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ADAPTING VEHICLE DIESEL ENGINE TO POWER GENERATION - CONVERSION ASPECTS

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Abstract: *The paper reports the research work performed to convert a diesel engine used in commercial vehicles in a generating set of 65 kVA. The design, manufacture and testing of the prototype were performed, being emphasized the main conversion problems such as derating from 2800 rpm to 1500 rpm, changing of fuel flow rate of the injection pump, adapting air flow rate by means of selection of a by-passed turbocharger and intercooling. A special attention was paid to engine speed stability to which were imposed stringent conditions in order to ensure a constant frequency of the generated AC voltage.*

Key words: *diesel engine, generating set, engine conversion.*

1. Introduction

Many of the heavy duty diesel engines, typically used on commercial vehicles, can be converted for other industrial applications such as maritime, railway, construction, pumping or electrical energy generation. A diesel generating set can be a reliable source of electricity in isolated areas without access to the power grid or as an emergency power supply for vulnerable places such as hospitals in case of power grid failure; it can be actuated by a diesel engine and most of engine manufacturers offer some adapted versions of the basic vehicle engine to other specific purposes [1-3]. The conversion may require some changes in the basic design of the engine or its ancillary systems such as suspension, ventilation, cooling, heating (jacket water), intake, exhaust, fuel storage, sound attenuation and starting. There are several sensible aspects in the work of converting a vehicle engine to act as a power generator: sizing, demand of overload power, speed variation limits, cooling, injection, being imposed specific requirements from industrial engine regulations [4], [5].There are two operation modes for generators: stand by generator which is an emergency power source running several hours per year and prime power generator which must operate continuously. The specific demand of power for the generator can be expressed as Prime Rating in which power output may sustain typically a peak of 110% from the electric power (kW), 10% overload capability being kept for emergencies duration of 1 hour out of 12 hours operation (DIN 6271-B) and as Load Continuous Rating in which power output should be kept continuously without any overload

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capability (DIN 6271-A). As a general rule, the diesel generators are used at lower speeds and loads than rated ones in vehicles imposing the change of the injection characteristics.

This study reports the research work performed to adapt a 114 kW truck engine to the demands of generator sets produced for Romanian market, starting from the requirements of the contractor, passing through the phases of design, prototype manufacturing, experimental testing and certification.

2. Design Requirements

The diesel generator contractor, Electric Machine Works [6], intended to enlarge the range of generating sets around electric power of 65 kVA using diesel engines operating to a stabilized speed of 1500 rpm. Previously, there were manufactured two models of diesel generators of 125 kVA and 155 kVA based on two vehicle engines from ROMAN Truck Company, D2156MTN8 and, respectively, 1380V8DT, which succeeded to meet the expectations of the contractor. The main characteristics of the new diesel generator were the following ones [7]:

- load continuous rating 60 kW;
- prime rating 65 kW;
- rated speed 1500 rpm;
- non-uniformity speed degree, $\delta = 1/200$;
- applicable as generator, driving pump or stationary engine.

The main change of the engine prepared to work as a generator is the lowering of the rated power speed from 2800 rpm to 1500 rpm which means the change of the moment when injection pump governor starts operating.

The most suitable engine to comply with the demand of the generator was a direct injection turbocharged diesel engine type, 550-L6-DT, manufactured by ROMAN Truck Company, described in Table 1.

Engine parameters Table 1

Bore x Stroke	102 x 112 (mm)
Cylinder configuration	6 in line, vertical
Total displacement	5.5 l
Compression ratio	17 : 1
Rated power	114 kW
Rated speed	2800 rpm

The tested engine was 550-L6-DT, series 5097, which was symbolized according to the generator version as 550-L6-DT-GE (from Generator Electric).

The operation of the generator imposes some very tough conditions towards the variability of the engine speed which are the following ones:

a) variation of engine speed at constant load to be 0.8% from rated speed;

b) permanent variation of engine speed, in percentages from rated speed at idle speed and from idle speed to the rated speed to be maximum 4.5% from rated speed;

c) Instantaneous maximum speed variation from rated speed to maximum idle speed to be maximum 15% from rated speed.

d) Time of speed recovery to be maximum 10 s.

3. Engine Testing

In order to adapt the basic engine operation to the requirements of the generator, several steps were performed, after a preliminary engine running in of 60 hours on the instrumented dynamometric engine test bench from Road Vehicle Institute INAR, Braşov:

- the adjustment of fuel flow rate for the required power;
- the selection of the appropriate turbocharger and intercooling;
- the checking of the variability requirements imposed to engine speed.

The engine was run in the following equipment: no compressor, no fan, uncharged alternator, in line injection pump, centrifugal speed governor. The dynamometric test bench was fitted with all the instruments and sensors required for the accurate measurement of engine performance, according to the engine testing standard [8]. During tests, the ambient conditions were the following ones: barometric pressure 718 mm column Hg, average air temperature 26 ºC [9].The engine performance was corrected with correction factors due to atmospheric conditions, according to standard [4].

There were measured the engine parameters required to plot the characteristics of speed at full load (with series turbocharger and modified turbocharger, the characteristic of speed at full load with intercooling, the governor and idle characteristics, permanent and instantaneous speed variation.

4. Test Results

The control of injection timing is essential in minimising fuel consumption and emissions.The engine was tested for finding out the optimum injection timing, which was 26ºBTDC, close to the value indicated in the engine standard of 28 ± 1ºBTDC.

4.1. Fuel Flow Rate Adjustment

The injection pump prepared for the generator set is ROPES 6A80D type with speed limiting RSV governor adjusted to maximum power at 1500 rpm. The adjustment was fixed on the injection pump test bench with the full lever position, being measured the fuel flow rate of the injection pump for 1000 pump pulses. The variation of the fuel flow rate can be seen in Figure 1 with the observation that the measure speed of the pump was replaced on abscissa with equivalent engine speed.

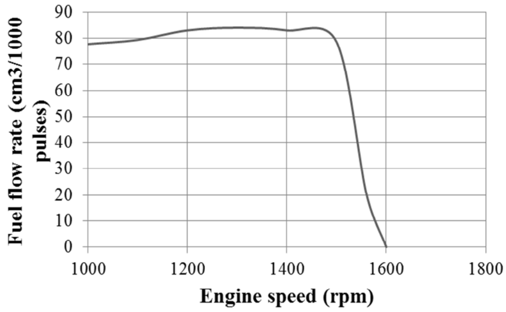

Fig. 1. *Fuel flow rate versus speed*

The fuel flow rate injected at 1500 rpm was adjusted to correspond to the maximum fuel flow of the basic engine at speed of 2800 rpm. So the original adjustment of the fuel pump was kept, being modified only the governor in-operation speed.

4.2. Turbocharger - Intercooling

A preliminary test with original turbocharger fixed geometry type H1S showed that the smoke number, the fuel consumption and the exhaust temperature were higher than prescribed values, that is why a bypass type turbocharger-HB1C was tested, controlling through the turbine the exhaust flow rate, with results plotted in Figure 2. Both specific fuel consumption and hourly fuel consumption were lowered

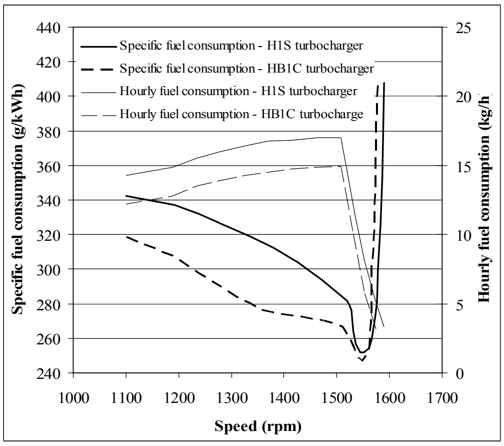

Fig. 2. *Turbochargers performance*

when by-pass HB1C turbocharger was used because it ensures a higher intake air flow rate, so the current turbocharger H1S which equipped the engine was replaced with by-pass HB1C turbocharger during further testing. Anyway, both turbochargers failed to reach the rated power, so a new solution was to be adapted-the intake air intercooling.

During the compression in the compressor the air becomes rapidly very hot, reducing its density. Using the intercooling, the air is cooled in an air-to-air heat exchanger, increasing its density and enhancing the fuel combustion as more fuel can be introduced in the combustion chamber, at the same air-fuel ratio.

The engine equipped with HB1C turbocharger and air intake cooling succeeded to reach 65 kW at 1500 rpm and an increased torque with 10% over a broad range of engine speeds, as is illustrated in Figure 3. The increase of power output due to intercooling was constant of approximately 4 kW on the whole range of speeds.

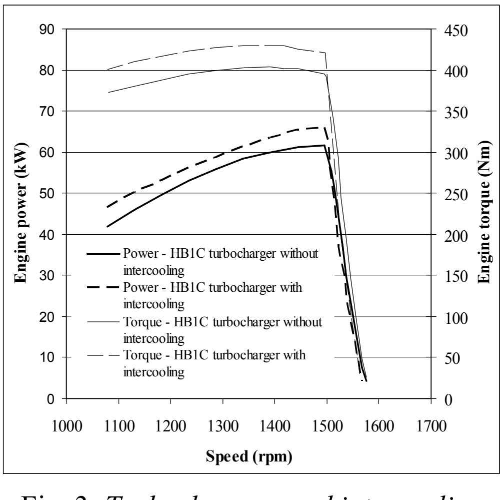

Fig. 3. *Turbochargers and intercooling*

Also the intercooling provides a significant reduction of the specific fuel consumption, ensuring a very good fuel economy of the diesel generator, in average of 20 g/kWh as is presented in Figure 4.

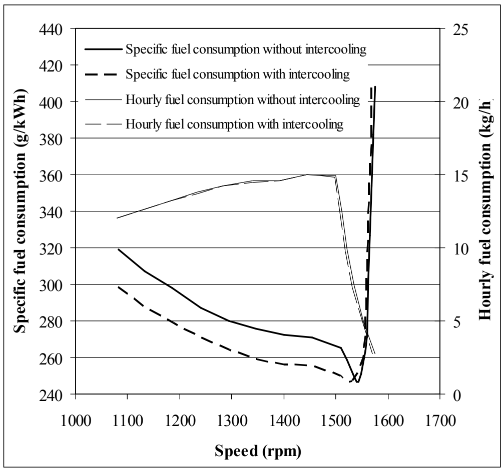

Fig. 4. *Intercooling fuel economy*

The gain of the intercooling can be seen in Figure 5 as an average reduction of intake air temperature of 25 °C.

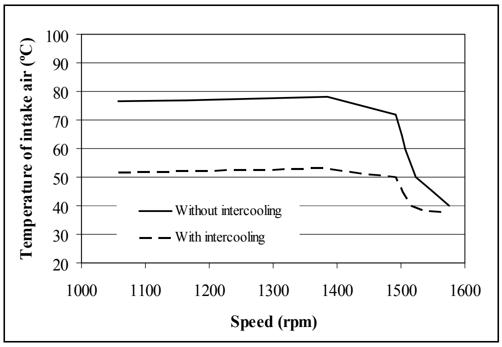

Fig. 5. *Intake air cooling*

In the first phase of the research work it was investigated the capacity of the engine to meet the generator requirements with the original equipment from the vehicle solutions (H1S turbocharger). As the results in terms of power and fuel consumption were unsatisfactory, it was replaced the turbocharger with a by-pass type, the fuel consumption being lower, but the power being lower too. The third phases implied the adding of intercooling, thus leading to very good results. Other parameters as engine torque and exhaust gas temperature were measured, having fair values, as presented in Table 2. The oil specific consumption was

Engine variables during research work Table 2

Engine parameter	Unit	Version of turbocharger			Standard values
		H1S	HB1C	HB1C + intercooling	
Rated power	kW	62.2	61.6	65.9	65
Rated speed	rpm	1500	1500	1500	1500
Max. idle speed	rpm	1566	1566	1566	max.1570
Min. idle speed	rpm	725	725	725	700 + 50
Specific fuel consumption at rated power	g/kWh	281.5	265.2	250.2	max.255
Exhaust gas temperature after turbocharger	ºC	620	570	540	max.550
Max. engine torque	N · m	406	406	429	-
Max. torque speed	rpm	1400	1400	1400	-

measured by weighing, on 3 hour operation at rated power, being 1.35 g/kWh, smaller than required limit of 1.5 g/kWh prescribed in the product standard.

4.3. Engine Speed Variability

The engine speed variation is the most important parameter in the behavior of the generator, thus yielding in the quality of generated AC voltage frequency.

The checking of the requirements formulated in chapter 2 on engine speed variability lead to the following results, illustrated in Figure 6.

a) Variation of engine speed at constant load to be max.0.8% · n_n (n_n - rated speed, in this case 1500 rpm) -The measured variation of engine speed at constant load was 9 rpm, meaning 0.6% · n_n.

b) Permanent variation of engine speed, in percentages from rated speed at idle and reversed, max. 4.5% · n_n. The measured permanent variation of engine speed, from rated speed to idle speed and reversed was 66 rpm meaning 4.4% · n_n, lower than admitted.

c) Instantaneous maximum speed variation from rated speed to maximum idle speed. The measurement of the maximum instantaneous speed variation was 75 rpm, meaning 5% · n_n much lower than imposed value of 15%.

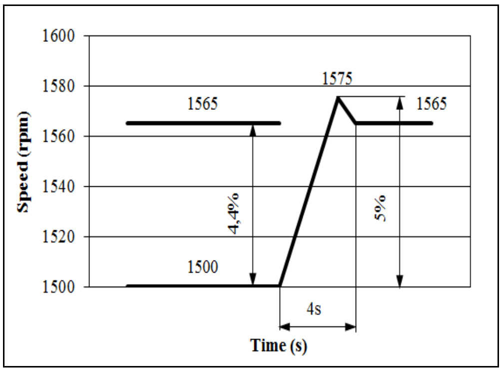

Fig. 6. *Engine speed variation limits*

d) Time of speed recovery to be maximum 10 s - The measurement of engine speed recovery lasted only 4 s.

The engine was mounted on a platform being fitted with installations such as suspension, ventilation, cooling, intake (air

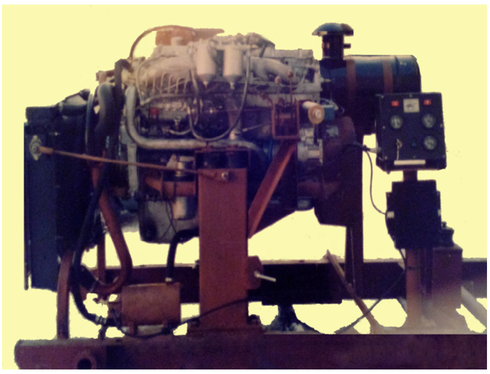

Fig. 7. *Engine generator on platform*

filter), exhaust (muffler), fuel tank and control panel as it can be seen in Figure 7.

5. Conclusions

By changing the turbocharger from a series type to a bypass type and by using an intercooler the engine performance met the requirements of the diesel generator, in terms of power and specific fuel consumption.

Variability of engine speed was checked proving to have a high stability, meeting the demands of the generator designer.

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