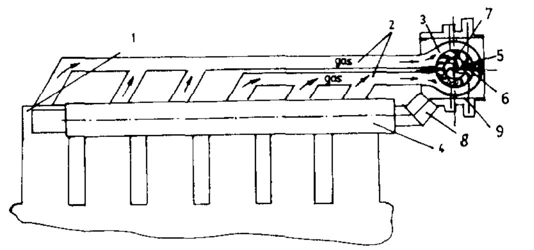

Fig.1 Turbocharging systems in the diesel engine. 1 - cylinder ; 2 - exhaust pipe ; 3 - gas passage channel ; 4 - shaft ; 5 - wheel blade ; 6 - nozzle assembly ; 7 - blade ; 8 - mechanical transmission ; 9 - shaft

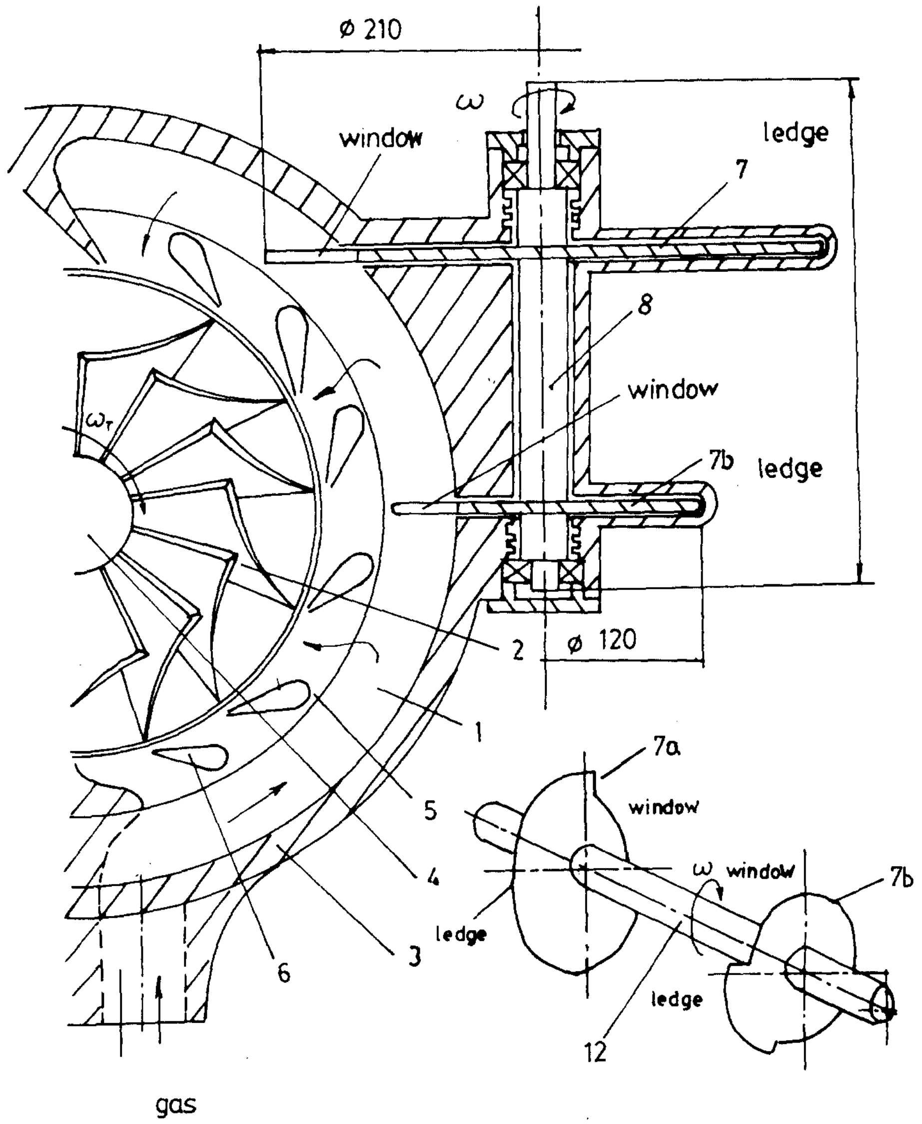

Fig.2 Systems of turbocharging with turbo blades 1 - gas passage channel ; 2 - wheel blade ; 3 - turbine case ; 4 - turbine shaft ; 5 - nozzle assembly ; 6 - blade ; 7 - disks ; 8 - shaft

is turned with a frequency equal to the gas pulsating frequency in exhaust pipe 1 and gas passage channel 3 . Disks 11 open the nozzle assembly along gas passage canal 3 in the period of greatest value of the pressure and mass flow rate, while the disks edge closes the nozzle assembly in the period of the lowest value of the gas pressure and gas flow rate. The pressure in gas passage channel 3 before the nozzle assembly 8 with blade 9 and before wheel blade 5 is increased. Any joint operating of the compressor and engine needs the hydraulic resistence and the compressor power to conform with each other during the change of the nozzle assembly according to the crank angle. According to the type of synchronization employed, the permit capacity changes smoothly in the stages. Instantaneous values of resistance are redistrubuted in the phase of exhaust during one pulsation. In the phase of maximum gas flow, the highest resistance is recorded in the exhaust manifold; and the resistance is formed in the turbine. The pressure ratio on the compressor depends on the possibility of forming a surge. The correlation between the air flow rate and the pressure ratio in conditions of synchronization is provided without a surge by operating the compressor. Characteristics of the joint operating of the engine and compressor are defined according to the change of the nozzle assembly area at the compulsory exhaust and scavenging subphases. For these subphases the minimum values of the passage permit capacity of the nozzle assembly are selected. The hydraulic characteristics may approach the surge zone, but remain at a secure distance. The tuning of the compressor for joint operating of an internal combustion engine with synchronized turbocharging is made by a combination of experimental and theoretical approximations.

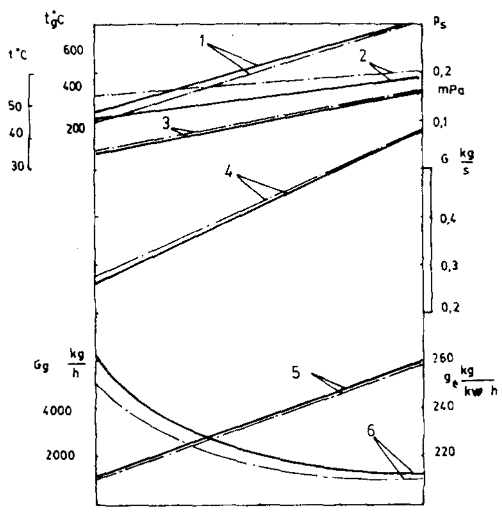

Fig.3 Load performance of diesel 6FC 18/22[(—) : without synchronization ; (— · —) : with synchronization]. 1 - temperature before turbine ; 2 - super charging pressure ; 3 - air temperature of supercharging ; 4 - air flow rate ; 5 - gas flow rate ; 6 - fuel consumption.

4. RESULTS

As shown in Fig.3 the most essential benefit of economizing fuel consumption ge at 4.16% at partial (55%) load of the engine can be achieved through this synchronization. When the nominal load benefit is 1%, the average benefit is approximatly 2.23%. The temperature of the exhaust gas tg is decreased. Pressure, temperature and flow rate of the air are increased. The gas flow rate does not change significantally. Increasing the advantages and coefficient of air excess decreases the temperature and toxicity level of the exhaust gas.

5. CONCLUSIONS

1. Problems in the joint operating of cylinders can be decreased by the redistribution of the gas flow energy at the phase of exhaust.

2. The redistribution of gas flow energy allows the possibility of decreasing power losses in the turbine, by a redistribution of internal power.

3. This synchronization allows the possibility of decreasing the free exhaust subphase, and increases the subsequent expansion ratio delta and the indicator of efficiency.

4. The principle of synchronization and the order of the work and of the device for synchronization are shown diagramatically.

5. The synchronization of energy and the geometric characteristics increase the efficiency of the diesel, and decrease fuel consumption and the toxicity level of the exhaust gas.

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