COMPLICATION BY CONVERSION OF SPARK IGNITION ENGINE TO CNG ENGINE

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Abstract:

This paper reports on the testing of a Skoda Auto 1,2 HTP engine powered by compressed natural gas in the Department of Engines and Vehicles engine laboratory at the Technical University of Liberec. This engine was equipped with CNG fueling. The goal of the measurement was the verification of a functional specimen and to obtain data for comparison with gasoline powered version of the engine. The paper considers mainly the problems which were observed during settings of control parameters for CNG and which could happen in serial operation. The article shows controls employed by the ECU for CNG operation and its manipulation with values for gasoline unit and describes basic principles of Sequent Fastness fuel system functions. It is here summarized which way of parameter settings for CNG could be as the most convenient.

Key words: CNG, gas engine, ECU settings

1. INTRODUCTION

Automotive gaseous fuel engines can be equipped with all sorts of fueling systems, starting with a mixing device and engine with injection of the gaseous fuel into individual intake ports via electromagnetically controlled valves. Mixing devices cause a higher pressure drop in the intake, therefore, multi-point injection into the intake is preferable from the point of engine power.

Fuel injection into the intake manifold is the sole method used with engines equipped with EOBD on-board diagnostics. The injector valves can be controlled by the original engine control unit, or by an auxiliary unit which only controls the accessories for the gaseous fuel. In the case of two control units the entire system is more complicated and required a good communication and interplay between the original and the auxiliary unit. This configuration is typical for conversion kits, such as the Sequent Fastness system, which was tested in our laboratory on a 40-kW Škoda Auto HTP engine.

2. TESTED ENGINE

The Škoda Auto 1.2 HTP/40 kW EA111.03D belongs to the new generation of powertrains developed and manufactured by Škoda Auto, a.s., for Škoda Fabia cars and other vehicles of the Volkswagen group. The HTP (High Torque Performance) designation denotes one of the features of the engine, which is its high torque of 108 Nm (80 ft-lb.) achieved already at 3000 rpm. Škoda 1.2 HTP - 40 kW is an inline liquid-cooled atmospheric three cylinder gasoline powered spark ignition engine with four main crankshaft bearings, one counterbalancing shaft. Main parameters are displacement 1198 cm3, bore 76,5 mm, stroke 86,9 mm, compression ratio 10,3 : 1. It is equipped with contactless electronic ignition with three coils placed over the spark plugs, sequential multi-point injection of fuel before the intake valves, an electronic regulation of the throttle without a mechanical link with the throttle pedal, and with three-way catalyst and two exhaust gas oxygen sensors.

The fuel pump, gasoline injection, throttle plate and the fuel tank vent electromagnetic valve are controlled by a SIMOS 3PG electronic control unit (ECU), which also monitors and tracks the position of various parts of the engine. The EA 111.03D engine at the departmental laboratory was originally equipped with a SIMOS 3PG ECU into which data was uploaded using a MODAC system. A new ECU SIMOS 9 (prepared by Škoda Auto) was then installed with gasoline injectors operating at 4 bar (59 psi) pressure. BOSCH 7A spark plugs were used.

3. CNG FUEL SYSTEM

BRC Sequent Fastness (M.T.M., Italy) was used as a CNG fueling system. It is a sequential muti point gaseous fuel injection system. The injectors are installed on the intake manifold and fed from the pressure reduction valve by rubber hoses. The system is connected to the original wiring harness, and connects to the engine rpm, exhaust gas oxygen sensor upstream of the catalyst, individual gasoline fuel injectors, and throttle plate control signals. The injectors are placed on a common fuel rail with shared fuel gas pressure and temperature sensors.

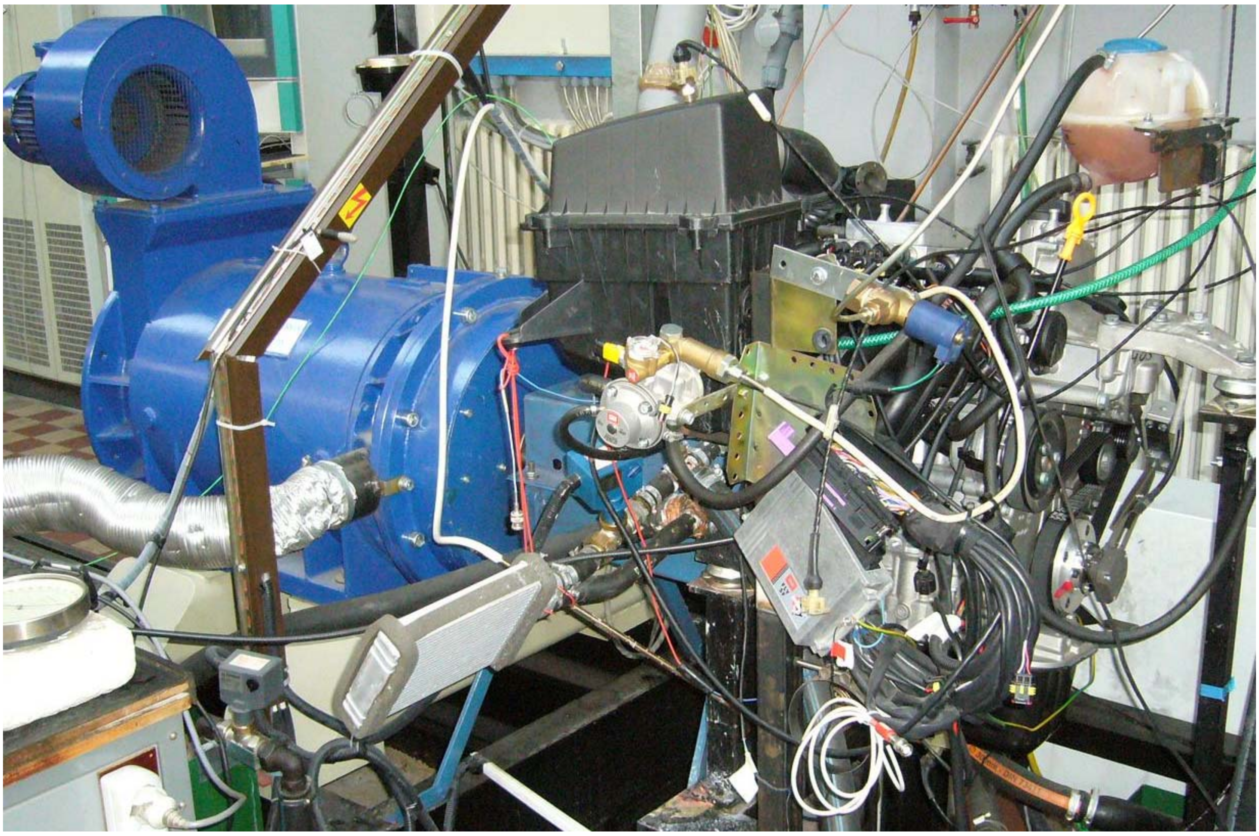

Figure 1 *Tested engine ŠA1.2 HTP and dynamometer ASD 235 on the test stand in laboratory KVM.*

Figure 2 *Detail of CNG common rail with CNG injectors, which was displaced close to cylinder head and original fuel rail for gasoline.*

The fueling system was delivered with software for both diagnostics and for calibration and optimalization of the ECU for operation on CNG. User-settable parameters included air-fuel ratio and ignition timing settings, and conditions under which the system reverts to gasoline operation.

4. MEASUREMENTS

The EA 111.03D engine was installed at the KVM FS TUL laboratory on test stand no. 6 equipped with a ASD 235 asynchronous engine dynamometer (Mezservis) and with automated electronic data acquisition system for recording operating conditions, emissions, and indicated pressure inside no. 3 cylinder.

The following tests were conducted:

- an 8-point torque curve for 95-octane gasoline (BA 95) and CNG operation
- 3000 and 5000 rpm 7-point load curves for BA 95 and CNG.

5. CNG ECU ADJUSTMENT

The engine was run according to the gasoline ECU settings during operation on gasoline. Prior to the operation on CNG, the CNG ECU was calibrated with the signals for throttle position sensor, engine rpm, and manufold absolute pressure using software and methodology provided to the laboratory by the M.T.M. representative.

An initial calibration of the system was then performed during operation in three selected points (idle, idle with a mild load, and 3000 rpm without a load) on gasoline and subsequently on CNG, in order to develop conversion factors which will be then applied to obtain CNG fueling rates from commanded gasoline fueling rates.

After the initial calibration, a secondary calibration was performed, during which air-fuel ratio and ignition timing has been adjusted. (Compared to gasoline, operation on CNG uses lesser enrichment and is at close to stoichiometric air-fuel ratios.) The air-fuel ratio correction factors were adjusted to λ = 0,92-0,96 at full torque, which is similar to gasoline operation. The reason for the enrichment is the decrease of the exhaust gas temperatures in the catalyst in order to protect the catalyst, which is located close to the exhaust manifold. The engine was thus initially controlled, during operation on CNG, by optimized air-fuel ratio. The air-fuel ratio correction factors are set in one map based on engine rpm and throttle position in three areas: Closed-loop operation with no enrichment using exhaust gas oxygen (EGO) sensor, open-loop operation where EGO sensor is disregarded, and enrichment is applied based on engine torque and exhaust gas temperatures, and intermediate region between these two areas, where the EGO sensor feedback loop might or might not be operational and where the correction factors are set based on experience. Ignition timing was identical for both fuels, as timing correction feature was not fully operational on the CNG unit. An original assumption that the engine can operate on CNG according to gasoline engine settings was determined, during experimental measurements, to be risky considering high exhaust gas temperatures, and to yield low power due to enrichment at full load. Measurements were thus taken only at several points. For subsequent measurement, an upgraded software for the CNG ECU with timing adjustment capabilities was installed. For CNG operation, the ignition was advanced, compared to gasoline operation, 3 crankshaft degrees at low, 6 degrees at medium, and 9 degrees at high load, which was the initial adjustment made by a M.T.M. technician. The correction factors are set in a map according to engine rpm and intake manifold absolute pressure.

The last approach at ECU settings was to minimize all correction factors, notably the correction of ignition timing. The operational parameters of the gasoline converted to CNG are showin in Figures 3 and 4.

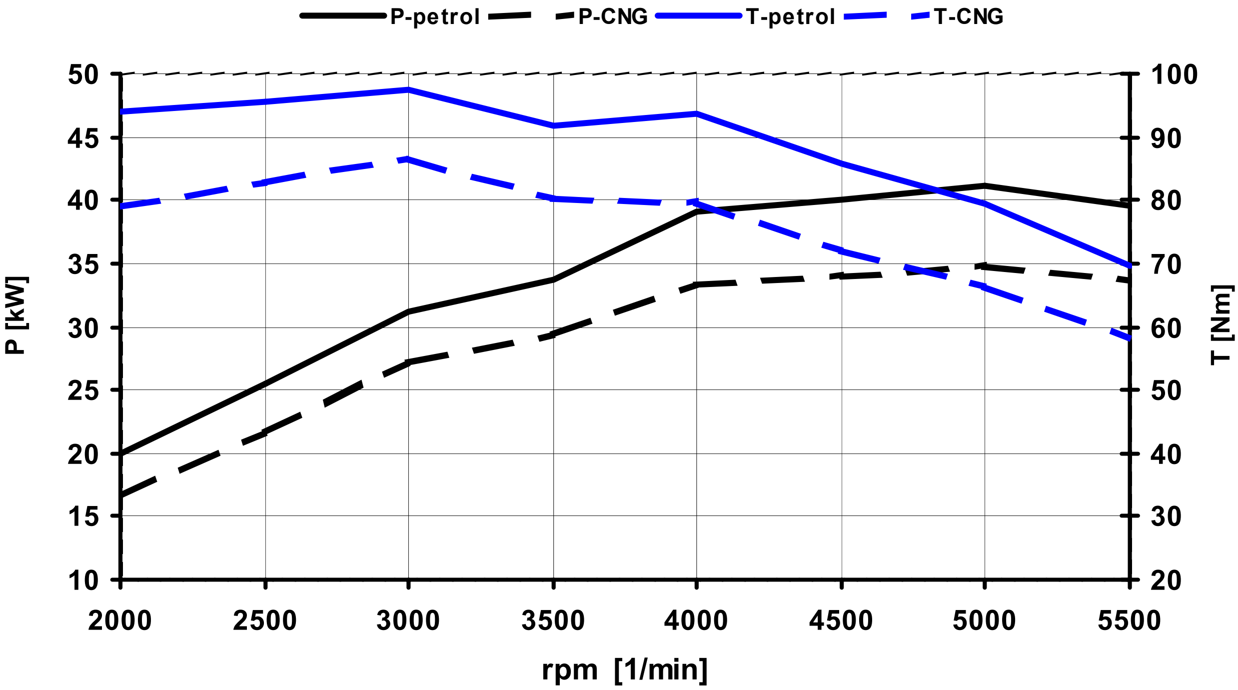

Figure 3 *Comparison of engine power and torque for gasoline (petrol, solid line) and CNG (dashed line) operation at full load.*

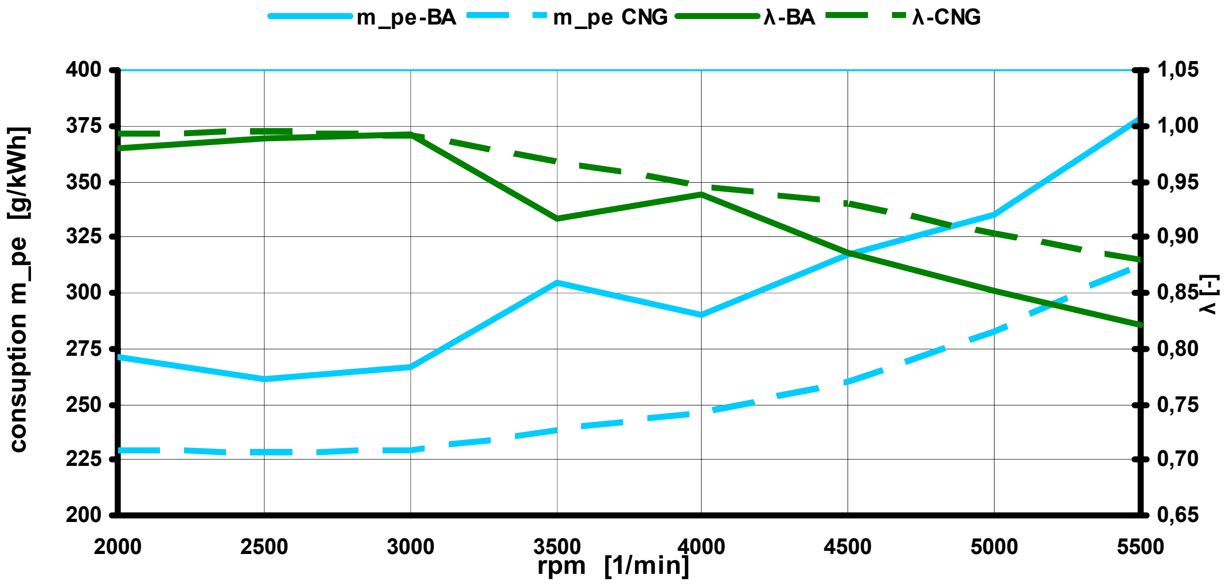

Figure 4 *Comparison of brake-specific fuel consumption and air-fuel ratio for gasoline (petrol, solid line) and CNG (dashed line) operation at full load.*

6. TROUBLES EXPERIENCED DURING OPERATION OF THE ENGINE ON CNG

Since the initial calibration of the CNG ECU the regulation was unstable – high enrichment was observed during decrease of load at constant rpm, resulting in a misfire on one cylinder which was then subsequently disabled. These problems were resolved after a consultation with a M.T.M. technician and new basic calibration of the unit. Also, steady-state operation at low load was problematic, as the most critical variable – intake manifold pressure – varied due to the dynamometer constant rpm regulation: Either the load and MAP were too low, or the rpm were too high. The automatic calibration thus could not have been accomplished. This was resolved by running at 1000 rpm in lieu of idle rpm.

Another major problem experienced were unstable transitions from high loads to idle. The engine rpm decreased to around six hundred, after which the engine had to be shut down as it was running erratically and the accessories belt was slipping. These regimes were then avoided, until it was discovered during subsequent testing that the engine operates at closed loop, but the fueling rate correction is as high as 28% instead of the ±15% limit. Such high enrichment was problematic for the gasoline ECU. This operating area was then redesignated as open loop with a correction factor of zero, so that the feedback control can be accomplished within the ±15% limit. After this correction of low rpm regimes the transitions to idle were flawless. This has also resolved an ECU low fuel level warning.

The maximum torque has increased after the implementation of the ignition timing corrections, but this has also resulted in frequent ECU errors of unreliable crankshaft and camshaft position sensors. The gasoline ECU has then probably delayed the ignition timing to avoid knock, as shift in timing was observed. No solution of this problem was found. It is believed that the culprit is the additional connection of sensor outputs to CNG ECU, which could have altered the signal received by the gasoline ECU. Neither the driving principle behind gasoline ECU timing setting was found. A plausible explanation is that the CNG ECU crankshaft or camshaft position signal is shifted by an angle corresponding to the desired correction. This could also have caused the problems as the gasoline ECU constantly monitors crankshaft and camshaft position and the alteration of the signal has been interpreted as an excessive disagreement, such as if the timing belt would have skipped a tooth. It is therefore deemed advisable to avoid such corrections for CNG operation, and in case of serial production of such engine, use the gasoline ECU to control the ignition timing.

The Fastness wiring harness contains an EGO sensor connection, but since the fuel metering is controlled by the gasoline ECU, this connection is only orientative, and no changes in operation were observed after it was disconnected. As the EGO sensor output would be split between gasoline and CNG ECUs, just like the engine rpm sensor, its connection is not recommended considering the stability of the engine.

The Fastness software allows for setting of the conditions under which the fuel is switched. The pressure reduction valve, cooled by the expanding fuel gas, is heated by the engine coolant. CNG operation is therefore allowed only after a set time has elapsed since the engine start, a minimum of two seconds, and after the coolant has reached a set temperature, a mininum of 15°C (59°F). The unit can thus be programmed to switch to CNG almost immediately after the engine starts, but the engine cannot be started on CNG. Our experience with bus engines demonstrates that engines can be started on CNG at stiochiometric air-fuel ratio; therefore, the ability of the system to start the engine on gaseous fuel is recommended.

6. CONCLUSIONS

A 1.2 HTP engine was converted to operation on CNG using a Sequent Fastness system. Several problems has occured during testing of this engine, which could also happen during ordinary use. The most critical one was unstable operation after transition to idle and somewhat troublesome ignition timing regulation with frequent errors logged into the gasoline ECU. Both of these problems were caused by not quite appropriate setting of the CNG ECU parameters. Calibration of the fuel system requires experience and should be done with great care, especially for ignition timing corrections.

The approach deemed most appropriate is one of regulation of air-fuel mixture using a CNG ECU and setting of ignition timing for both fuels in the gasoline ECU. This, however, requires a change in the gasoline ECU settings. This might still be the most feasible way for mass-produced CNG engines. Operation on gasoline should then be limited to engine starts and emergency travel should one run out of CNG. Optimization of ignition timing for CNG will result in less than optimal performance on gasoline both in terms of power and emissions. The engine exhibits slightly reduced power while running on CNG. This is not due to the fuel system accessories, but to the different properties of CNG and gasoline. Despite the observed problems, Fastness appears to be a well refined system, which can be recommended for aftermarket conversion or, in case of interest from automobile manufacturers, for factory use.