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INFLUENCES OF ELECTRICALLY ASSISTED CHARGING UPON FUNCTIONAL PARAMETERS OF THE S.I. ENGINES

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Abstract: *The present paper studies how an electrically assisted charging system influences the functional parameters of spark ignited engines. These influences are studied through the city cycles performed with a modern turbocharged car. The main objective that triggered researches was to improve transient response of the internal combustion engine, with focus on city driving. The issue of turbo lag is well known from decades, but sadly most of turbocharged engines are engineered for peak power output, rather than drivability. Steady–state torque became a simple number car manufacturers use to maintain competition, though the majority of daily driving schedule involves transient conditions. In fact, only a very small part of a vehicle's operating pattern is true steady–state, e.g., when cruising on a motorway. The fundamental aspect of transient condition lies in its operating differences compared with steady–state operation. Whereas during steady-state conditions, engine speed and fueling, hence all other engine and turbocharger properties remain practically constant, during transient operation, both engine speed and the amount of injected fuel change continuously. Consequently, the available exhaust gas energy varies, affecting turbine enthalpy, air supply and boost pressure. Due to various dynamic, thermal and fluid delays in the system, air–supply is delayed compared with fueling, eventually affecting torque buildup (drivability) and exhaust emissions. Tests were done on a compact SUV (Sport Utility Vehicle) which has a greater ground clearance, and it is powered by a spark ignited turbocharged engine to which an electrical charger unit was also fitted. The latter was powered by the car's own battery. The analyses made upon test data showed a considerable advantage for the electrically assisted version with regard to transient response, generated by the increased pressure and mass flow of the air entering into the combustion chamber through the intake manifold when the electric charger was active, which allowed a greater fuel quantity to be injected, delivering torque from early idle speed.*

Key words: *transient, steady state, electric charger*

INTRODUCTION

Beginning from the third millennium, more and more internal combustion engines are equipped with charger and intercooler units. This configuration made it possible to develop smaller, yet more powerful engines. Charging the engine is benefic because it not only increases its (specific) brake power, but also because it provides better fuel economy and reduced CO_2 emissions –increased mechanical efficiency (downsized engines) and positive pumping work – and, in some circumstances, reduced exhaust gas and noise emissions.

During recent decades, the increasingly stringent exhaust emission regulations have dominated the automotive industry, and forced manufacturers to new developments. Sophisticated high-pressure injection systems, exhaust gas recirculation (EGR), exhaust after-treatment systems are among the measures applied for reduction of pollutant emissions and fuel consumption. Along with the improvement in fuel consumption and reduction of pollutant emissions of engines, in the last few years studies were carried out to conceive more advanced turbocharging units that would banish disadvantages of these engines (5). As a result, for petrol engines today we have twin scroll (Fig. 1) and variable geometry turbochargers (VGT), as well as sequential twin turbo and most recently tri-turbo (Fig. 2) systems.

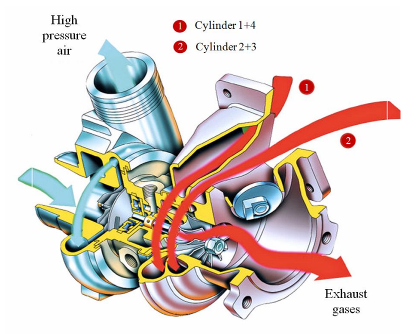

Figure 1. Twin-scroll turbocharger

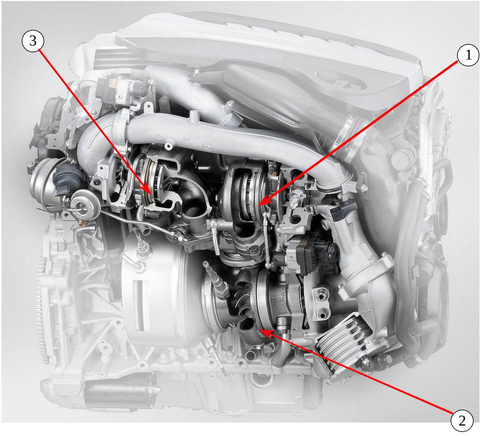

Figure 2. Tri-turbo charging system

Although these solutions represent a major step forward in banning the turbo-lag, they cannot give the naturally-aspirated (N.A.) like responsiveness to the turbocharged engine. This is noticeable especially in higher gears and lower engine speed range (Fig. 3). In case of a modern engine which is equipped with a twin-scroll turbocharger, if 3rd gear is selected, from idle engine speed of 800 rpm in order to achieve nominal boost pressure, in transient conditions 8 s are needed. This late pressure build up influences torque build up and makes possible the development of uneconomical driving habits in city cycles.

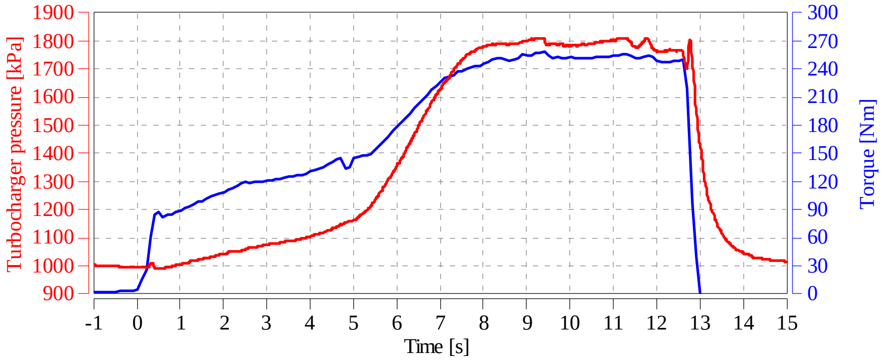

Figure 3. Transient response of a twin-scroll unit charged engine

Turbocharger compressors are characterized by low delivery pressure and mass flow at low rotational speeds, as well as by relatively narrow flow range. The points that need to be addressed for better engine response are located exactly in this behavior. Improvement can be achieved,

- when focusing on the engine exhaust side, by somehow accelerating the turbine.

- alternatively, we can focus on the inlet side by directly increasing the air-supply delivered to the cylinders.

MATERIAL AND METHODS

Experimental research was done on a 4x4 driven, high ground clearance compact SUV, which allows off road trips also. The choice to add an electric charger was taken especially considering the requirements that the car had to meet: high torque at low engine speeds in order to be able to pass obstacles at low velocity. The main characteristics of the engine that equips the research model are shown in table 1.

Table 1

Characteristics of the studied engine

Nr.	Parameter	Value	Measuring unit
1.	Bore	77.00	mm
2.	Stroke	85.80	mm
3.	Bore/Stroke ratio	0.9	-
4.	Number of cylinder	4 in line	-
5.	Displacement	1598	cm^3
6.	Compression ratio	10.5:1	-
7.	Number of engine strokes	4	-
8.	Valve/cylinder	4/1	-
9.	Power@speed	160@6000	kW/rpm
10.	Torque@speed	280/1600	Nm/rpm
11.	BMEP	2202	kPa
12.	Injection system	Gasoline direct injection	-

Taking into account the imposed specifications, a stand-alone electric charger was chosen, this is connected in parallel with the car's own turbocharger. It is driven by a switched reluctance electric motor with extremely low inertia, having 6 poles on the stator and 4 poles on the rotor. The radial compressor wheel is machined from a one piece aluminum alloy. It is designed in such a way that the mean operating points to be identical with the optimal operating points of the electric motor. The main characteristics of the electrical charger are given in table 2 [4].

Table 2

Characteristics of the electric charger

VTES electrical charger	Performances
Maximum pressure ratio	1.47
Maximum air mass flow through the unit	400 kg/h
Maximum speed (transient)	70000 rot/min (72000 rot/min)
Time to maximum speed	<350 ms
Peak shaft power	4.7 kW
Current draw – Idle	2.8 A
Current draw – acceleration	440 A
Current draw – steady state	200 A
Operating temperatures	-40 la+125 C

Figure 4 shows the structural position of the electric charger. To ensure the parallel working of the two charging units, there is need for a unidirectional valve to be installed on the intake side, between the charging units and the air filter to block the air flow from the electric charger back to the air filter.

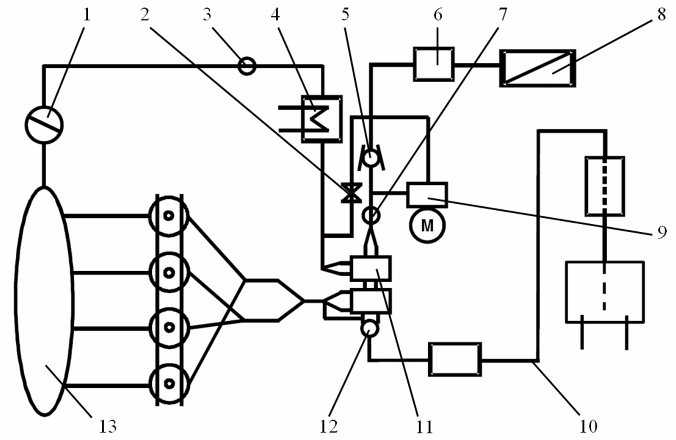

Figure 4. Structural design of the engine
1 - throttle, 2 - by-pass valve, 3 – charge pressure sensor,
4 - intercooler, 5 – unidirectional valve, 6 – air mass flow meter, 7 – pressure sensor,
8 – air filter, 9 – electric charger, 10 – exhaust system, 11 - turbocharger,
12 – oxygen sensor, 13 – intake manifold

RESULTS AND DISCUSSIONS

From the data of the first tests performed on the car with electrically assisted charging, the current draw of the electric charger was checked. (Fig. 5)

In order to be able to quantify the advantages of electrically assisted charging units, city cycle tests were performed, in city-traffic specific conditions. These tests were performed on a well-defined route, with a specific lap-time varying between 900 and 1000 s, containing sections which included parts of the city, with many crossroads and low visibility streets, but sections with wider, straight lanes, where speed limit was set to 60 km/h, also. Tests were performed in the same driving style, by the same driver, in the same traffic conditions. Differences between throttle position, engine speed, amount of developed torque, but gear change frequency also were among the analyzed parameters throughout the test data.

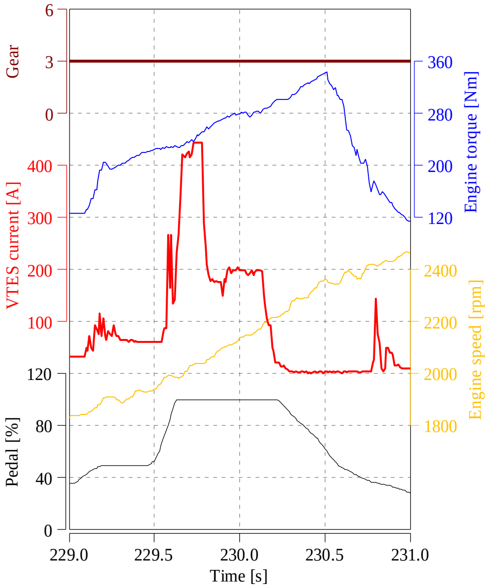

Figure 5. Current draw of the electric charger

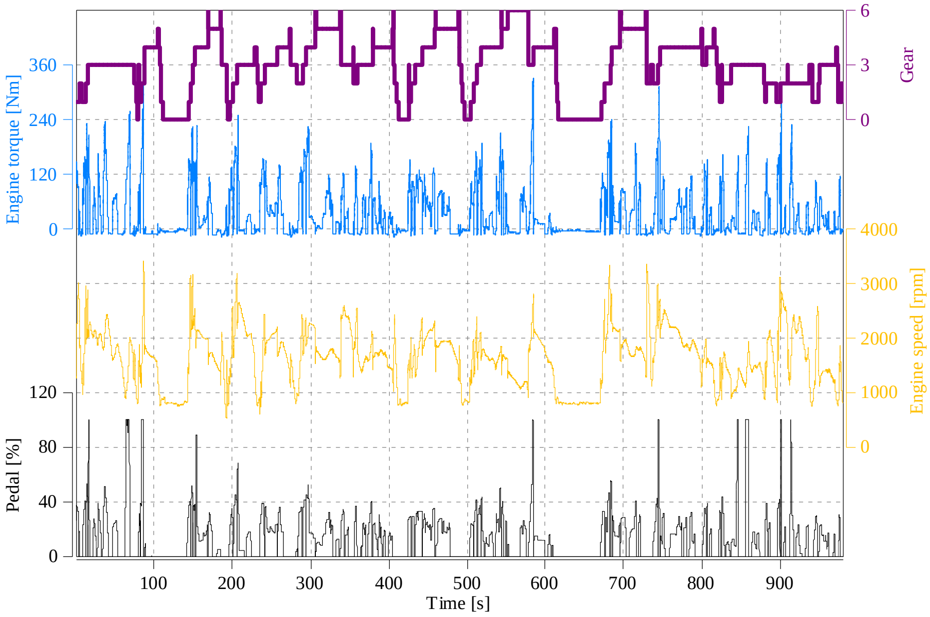

Figure 6. City cycle performed without electric charger

During the tests, current drawn by the electrical charging unit and voltage between it's two poles were permanently measured. Having these data sets, the total energy consumed by the electrical charger during one lap was calculated.

Figures 6 and 7 show the variation of main parameters studied in these tests. Statistical analysis of these parameters exhibit the occurrence of "WOT" (Wide Open Throttle) events, which is three times greater when performing the city cycle without the assistance of the electrical charger then in the case when the cycle is performed with active electrical charger, though the difference between the average of developed engine torque was only one tenth of Nm. This is because of the greater amount of available torque, which gives the driver the assurance of a safe trip. It has to be mentioned that among the tests that were carried out, the two analyzed ones were conducted in the above mentioned order. In the opposite situation the difference between "WOT" events occurrence would be greater.

Likewise, one can notice fewer gear changes for the electrically assisted solution, which is explained by the wider speed range the torque is developed. Performing a detailed analysis of measured data, a slight decrease in average speed at which the engine operated during the test is shown, which projects lowered fuel consumption, especially by reducing friction losses associated with the new working conditions. Sections where vehicle velocity was zero and engine speed was idle were extracted from the analyzed domain.

Electrical charger showed an energy consumption of 123.5 kJ during the test. Lower calorific value of gasoline is 43,800 kJ / kg fuel [1] and the alternator output at engine speeds of 1700 rpm (average engine speed during the test) is around 0.7 [3]. Engine efficiency when transforming the chemical energy of fuel into mechanical energy is chosen in accordance with engine speed and load (load is small, ECU is governing alternator in such a way that higher current is delivered only after the load is reduced, not to affect performance) [2].

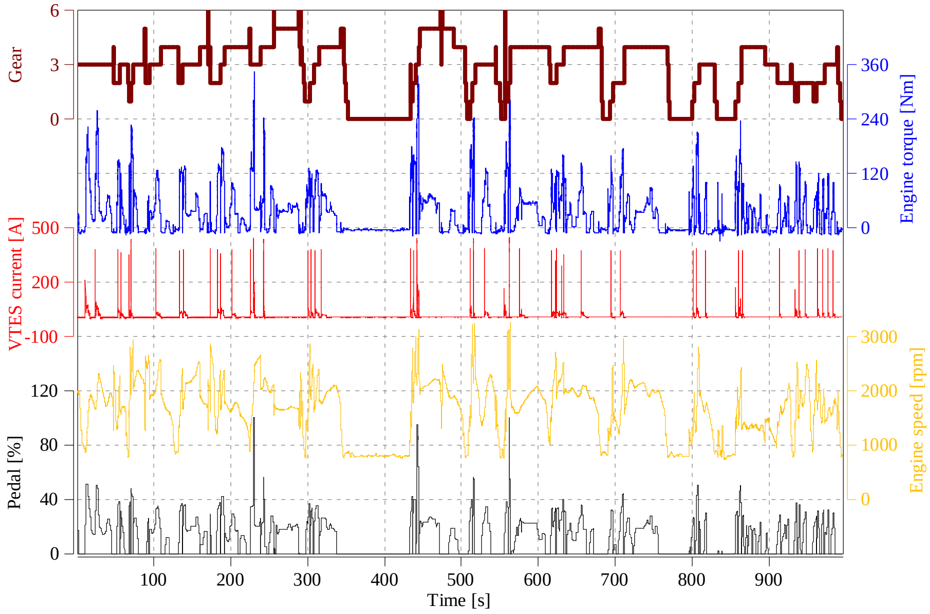

Figure 7. City cycle performed with active electric charger unit

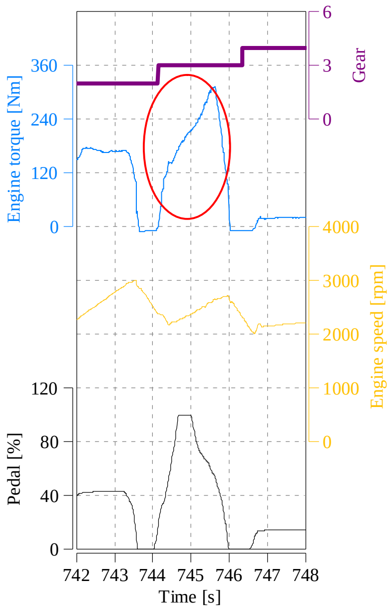

Figure 8. Torque build-up of the standard engine

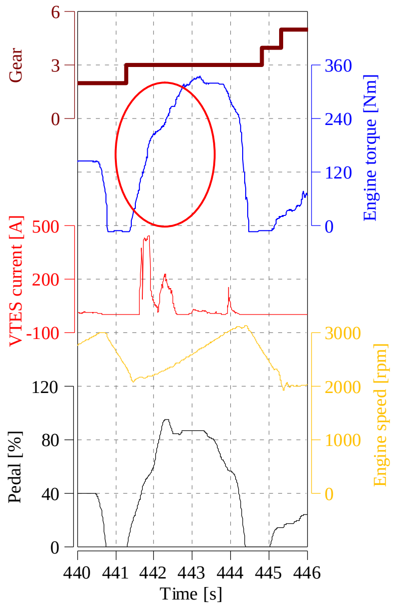

Figure 9. Torque build-up of the electrically assisted engine

In these circumstances the alternator generates 6132 kJ energy out of one kg of fuel. Accordingly, to generate 123.5 kJ of energy, necessary to engage the electrical charger, the engine consumes 0.020 kg fuel, or 0.027 liters of gasoline. In exchange for this minor amount of fuel, the engine provides superior performance, and the chance to save fuel by operating with high efficiency over a broader speed range (by increasing BMEP, BSFC decreases), and having greater elasticity suggests driving at lower engine speeds.

It is noteworthy that the electric charger not only develops higher pressure in the intake manifold at lower speeds, but contributes to the fast increase of turbocharger speed also. In figures 8 and 9 can be clearly seen that values of effectively developed torque and the shape of these curves is different also. Without electrical charger, the shape is convex, but with active electrical charger, the shape gets concave, much more convenient while driving. Although in both cases engine speed from which the car was accelerated exceeded 2000 rpm, the advantage of using electrical charger translates in the first 1.5 seconds into 60 Nm.

CONCLUSIONS

Current draw of the electrical charger is very high, but because of the short periods it is in use, doesn't overwhelm the car's own battery pack.

Statistical analysis of the tests shows less 100% throttle handling and lower average engine speed when the electrical charger is active, projecting fuel economy.

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Benefits of electrical assist stands out when "WOT" is applied, otherwise the effect added by the electrical charger will be lower.

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