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Impact of Crank Lengthening on the Performance of an Overhauled Diesel Engine

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Abstract: To restore the original power, economy and technical indicators of an overhauled diesel engine, the crank lengthening method was adopted and tested in the study. The crank of a Dongfanghong type 4125A diesel engine was extended by 0.75 mm, which is within the range tolerable to the structure. The internal combustion engine rig test method was adopted and a hydraulic dynamometer, comprehensive engine tester, smoke meter and additional instruments were employed to measure the indicators cylinder pressure, speed control characteristics, power, reliability and economy of the diesel engine before and after rebuilding for comparison. The results show that the rebuilding method in which the crank is lengthened increased the maximum power of the diesel engine by 2.32 kW, decreased fuel consumption by 5 g/(kW·h), decreased the exhaust gas temperature by 27°C, decreased the smoke density by 0.2 BSU and increased the mean pressure of various cylinders by 0.31 MPa. The results confirm that the crank lengthening method is effective at restoring the original power, economy and technical indicators of an overhauled diesel engine.

Key words: Diesel engine, crank, power, speed control characteristics, reliability

INTRODUCTION

Many problems can cause power loss in a diesel engine after repair. The primary problem is increased leakage between the cylinder and piston, which decreases the cylinder working pressure and engine compression ratio. The leakage increase is related to quality and fit precision of the parts and has been viewed as the key problem for improving engine power after repair over many years.

Most existing studies focus on engine motion simulation and structural parameter design optimization. For example, Zhang *et al.* (2011) simulated the kinematics and dynamics of the crank connecting rod by performing a stress analysis on the dynamics and kinematics of an 8V150 diesel engine to determine the torque output characteristics and provide references for optimizing diesel engine-related parameters. Qiao and Huang (2012) determined the motion curve and force curve of the piston, the tangential force curve of the crankshaft and the output characteristics of the diesel engine by simulating the kinematics and dynamics of the crank-connecting rod mechanism to support an optimized design and finite element analysis of the crank-connecting rod mechanism. However, relatively few studies on improving the power of a diesel engine after repair have been reported. Bayrakceken *et al.* (2007) analyzed the reasons that certain diesel engine components prematurely fail and proposed that improper heat treatment was an important problem that caused crank failure. Yue (2008) analyzed the causes of power and fuel economy losses in a type 195 diesel engine after overhaul. They proposed that several adjustments were needed to restore the technical specifications of these diesel engines and to maintain the cylinder compression pressure. These included adjustments to the fuel injection advance angle and the oil pressure of the auxiliary plunger fuel pump and delivery valve seal. Wang and Wang (2010) noted that the major problems that cause insufficient power in a repaired engine include poor sealing, low fuel injection, low volumetric efficiency and incomplete combustion. Further, such problems are caused by a broken valve spring, too large or too small valve clearance, exhaust pipe and muffler clogging, carbon residue deposition in fuel injectors, diesel engine filter clogging and air filter clogging, among others.

Yang (1993) noted that poor engine seals are related to the upstroke speed of the piston; leakage decreased

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with increasing upstroke speed and thus the thermal efficiency of an old diesel engine is higher under high-speed operation than low-speed operation. Therefore, if the fitting between the cylinder and the piston or the piston rings deteriorates, then an improved piston upstroke speed is conducive to reducing the leakage between the cylinder and piston, which produces improved power and economy in an engine. Zhao *et al.* (1997) proposed to increase the crank radius to increase the piston upstroke speed without changing the speed of the engine.

In the study, the crank-lengthening method was adopted. The impact of this method on the diesel engine power after repair was studied through investigations and methods to restore the original power, economy and technical indicators in an overhauled diesel engine were explored.

MATERIALS AND METHODS

An overhauled diesel engine with a lengthened crankshaft and the test methods: An overhauled Dongfanghong type 4125A diesel engine (YTO Group Corporation, China) was studied. The piston-cylinder liner clearance, clearance between the piston ring and ring groove edges, journal-bearing clearance, technical status of the crankshaft as well as connecting rods for the engine met the technical requirements for repair (Wang, 2011). The fuel injection advance angle of this diesel engine was 17.5° before the top dead center. The fuel injection pressure was 12.3 MPa. The calibrated power/rotation was 40 kW/1300 r/min. The standard size of the crankshaft connecting rod journal of the 4125A diesel engine was ground to +0.75 mm with a crankshaft grinder. The rod journal was fitted with +0.75 mm bearings and was offset-ground outwardly along the crank (i.e., the crank was lengthened by 0.75 mm).

Methods compliant with the Performance Test Methods for Reciprocating Internal Combustion Engine-Test Methods (GB-T 1105-1987) were used to test the diesel engine. GB-T 1105-1987 specifies methods for rig testing the performance of general-purpose reciprocating diesel engines and reciprocating petrol engines. The fuel oil and engine oil in the test should be used in accordance with the provisions in the manual for the internal combustion engine and the oil quality should comply with the provisions for related petroleum product standards. Smoke suppressants were not added to the fuel oil. Accessories compliant with professional standards were installed in the internal combustion engine during the test, but only the internal combustion engine was tested. During the test, the internal combustion engine was not adjusted. The fuel oil, engine oil and cooling medium temperatures complied with professional standards or product manual provisions.

Test equipment and methods: The diesel engine power was measured with a hydraulic dynamometer (model D350, Jiangsu Qidong agricultural machinery repair and manufacture factory). The D350 hydraulic dynamometer is an energy-absorption type hydraulic dynamometer with water paddles. During operation, the water-resisting rotor connected to the engine propels the water entering the internal cavity of the hydraulic dynamometer, throws the water to the inner wall of the stator through the centrifugal force and forms a rotating water ring. The rotational movement of the water ring is impeded by the water-resisting columns arranged on the inner wall of the stator housing. Therefore, a strong water vortex is generated between the stator and rotor. Such liquid-solid friction and collision consumes power from the engine and converts much of the energy into heat, which is then absorbed and carried away by the flowing water. A small portion of the heat is conducted through the housing. Because the heat capacity of water is large and the water flow rate can be adjusted over a wide range, the power absorption range is relatively large.

A comprehensive engine tester (model QFC-5D, JiNan Zhongbao Automobile Testing Equipment Co., Ltd) was used to measure overall performance of the diesel engine (Sanli *et al.*, 2008). The QFC-5D engine tester is a comprehensive engine analyzer that reads car computer error code and manages the files in one system. It analyses the engine ignition system, boost system, charging system, dynamic balance of the engine and engine guide noise, among other functions.

The diesel engine exhaust smoke intensity was measured with a smoke meter (model FQD-102, Wenzhou Instrument Factory). The working mechanism of the FQD-102 exhaust smoke meter was to extract a certain volume of exhaust gas from the diesel engine exhaust pipe with a piston suction pump and pass it through white filter paper with certain area so the carbon particles in the exhaust gas adhere to and blacken the filter paper. Light absorption for the smoke deposit on the filter paper is then measured with an optoelectronic transmitter to evaluate exhaust smoke density in the diesel engine (Thu Zar *et al.*, 2011).

Test content and indicators

Comparison test for cylinder pressure: The engine was operated at the normal temperature (80-90°C water temperature) and then powered down before measuring the cylinder compression pressure. The fuel injectors were removed from the diesel engine and cleaned thoroughly. The tapered rubber head of the cylinder pressure gauge was then pressed into the spark plug hole (injector) and the crankshaft was turned for 3-5 sec with a starter. One person inserted the cylinder pressure gauge plug to seal the cylinder spark plug hole. A second person fully opened the choke and the throttle, switched on the starter motor and ran the engine for 3 to 5 compression cycles. The first person removed the pressure gauge when the pointer indicated zero cylinder pressure. The above procedure was repeated three times to measure the same cylinder and the highest reading was recorded as the measured data.

Comparison test for the engine power and economy: Depending on the application, the speed of an internal combustion engine should be maintained at the calibrated speed or a certain percentage of the overload speed during the test and its load characteristics measured under such conditions. The speed of the internal combustion engine was maintained at the calibrated speed or additional professional-standards-specified speeds; the load was gradually increased from low to the maximum and the torque, fuel consumption, exhaust gas temperature and additional parameters were measured for each load (Lu and Wang, 2011).

Comparison test for the diesel engine speed control characteristics: During the test, the internal combustion engine was operated stably under the calibrated operating conditions or the overload condition. The entire load was first unloaded to raise the engine to the maximum no-load speed or the maximum overload no-load speed and then gradually increased until the above conditions were reached. The steady speed, torque, fuel consumption and additional parameters for the engine were measured for each load and a speed control characteristic curve was generated under the calibrated condition or overload condition.

Diesel engine reliability test: At full throttle, the speed was evenly raised from the maximum-net-torque speed to the maximum-net-power speed and then evenly decreased to the maximum-net-torque speed. The above alternating operating conditions were repeated. The throttle was then closed and the speed was reduced to idle. It was then reopened gradually and evenly to achieve the rated speed or maximum speed under no load specified by the engine manufacturer. The throttle was closed to evenly slow the engine to its maximum-net-torque speed. Until this step, one cycle was completed. The engine ran for 4000 cycles and the duration of the run was 2000 h. The piston-cylinder liner fitting clearance, piston ring side clearance, piston ring end gap, journal-bearing clearance and bending and twisting of the connecting rod, among others, were then measured and compared with the standard and repairable values (Yao *et al*., 2000).

TEST RESULTS AND ANALYSIS

Cylinder pressure: A comparison of the cylinder pressure before and after the rebuild is shown in Fig. 1.

Figure 1 shows that the pressures for the various cylinders significantly increased after crank-lengthening. On average, the single-cylinder pressure for the four cylinders increased by 0.31 MPa. The first reason for the pressure increase is that the compression ratio increased. The piston stroke increase caused the compression ratio to increase from the original design of 16 to 17.3. The second reason is the increase in piston upstroke speed. The maximum piston upstroke speed increased from the original 11.925-12.045 m sec^{-1}, which is a 0.12 m sec^{-1} increase. The increase in piston speed generated less leakage and is a major reason for the pressure increase. The piston stroke increased from 152 to 153.5 mm, which is a 1% increase, the displacement volume per cylinder increased from 1.863-1.878 L and the air intake flow rate increased by 0.015 L, which contributed to the full combustion of fuel.

Power and economy: A comparison of the power and the economy indicators before and after the diesel engine rebuild is shown in Fig. 2.

Figure 2 shows that crank-lengthening had relatively large impact on diesel engine power. The maximum engine

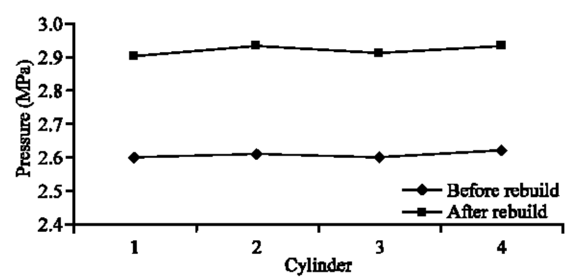

Fig. 1: Maximum pressure (MPa) measured in each of the 4 cylinders of a Dongfanghong type 4125A diesel engine before and after rebuilding and extension of the crank by 0.75 mm

power increased 2.32 kW, the fuel consumption rate decreased 5 g/(kW·h), the exhaust gas temperature decreased 27°C and the smoke density decreased 0.2 BSU. Various operation parameters of the rebuilt diesel engine were clearly altered favorably at maximum power. The rebuilt engine could operate at the maximum power. When the engine operated at the minimum fuel consumption rate, the fuel consumption rate decreased 3 g/(kW·h), the power was 5.78 kW higher than before rebuild, the exhaust gas temperature increased 53°C and the smoke density increased 0.2 BSU. The results show that after increasing the crank radius, the diesel engine had problems, such as an excessive exhaust gas temperature rise and increased smoke density at the minimum fuel consumption rate.

Figure 2 also shows that, at the mean exhaust gas temperature, the diesel engine power increased 4.7 kW, the fuel consumption rate decreased 2 g/(kW·h), the exhaust gas temperature increased 4°C and the smoke density decreased 0.2 BSU. The rebuilt diesel engine was clearly advantageous at the mean exhaust gas temperature. At the mean smoke density, the diesel engine power increased 218 kW, the fuel consumption rate decreased 2 g/(kW·h) and the exhaust gas temperature decreased 29°C. The various parameters were favorable for operating the diesel engine.

Speed control characteristics: A comparison of the speed control characteristics before and after the diesel engine rebuild is shown in Fig. 3.

Figure 3 shows that the diesel engine's maximum torque increased 30.4 Nm after the pressure increased. Further, a comparison of speed control characteristics shows significant decreases in fuel consumption rate, smoke density and exhaust gas temperature, which suggests that crank-lengthening was conducive to improving engine power.

Reliability: The overhauled diesel engine was installed in the test rig and loaded with the rated load after a cold/hot break-in. The engine operated continuously for 2000 h and was then powered down. The oil consumption measurements were 263 g/(kW·h) for diesel and 8.12 g/(kW·h) for engine oil. The key components were examined after engine dissembling and the technical indicators are shown in Fig. 4.

Figure 4 shows that the diesel engine oil consumption was within the normal range for this engine. Further, the technical parameters for the key engine components, such as the piston-cylinder liner fitting clearance (Fig. 4a), piston ring side clearance (Fig. 4b, c and d), piston ring end gap (Fig. 4e), journal-bearing clearance (Fig. 4f and g)

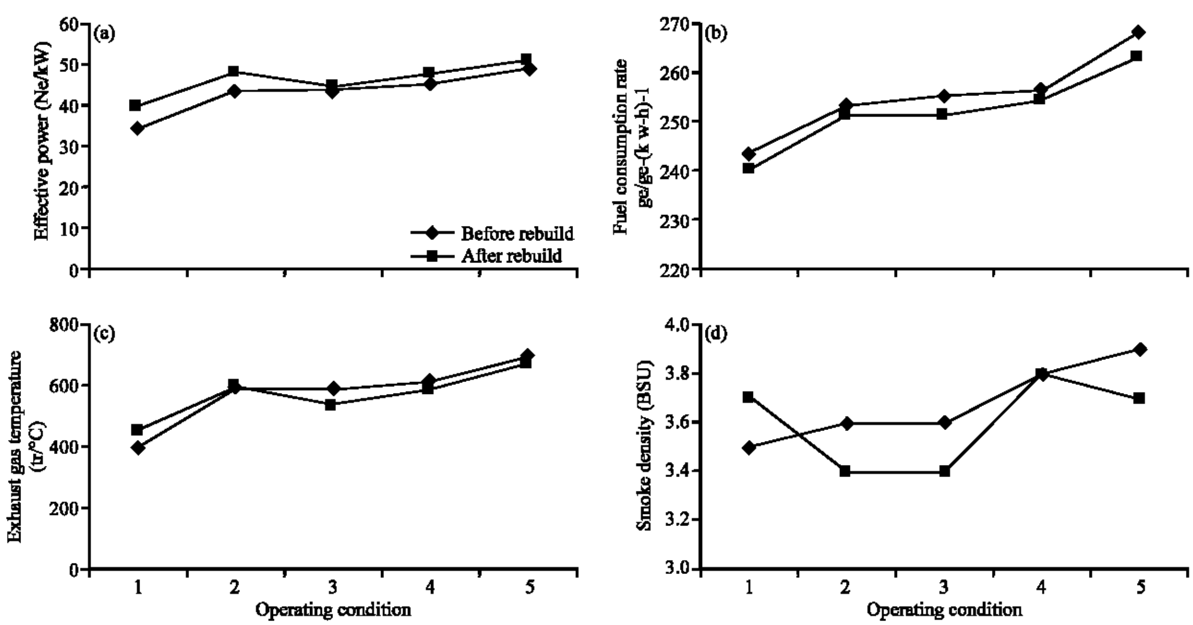

Fig. 2(a-d): Comparison of (a) Effective power (N/ kW), (b) Fuel consumption(g/kW h), (c) Exhaust gas temperature (°C) and (d) Smoke density (BSU) for a Dongfanghong type 4125A diesel engine before and after rebuilding and extension of the crank by 0.75 mm

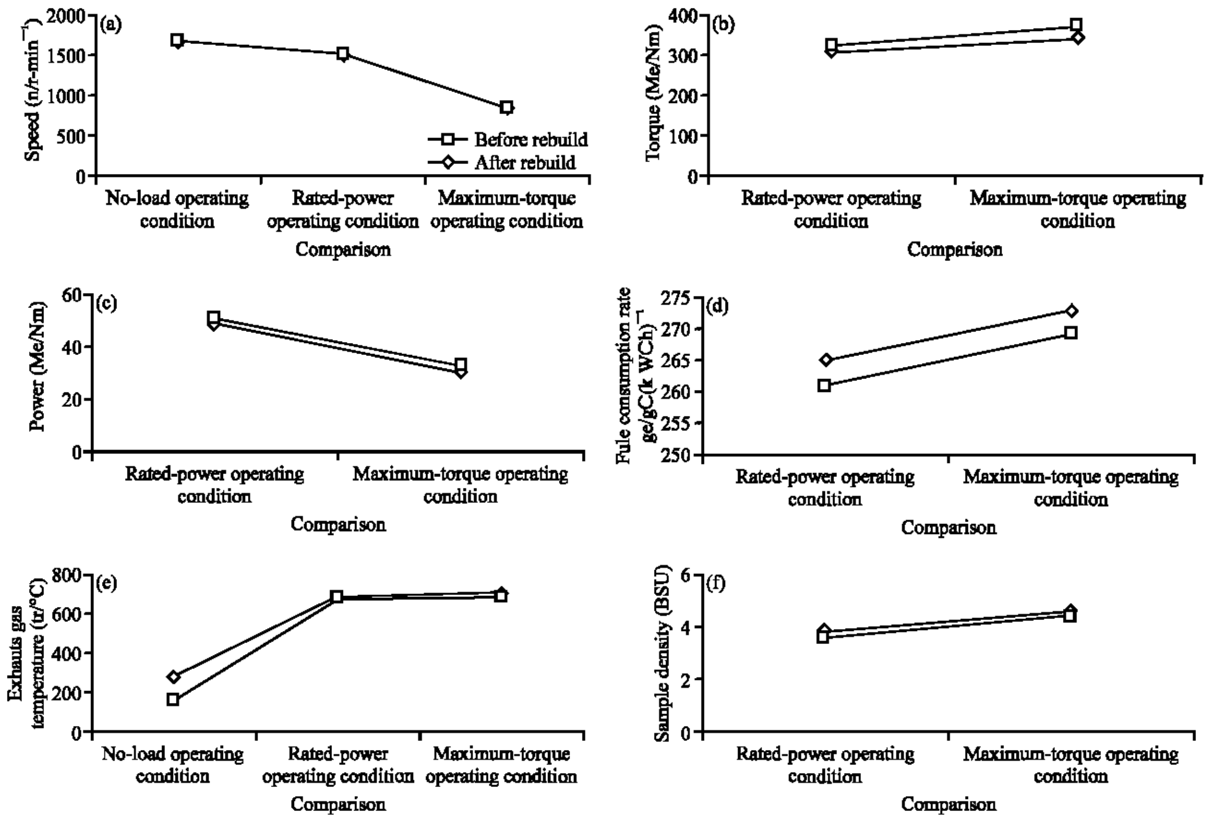

Fig. 3(a-f): Comparison of (a) Speed, (b) Torque, (c) Power and (d) Fuel consumption rate, (e) Exhaust gas temperature, (f) Smoke density, under different operating conditions for a Dongfanghong type 4125A diesel engine before and after rebuilding and extension of the crank by 0.75 mm

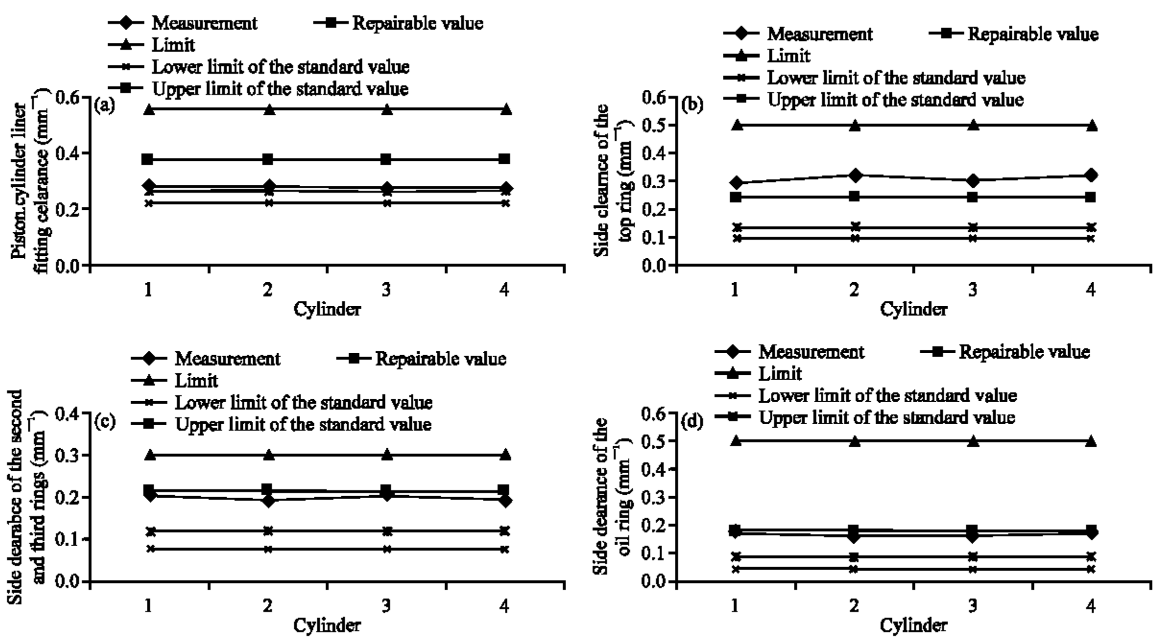

Fig. 4: Continue

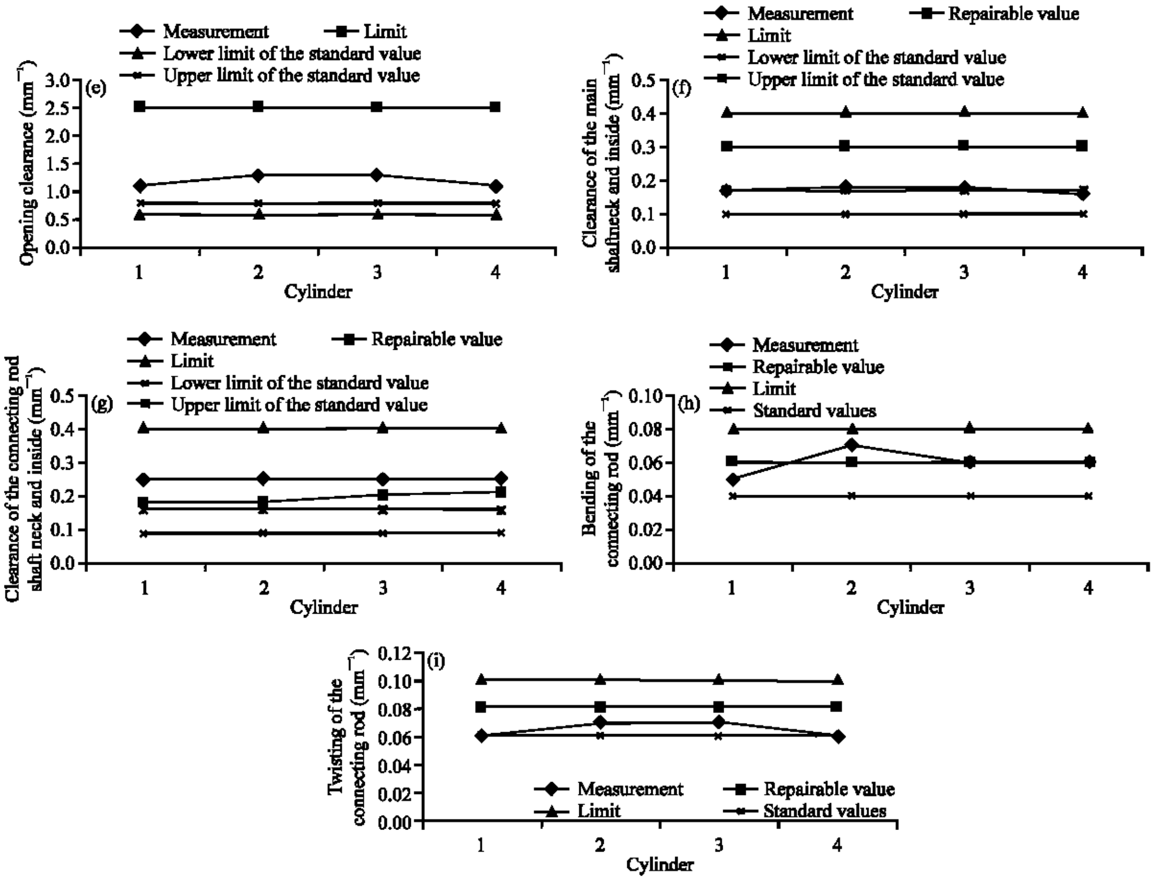

Fig. 4(a-i): Comparison of measured values of (a) Piston-cylinder liner fitting clearance, (b) Side clearance of the top ring, (c) Side clearance of the second and third rings and (d) Side clearance of the oil ring, (e) Opening clearance, (f) Clearance of the main shaft neck and inside, (g) Clearance of the connecting rod shaft neck and inside, (h) Bending of the connecting rod and (i) Twisting of the connecting rod, in each of the 4 cylinders of a Dongfanghong type 4125A diesel engine (after rebuilding and extension of the crank by 0.75 mm) with manufacturer-specified standard and tolerance

and connecting rod bending (Fig. 4h) and twisting (Fig. 4i), were within the repairable range after 2000 h of continuous operation.

CONCLUSION

Lengthening the diesel engine crank increased the compression ratio and average working pressure of the diesel engine at given speeds, which is conducive to improving the diesel engine power. The fuel consumption rate of the diesel engine decreased significantly after crank-lengthening, which improved the diesel engine power and economy.

After lengthening the diesel engine crank by 0.75 mm, the piston reciprocating stroke speed was increased by 0.12 mm sec^{-1}, which relatively improved the dynamic sealing between the piston and cylinder liner without increasing the engine speed. Thus, for the same power output, the diesel engine speed was relatively decreased, which is conducive to reducing diesel engine vibration and thus extending the working life of the various parts. Therefore, lengthening the diesel engine crank is a relatively safe method for restoring power after a rebuild.

After crank-lengthening, the speed of the piston that connects the rod was increased, but the oil consumption and the technical status of key components were in good condition. These results suggest that it is feasible to restore power for an overhauled diesel engine by lengthening the crank.

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