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COMPARISON OF THE TEST RESULTS OF THE DI 12 ENGINE AND THE INTEGRATED DRIVELINE EQUIPPED WITH THIS ENGINE

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Abstract:

The article presents a dynamometer test stand for diesel engines used in contemporary trucks and specialist military equipment. The stand makes it possible to test the operating parameters of the whole integrated driveline or the engine itself and to perform a wide range of engine and gearbox diagnostics. The paper contains the results of measurements of respective parameters of the engine and the integrated driveline during their steady-state operation. Tests were carried out for one complete integrated driveline and two DI-12 engines operating independently.

Keywords:

combustion engine, diagnostics, integrated driveline

INTRODUCTION

Military vehicles used by the Task Force White Eagle (the Polish Task Force) are operated under extremely difficult weather and terrain conditions. They are exposed to impacts exerted by the enemy's different types of shells and missiles or mines. Specialist vehicles were also used during the missions conducted under difficult weather and terrain conditions, e.g. in Lebanon and Chad. The major threats to the driveline of a military vehicle operated during combat missions and under difficult weather and terrain conditions include:

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- intensive operation and long runs, with a concurrently reduced time for maintenance of the vehicle and its units;
- highly changeable weather conditions, including changes in atmospheric pressure, ambient temperature and humidity;
- high air dustiness around the vehicle;
- limited availability of spare parts;
- poor quality of fuel;
- impact of improvised explosive devices (IED) and high-explosive anti-tank warheads (HEAT).

The introduction into the armament of the Land Forces of a modern armoured wheeled personnel carrier “KTO Rosomak” as well as a wide range of trucks, whose readiness for combat has to be secured, has made it necessary to ensure state-of-the-art technical services support both for current maintenance and for system diagnostics and vehicle overhauls.

The diagnostics of the vehicle’s integrated driveline and repairs of even the smallest defects provide the basis for the assessment of roadworthiness of the vehicle. Regular diagnostic checks carried out by highly qualified technical staff ensure a long-lasting and failure-free operation. Furthermore, military vehicles, particularly those having Vehicle Approvals to operate on public roads, have to meet the European standards concerning noxious substances in exhaust emissions. The fulfilment of the above requirement is supported by the on-board diagnostics systems ensuring the ongoing control of operating conditions of engine and vehicle systems. The technical condition of the vehicle’s driveline and control system can be checked most accurately at the dynamometer stand, over the entire range of engine speed and torque values during its operation in steady and unsteady states. A dynamometer brake makes it possible to apply a load to the engine or to the complete driveline, which provides the opportunity to perform tests that monitor the operation of the system, unavailable during typical service. Such stand has been built in the Diesel Engine Laboratory at the Military University of Technology in Warsaw (Fig. 1). The stand has been adapted to test the engine under loading, in two arrangements:

- complete driveline consisting of the SCANIA DI 12 engine and the automatic gearbox – ZF AG 7 HP 902 S Ecomat;
- SCANIA DI 12 engine alone.

The engine and the gearbox have their own control system, installed in the driver’s panel. The controllers of these two devices are interlocked by means of a master controller called a coordinator.

1. TEST STAND FOR THE DRIVELINE AND SCANIA DI 12 ENGINE.

Zöllner PS1-3812/AE, a hydraulic brake, represents the basic unit of the stand and makes it possible to simulate the operational loading of a diesel engine. The tests of the integrated driveline were carried out at the third gear ratio (i = 2.01), which ensured the stable engine operation at a wide speed range of the brake.

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a) b)

Fig. 1. Dynamometer stand for testing the driveline of KTO Rosomak:
a) view of the engine with the gearbox, in the background on the right – the control room,
b) Texa diagnoscope with a computer for measurements and the driver's
panel from KTO Rosomak.

Source: Own elaboration

The first variant of the stand was prepared to test complete integrated drivelines over the entire range of engine speed and torque values. The flange of the gearbox output shaft was connected to the brake by means of a 690 mm long shaft (Fig. 2a).

The second variant was prepared to test the engine alone, without the gearbox. To test engines without the gearbox it was necessary to mount a longer jointed shaft (1,595 mm), to compensate for the dimensions of the gearbox. It was also necessary to install a countercurrent heat exchanger, instead of the water-air cooling system used in the vehicle. The use of the longer shaft required the installation of an additional guard, mounted to the base plate of the stand (Fig. 2b).

a) b)

Fig. 2. View of the test stand: a) with a complete driveline, b) with an engine.

Source: Own elaboration

The whole process of driveline testing was divided into three stages, which should occur one after another to ensure the correct verification of the operation of respective component parts of the power transmission system:

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- engine electronic system diagnostics using the computer-aided diagnostic system;
- gear box electronic system diagnostics using the computer-aided diagnostic system;
- determination of engine performance under different operating conditions.

The engine was controlled from the measurement room by means of a servomechanism acting on the position transducer for the driver's accelerator pedal. The whole driver's panel was disassembled from the armoured personnel carrier. The complete dashboard, combined switches together with the steering gear, the accelerator pedal and the gearbox control system were placed in the control room. All elements were connected by means of standard cables and tested. The engine was ready for operation and fully controllable.

The stand was equipped with devices for measuring:

- fuel consumption;
- exhaust gas temperature;
- air pressure after the supercharger;
- exhaust smoke;
- exhaust gas composition (content of gas components in exhaust gas).

The fuel consumption was measured by means of a mass flow meter, AVL 733. The device works by measuring the time during which a certain mass of fuel, drawn from the measuring vessel, is consumed.

Exhaust smoke levels were measured by means of a smoke meter, AVL 439. The smoke meter was placed near the engine and connected to the engine exhaust system through a heated gas path.

The CEB II exhaust gas analyser system made by AVL was used for measuring gas components in exhaust gas. Exhaust gas was drawn from the exhaust outlet pipe with a probe connected to the exhaust gas rough filter by means of a heated hose. The filter removes particulate matter from exhaust gas, which is then transferred to analysers through a heated gas path.

2. RESULTS OF THE DRIVELINE TESTS PERFORMED AT THE DYNAMOMETER STAND

The tests of the engine were performed at the stand in two stages, by measuring its operating parameters at steady state as a function of load applied to the engine and at unsteady state. The tests of the integrated driveline disassembled from the UB 02221 personnel carrier were carried out at the dynamometer stand during the engine operation at steady and unsteady states. Engine performance was determined across the engine speed and load range in two operating modes: economy (standard) mode and dynamic (combat) mode.

Engine performance for the Scania DI-12 engine together with the complete driveline was determined for the engine speed range of 1,300-2,300 rpm. When the switch in the control desk was set to the dynamic (combat) mode the engine reached the power

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of 330 kW, whereas in the standard mode the maximum power was 261 kW (Fig. 3a). With reference to the maximum rated engine power, the measured power value was lower by about 9%, but the engine was influenced by loads caused by the resistance of the gearbox and the cooling system, in which fans are driven by the hydraulic system, powered by the engine flywheel. Therefore, it can be concluded that the engine reaches its rated power output. In the economy mode the power output of the tested engine was lower by about 20% as compared to the combat mode. A reduction in power, in comparison with operation in the combat mode, is related to a decreased maximum fuel charge, which is determined by the engine control system (Fig. 3b).

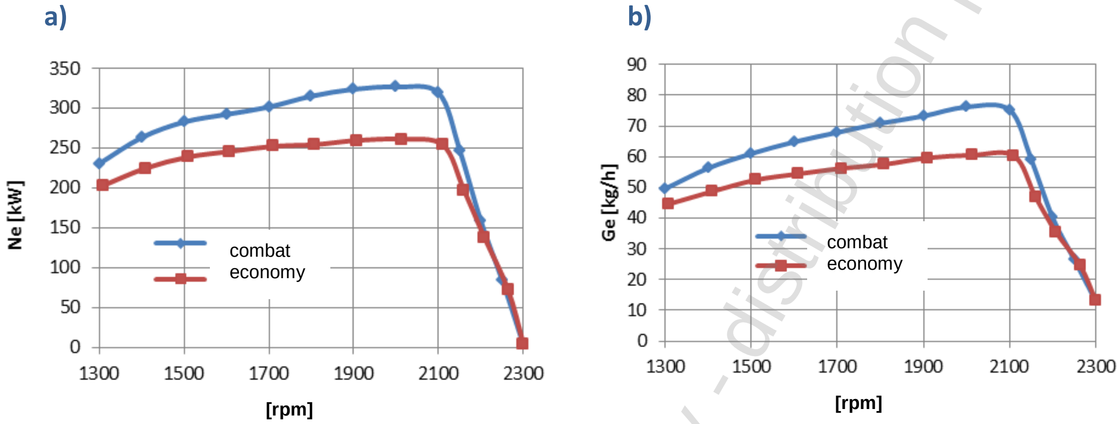

Fig. 3. Performance parameters of the driveline of KTO Rosomak:
a) power output, b) hourly fuel consumption

Source: Own elaboration

The specific fuel consumption at the maximum load of the engine operating in the combat mode increased slightly across the entire range of engine speed (Fig. 4a) and was comparable to the fuel consumption when the engine operated in the economy mode. The minimum value g_e = 216 g/kWh. The difference in the fuel consumption resulted in the difference in the exhaust gas temperature of 45-60 K over the entire range of engine useful speed (Fig. 4b).

Concurrently, across the entire speed range of the engine operating in the combat mode, the air pressure in the suction manifold after the supercharger increased by about 0.2-0.3 bar (0.02-0.03 MPa) (Fig. 5a). Thus, the air supply to the engine was enhanced, ensuring good combustion conditions for the increased fuel charge. It was the consequence of a higher temperature of exhaust gas and the corresponding enthalpy of exhaust gas supplied to the engine turbocharger.

The undesirable effect of increased fuel charges during the engine operation in the combat mode is a significant rise in the level of exhaust smoke at high speed values. Within the speed range of 1,800-2,100 the exhaust smoke level increased by as much as about two and a half times (Fig. 5b) in comparison with the engine operation in the economy mode.

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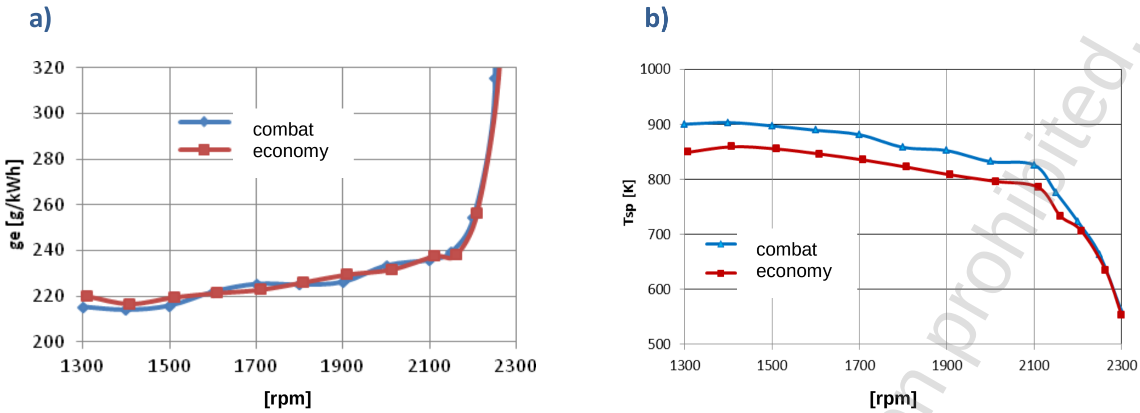

Fig. 4. Performance parameters of the driveline of KTO Rosomak as a function of speed: a) specific fuel consumption, b) temperature of exhaust gas leaving the turbocharger.

Source: Own elaboration

The load curves confirm the hypothesis that the difference between the two engine operating modes is caused only by a change in the maximum fuel charge. At lower loads, the curves for all measured parameters of engine operation practically overlap. It is demonstrated by all load curves plotted during the engine operation at a speed of 1,400 rpm, 1,600 rpm, 1,800 rpm and 2,000 rpm.

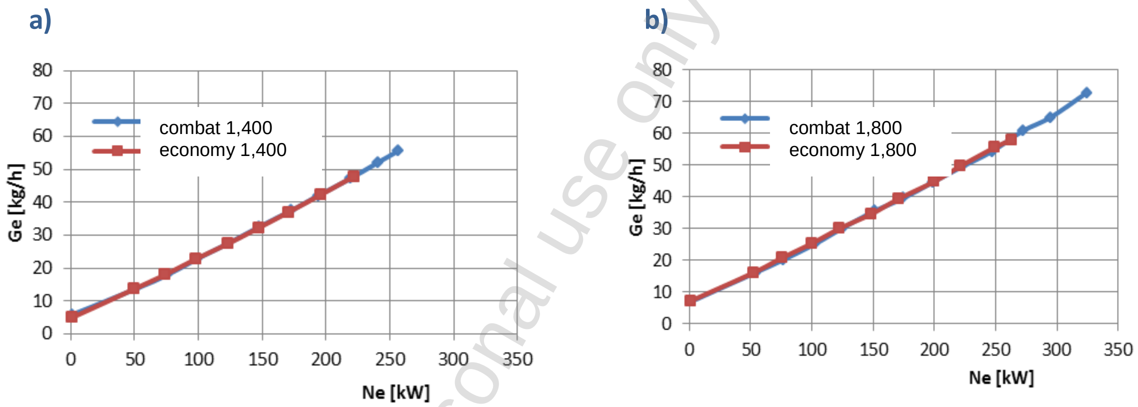

Fig. 5. Performance parameters of the driveline of KTO Rosomak for the full load range – hourly fuel consumption: a) n = 1,400 rpm, b) n = 1,800 rpm.

Source: Own elaboration

3. COMPARISON OF THE TEST RESULTS FOR THE DI-12 ENGINE WITHOUT THE GEARBOX AND FOR THE INTEGRATED DRIVELINE

The tests of the engine without the gearbox and the radiator were carried out after the repair of the oil sump. After the adaptation of the stand for testing the engine alone, its performance was determined across the engine speed and load range in two operating modes: economy mode and combat mode. The plotted curves were compared with the corresponding curves for the engine tested together with the gearbox. Thus, it was possible to compare the two tested engines with respect to the repeatability of their operating parameters and properties of KTO Rosomak engines. The study focused

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on the comparison of selected operating parameters for the engine operation in the combat mode only.

a) b)

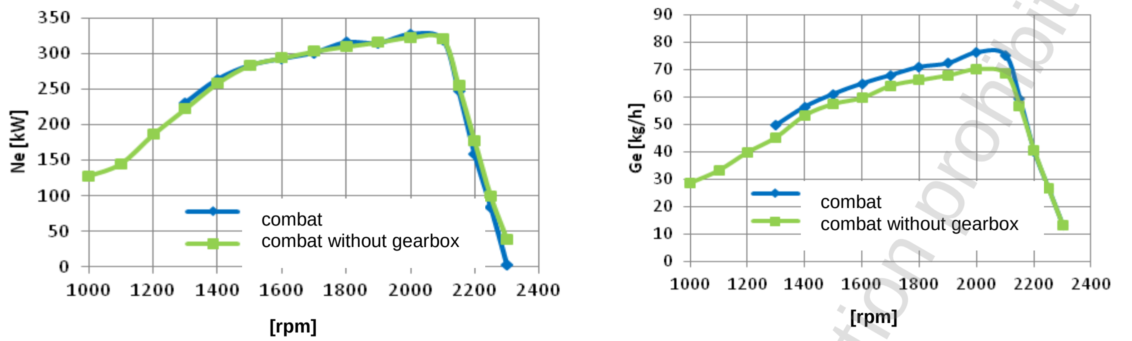

Fig. 6. Comparison of engine performance as a function of speed:
a) power output, b) hourly fuel consumption

Source: Own elaboration

a) b)

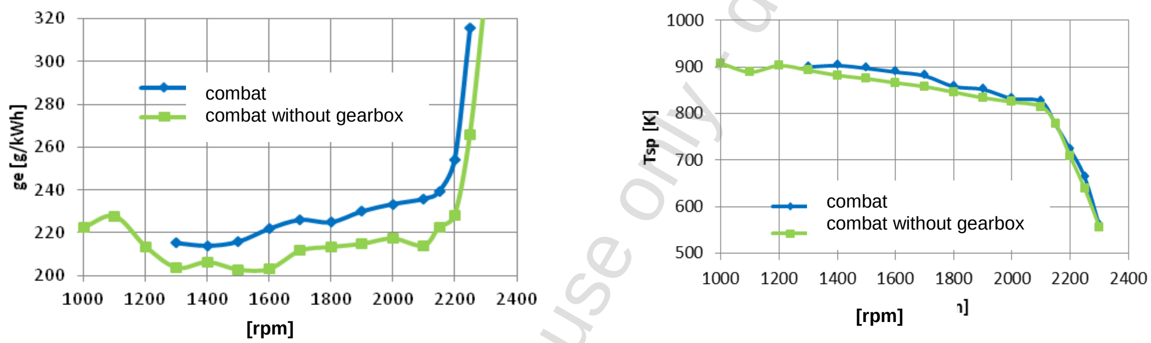

Fig. 7. Comparison of engine performance as a function of speed:
a) specific fuel consumption, b) exhaust gas temperature

Source: Own elaboration

a) b)

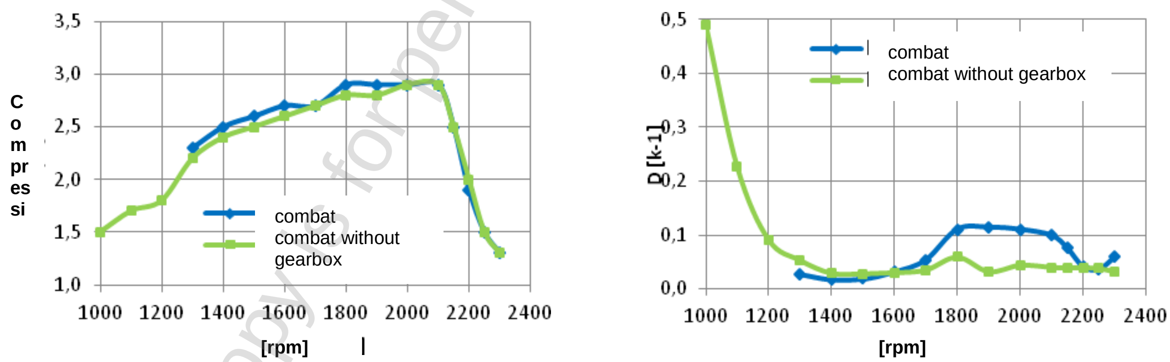

Fig. 8. Comparison of engine performance as a function of speed:
a) compression b) exhaust smoke

Source: Own elaboration

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When the switch in the control desk was set to the combat mode, the engine reached the power of about 330 kW, i.e. the same value as achieved by the engine integrated within the driveline (Fig. 6a). Also in the economy mode the power of the engine alone was comparable and totalled about 260 kW. With regard to the maximum rated power of the engine the measured power value was about 9% lower and, in principle, it did not differ from the power of the engine integrated within the driveline, however such value was reached at the reduced fuel consumption (Fig. 6b). A lower hourly fuel consumption, at a comparable engine power, resulted in a reduced specific fuel consumption by the engine operating without the gearbox (Fig. 7a) and a lower exhaust gas temperature (Fig. 7b).

The pressure of the air leaving the turbocharger was increasing as a function of engine speed, with a concurrent increase in the enthalpy of exhaust gas (Fig. 8a). In the case of the engine without the gearbox the pressure of the air leaving the turbocharger was slightly lower, but, concurrently, the temperature of exhaust gas in this engine arrangement was also lower.

The analysis of the plotted curves for exhaust smoke levels, measured by light absorbance by exhaust gas, showed a significant rise in the level of exhaust smoke at the lower speed range of the engine without the gearbox (Fig. 8b). The level of exhaust smoke during the engine operation at a speed of 1,000 rpm was about seven times higher than the level of exhaust smoke for the medium speed range, and in the dynamic mode a tenfold increase was observed. In the case of the engine with the gearbox it was impossible to verify this parameter, because of the limited engine speed range resulting from the brake characteristics. The rise in the level of exhaust smoke at a low speed was probably caused by a deterioration in the fuel injection (spraying) and combustion within this speed range. The reason for the above situation was a little amount of excess air, which was confirmed by the curves plotted for other components of exhaust gas.

CONCLUSIONS

1. The presented dynamometer stand is capable of providing a highly accurate diagnostics of the integrated driveline of the armoured wheeled personnel carrier Rosomak. The stand makes it possible to determine the operating parameters of the engine and to control its systems and to determine the operating parameters of the gearbox. The stand was built to carry out verification tests of the above units, during their operation and after overhauls.
2. The dynamometer stand can be used to perform tests of the driveline at steady and unsteady state, and the braking torque curve of the employed water brake makes it possible to apply high torque to the driveline even at a low speed, i.e. at a high gear ratio.
3. The measuring and diagnostic instruments of the stand ensure the complete and accurate diagnostics of engine units as well as error detection and elimination. On the basis of the results of the performed tests it was possible to verify

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the values of operating parameters of the DI-12 engine, during its independent operation and as a part of the integrated driveline.

4. At present, the stand is adapted to analyse the composition of exhaust gas and assess the technical condition of cooling system fans, which will contribute to the more detailed examination of the technical condition of the carrier's integrated driveline.
5. Changes in the power output of the engine, in both the combat and economy modes, result from the difference in the hourly fuel consumption only. In this mode the maximum fuel charge is reduced and the engine operates at a lower load and at a lower exhaust gas temperature. The difference in power values of the compared engines operating with or without the gearbox was definitely smaller. The observed differences resulted from a lower load applied to the engine operating without the gearbox, because the internal resistance of the driveline was thus reduced.

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BIOGRAPHICAL NOTES

Mirosław KARCZEWSKI, Ph.D., Eng. – currently working at the Department of Engines and Engineering of the Operation of Motor Vehicles at WAT (Military University of Technology in Warsaw) at the position of Assistant Professor. Author and co-author of over 80 articles and reports in the area of science and technology. Areas of interest: control of operational processes in Diesel engines, application of alternative fuels to feed Diesel engines, methods for measuring gas components and particulate matter in exhaust gas and reverse engineering in automotive applications.

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