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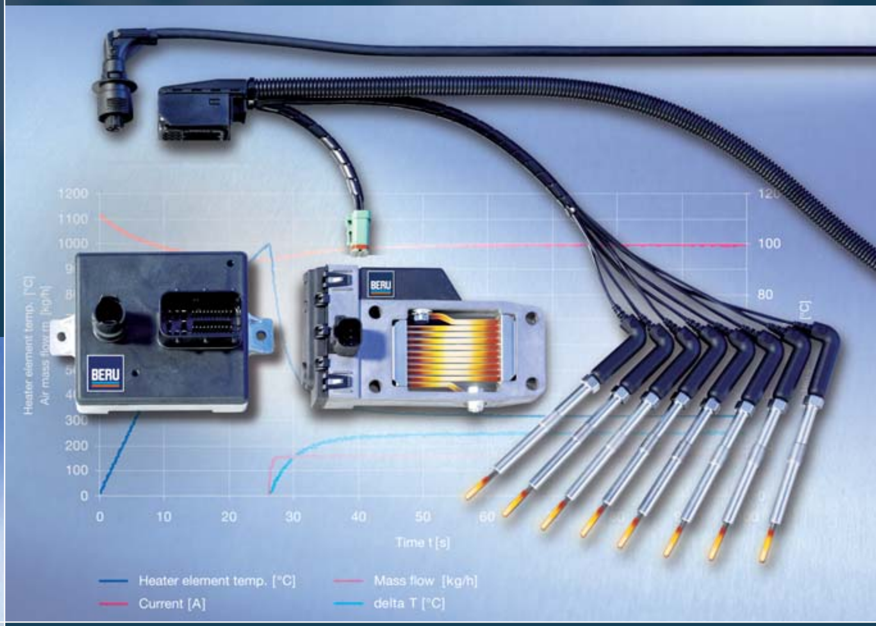

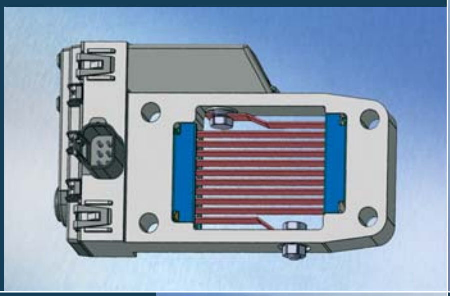

Beru second generation ISS diesel cold start technology with pre-heated intake air

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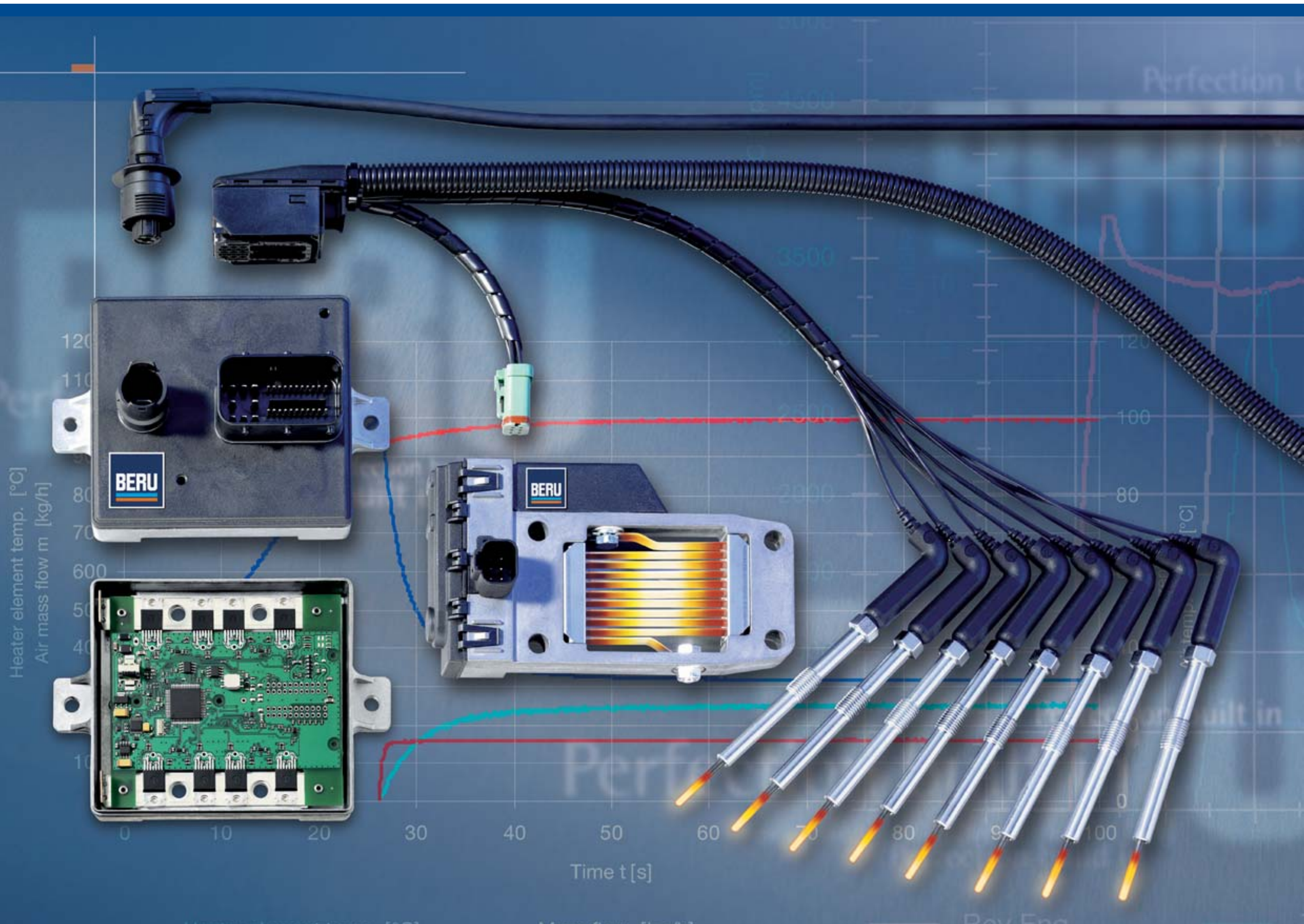
BERU

Second Generation ISS Diesel Cold Start Technology
with Pre-heated Intake Air

Market share in diesel engines has almost reached the 50 percent mark in Europe, and, in the USA, is increasing at a much more significant rate than that of petrol hybrids. Increasingly strict emission limits, coupled with endeavors to continue reductions in fuel consumption, are already indicating significant effects on future diesel engine design. Beru AG is taking account of this development with its enhanced Instant Start System (ISS).



1 Introduction

As an air-compressing, quality regulated, auto-ignition aggregate, a diesel engine needs some basic physical conditions in order to operate. For auto ignition systems, the temperature of the air at the moment of injection is very important. The compression temperature depends on a huge number of influencing factors, the most significant of which are the compression ratio and the combustion systems.

As a result of heat loss during flow through the injection channels, the gas temperature in antechamber and turbulence chamber engines are able only to reach levels at which starting assistance is required, even at normal ambient temperatures. In direct injection diesel engines the limiting start temperature without starting assistance is much lower and depends more on the starter speed, the blow-by and the injection application [2].

The cold start assistance that has dominated for years is represented by the glow plug which effects safe ignition of the fuel-air mixture up to displacements of around 1 dm^3 per cylinder [1]. For larger displacements the intake air is heated by flame glow plugs and, in future, heater flanges will increasingly take on this task.

In the battle to reduce consumption and emissions from diesel engines many developments are currently taking place in the engine interior: lower engine displacement, reduced compression ratio, higher boost rate, higher and cooler AGR rate, higher pressure, injection system flexibility and alternative combustion procedures to reduce NO_x.

However out of these concepts, which promise successful emission reduction, a whole series of new tasks arise:

- The trend of reduced compression ratio will intensify the problem of cold start capability.
- Additional functions such as intermediate heating and diesel particle filter regeneration heating, and expanded OBD requirements, are placing greater service life requirements on the glow plugs.
- In future, likely test cycles at -7°C will require, for example, higher glow plug temperatures, longer post-heating times and the use of a heater flange.

2 The ISS Cold Start System

As early as 2000 (see MTZ 61, 10/2000) Beru AG announced the series production of its electronically controlled ISS Instant Start System. This cold start system guarantees – even at extremely low temperatures of -25°C – an "SI engine-like key start", stable idling, proper acceleration and low emissions [3]. At BMW the ISS has been incorporated into series production since 2001 [4]; and since that time AMG, Audi, Chevrolet, GM, Isuzu, Jeep, Mercedes, Seat, Skoda and VW have also started to fit their diesel models with ISS. US manufacturer General Motors has been using ISS in its light trucks since 2004.

2.1 First Generation System

The ISS Instant Start System, **Figure 1**, consists of power electronic components and several quick start glow plugs. Beru developed these special ISS glow plugs on the basis of the self-regulating metal glow plugs. The power electronic component is a control unit designed as a module, capable of being attached to aggregates with up to eight cylinders (glow plugs). The engineering and electronics are designed to suit the thermal and mechanical conditions at the engine unit.

2.2 Function of the Control Unit

The glow plugs are impinged with currents of up to 35 A per load circuit and operated according to power parameters preset on the control unit. The heat loss incurred while the power electronic component is in operation is distributed through the ceramic circuit carrier and absorbed by an aluminum base all the while the glowing process is required. In this way operation is assured up to an ambient temperature of +125 °C, without the control unit becoming subject to outside influence.

2.3 Controlling the Heating Function

A programmed micro-controller ensures that the low-voltage glow plugs heat rapidly and operate under control. It takes account of cooling in the combustion chamber – for example caused by the engine speed – as well as other important parameters such as thermal drag-in from combustion under heavy load, and the coolant temperature. To do this, the application determines the relevant operating conditions inside the vehicle, on the engine test bench and on the road, with the aid of temperature measurement glow plugs, storing the relevant data on the control unit. Depending on its version, the control unit has a PWM, LIN or CAN interface to the engine control system. The actuating engine data required is thus transmitted and included in the calculation. To this end the control unit contains several models to reflect the heating and cooling behavior of the glow plugs.

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3 Second Generation ISS Cold Start System

The second generation introduced a logical enhancement to the proven ISS – an integral intake air heating system, **Figure 2**. Unlike the glow plug, which creates the purely local ignition conditions for the air-fuel mixture, a heater flange increases the temperature of the air flowing into the cylinder, thus producing better conditions for fuel ignition throughout. The design changes required a redesigned housing of the control unit and extended the previous functions. This technology is currently mainly used for Heavy

Figure 1: The first generation Beru ISS diesel cold-start system has, since 2001, supplied an "SI engine-like key start" in series production – even at extremely low temperatures of -25oC

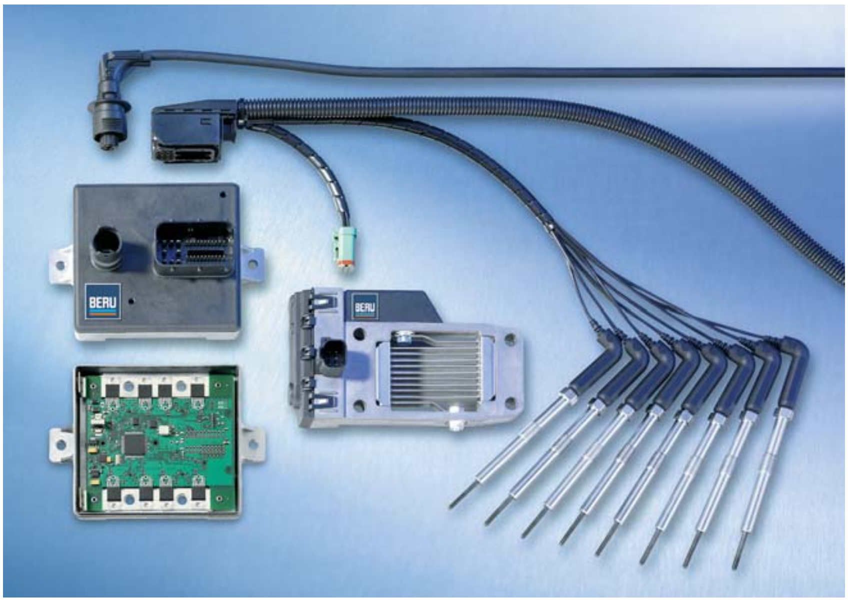

Figure 2: The second generation Beru ISS diesel cold-start system with new control unit and additional heater flange further reduces fuel consumption and emissions

Duty and Light Duty Trucks [5]. However, the future requirements of diesel engines mentioned above mean that we can expect this method to move into passenger vehicles.

In the second generation ISS the control unit controls the glow plug quick start function, and also provides optimum actuation to the heater flange in communication with the engine control unit. The additional heating of the intake air changes the effect of the system in the following ways:

- it improves start capacity at low temperatures
- it improves engine run up
- it stabilizes idling during the warm-up phase
- it reduces pollutant emissions and fuel consumption during the warm-up phase
- it increases electrical load on the engine, better aiding diesel particle filter regeneration in low consumption ranges.

3.1 Structure of the Heating Element

The central element of a heater flange is the heating tape. The necessary power can be represented by carefully selecting the alloy used for the heat conductor (specific electrical resistance) and by means of the size (L x W x H) of the heating tape. The design limitations derive mainly from the assembly area allowed and in the thickness of material (maximum surface load). The design of the heating tape indicates a resistance drop of approximately 20 per cent (ratio of turn-on power at T_{umg} to steady state power at approximately 1,000 °C).

The heating element is supported by ceramic insulators, plate springs and sockets on an aluminum frame. The plate springs ensure that the heating tape is pre-tensioned between the insulators, while also taking up the expansion in length of the heating element while in operation, **Figure 3**.

Depending on requirements the heater flange is either single or double pole. Depending on customer wishes, it is applied as either adaptor flange or module solution.

3.2 Integrating the Electronics

In order to adapt the power output to the relevant engine or driving situation, an electronic switch has also been incorporated. This ensures that the control unit impinges the heater flange with current as soon as it detects, from the engine parameters it has determined, that additional air heating is required. A power semi-conductor switch (MOSFET) with corresponding protective circuit actuates the unit. Signal and control lines connect the heater flange to the control unit, and transmit the following input signals to the heater:

- input signal 1 – pulse width modulation (PWM)
  PWM modulation actuation ensures infinitely variable heating power to correspond to the demand from the control unit.
- input signal 2 – heartbeat
  This is an alternating signal. If it is not present at the heater flange, the PWM signal does not switch through and the heater flange remains non operational.

The heater flange communicates with the control unit, providing functional parameters of voltage, current, temperature on the PCB as well as a digital feedback as to whether the heater flange is in cycle or not.

3.3 Second Generation Control Unit

Beru was asked to develop a start assistance system for an American customer to comply with the extended diagnostic requirements (OBD2) set by the California Air Research Board (CARB). These require any reduced function in a component within the start assistance system, apart from failure, to be displayed. This version has been in series production since 2005.

As a result of the commission, Beru designers designed a starting assistance control unit, which can be fitted on the engine, and which communicates with the components on the drive train via a customer-specified CAN interface, actuating eight glow plugs and a diagnosable heater flange.

The control unit developed for this commission, **Figure 4**, is built on an aluminum base; the cover has an integral high current plug to supply the eight glow plugs, and a 30-pin plug containing all the signal cables as well as the eight glow plug outputs. The plug complies with the widely used 54-pin "small" plug used in engine control systems, but only two rows of signal pins are used in this case.

The decision to use a high-temperature FR4 PCB as the circuit carrier made it necessary to fit the power semi-conductors on separate power rails. Using proven Beru resistance welding technology, the power semiconductors are welded directly to the conductive elements. The temperature is spread via the metal power rails.

3.4 Function of the Starting Assistance System

In this modified version too, the micro-controller controls the glow plugs, continually monitors their function throughout operation, and transmits any faults arising to the drive train CAN-BUS.

Besides reporting excess current and open load circuits, the integral adjusted voltage and current measurement unit also provides detailed diagnosis of the glow plugs in order to ascertain their operating condition. The control unit takes into account the glow plug model as well as the data known to the control unit from previous actuations.

The power required for the correct glow plug temperature is calculated from data received from the data bus (engine speed, injection quantity and coolant temperature) and is then passed on via a separate power switch. The current through the glow plugs is constantly monitored and any drop in voltage is corrected via the line.

Another function implemented in the quick-start system protects against thermal overload on the glow plugs when the ignition key is actuated repeatedly at close intervals (repeated start). The necessary heating energy can be determined from the glow plug model implemented in the system, and from the known history of the heating functionality as stored in the control unit, and then applied to the glow plugs. This "dynamic repeat heating function" ensures that, even in the case described, the glow plugs are at the correct temperature when the engine is started.

The control unit actuates and monitors the heater flange installed in the intake section. In this way the heated air helps to reduce emissions on starting the engine and during the run-up phase. Special engines with reduced compression tend to produce increased visible emissions, effectively prohibiting this type of specific energy feed.

The interface between the start assistance control unit and the heater flange transmits data and allows secure diagnosis of the heater flange functions, switching off in the event of a fault.

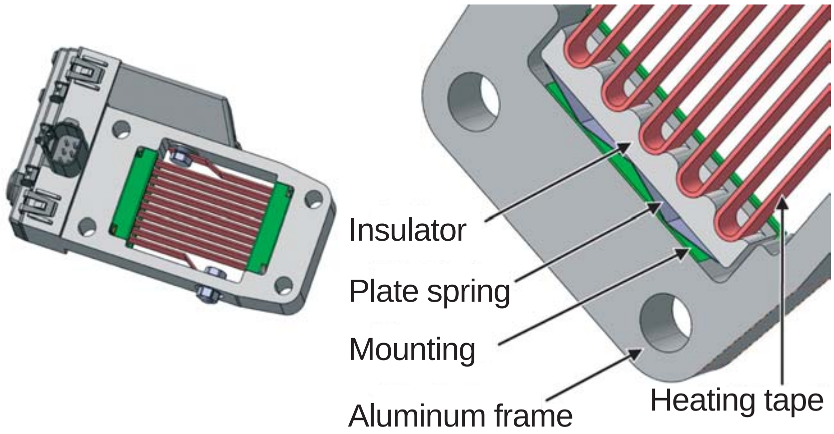

Figure 3: The heater flange added to the second generation ISS improves starting capacity and engine run-up at low temperatures

Figure 4: A view of the new ISS control unit, which can be fitted to the engine. It communicates with the drive train components via a customer-specified CAN interface, and controls the glow plugs and the heater flange

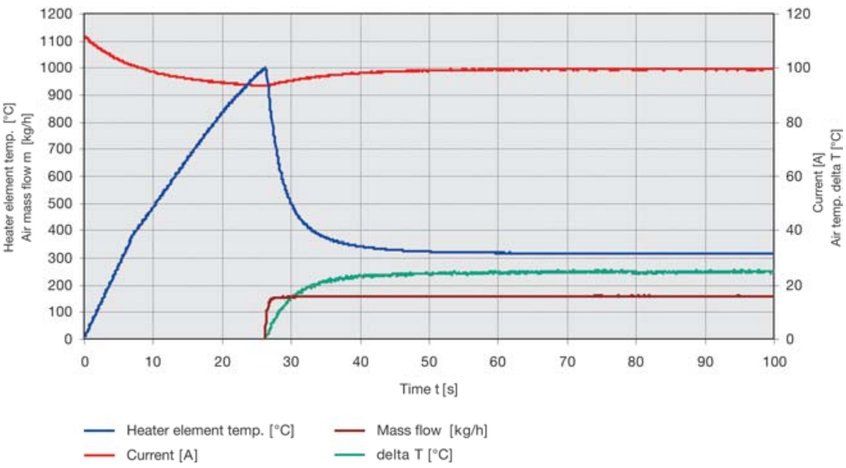

Figure 5: Laboratory measurements taken at a heater flange to illustrate the transfer of electrical energy into thermal energy

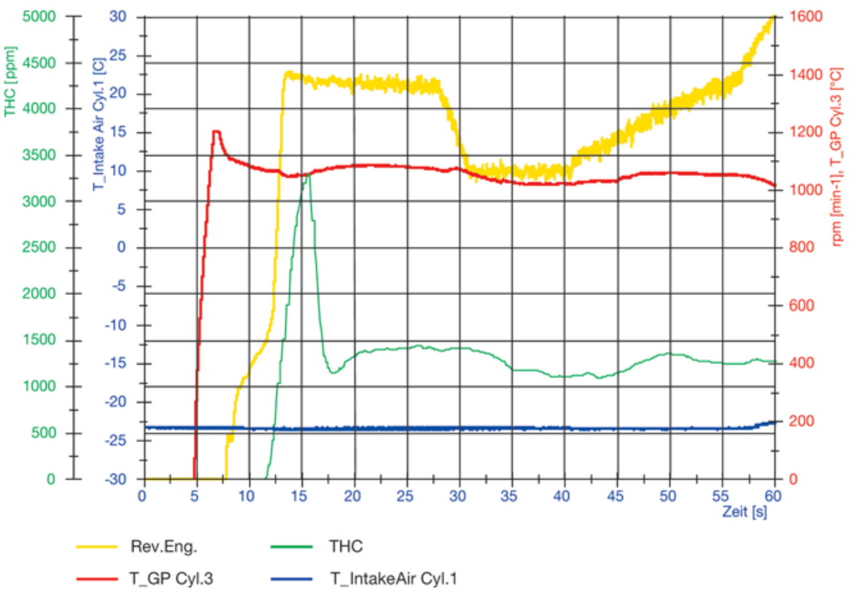

Figure 6: Measurement of HC emissions at -24 °C on engine test bench using an FID (Flame Ionization Detector) – without heater flange

At high currents of up to 320 A at the glow plugs and over 120 A at the heater flange, supply line inductivity means that measures are required to ensure operation with low feedback to the on-board power supply. A patented process ensures that the glow plugs and the heater flange are actuated in an interlaced manner, and that the most constant current possible is taken from the vehicle power supply. So, for example, when the high current to the intake air pre-heater is switched off, the glow plug's pulse width modulation is synchronized in such a way that the negative current gradient is minimized and inductive interference does not occur at the onboard power supply.

3.5 Programming the Control Unit

Since the starting assistance control unit is an engine sub-system, it is fitted when the engine is manufactured, complete with the necessary engine cable harness. At this time the engine control unit has not yet been incorporated, as a part of vehicle chassis, into the system. It will be connected to the quick-start system at the automotive plant. Therefore the absence of the starting aid system already active at the engine plant can be used to store engine data into the EEPROM. For example the characteristics of the Common Rail Diesel Injection injectors can be defined individually to every engine. These parameters, determined at the engine plant, are temporarily stored in the non-volatile memory of the starting aid system.

At the automotive plant these data are then available for the injection electronics, can be called up via the CAN bus service function, and then applied to the engine control system.

4 Measuring Results on the New ISS

The typical heating behavior of a heater flange with a power take up of approximately 1.1 kW is illustrated in laboratory measurements; an unmistakable reduction in temperature of the heating element after applying an air mass flow rate of approximately 160 kg/h, shows that this design of heater flange successfully transfers electrical energy into thermal energy, **Figure 5**.

To test the HC emission behavior cold-start tests were carried out on various diesel engines ranging from 4 cylinder engines with cubic capacity of 0.5 dm^3, to 6 and 8 cylinder aggregates with approximately 1 dm^3 cubic capacity.

The illustration below, **Figure 6**, shows some sample cold-start measurements at -24 °C made on a 2.2 liter four cylinder series engine with a compression ratio of ε = 17. The HC measurements were made using an FID (Flame Ionization Detector). For comparative purposes some of the series of measurements were made with the glow plugs switched on, and other measurement series were made with the heater flange also switched on, **Figure 7**.

On the Instant Start System with only the glow plugs switched on, the engine starts spontaneously, the run-up is clean, and is followed by increased idling. Some 20 seconds after start-up the engine falls back to normal idling speed. Shortly after the start-up, HC emissions measure to a maximum value of just less than 3,500 ppm, which then falls back to a range between 1,000 and 1,500 ppm.

With the heater flange also switched on, the engine run-up reduces from the moment the starter is operated, and is represented subjectively as being much more dynamic. The maximum value of the HC exhaust emissions after start reduces by more than half. As the warm-up continues, this tendency to reduce emissions increases.

The operating cycles indicating incomplete combustion or increased firing delay

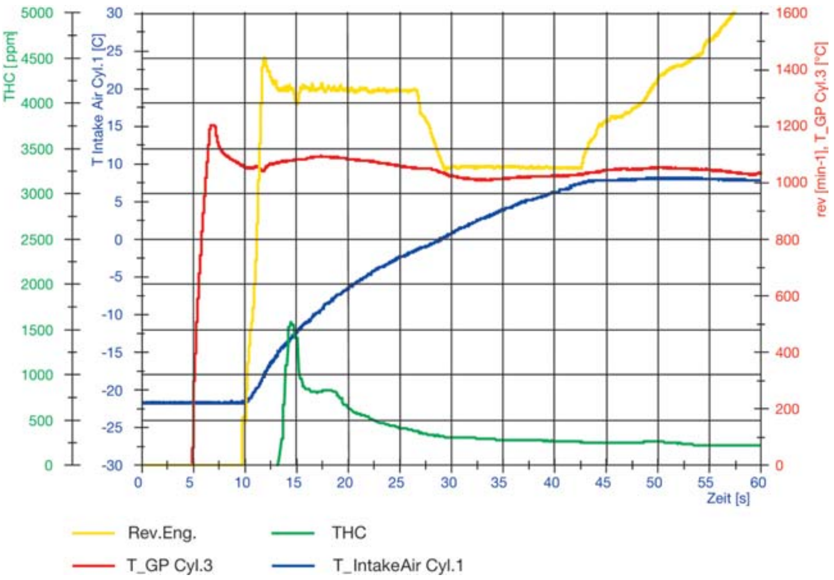

Figure 7: Measurement of HC emissions at -24 °C on engine test bench using an FID (Flame Ionization Detector) – with heater flange. The engine run-up is reduced and is more dynamic; HC exhaust emissions fall by more than half

and the resultant speed fluctuations are greatly reduced. Thus the noticeable lack of driver comfort caused by vibrations on the drive train is drastically reduced when the heater flange is switched on.

The measurements clearly show the effective interplay between the cold-start components – the glow plugs, glow plug control unit and heater flange in Beru's second generation ISS system.

5 Summary and Outlook

Future emission requirements of diesel engines have a noticeable effect on the design and process management for the next generation of engines. These indicate a much lower compression ratio and improved combustion processes, with lower raw emissions of NO_X. At the same time the comfort requirements of a cold start and additional functions such as intermediate heating and DPF regeneration heating increase life cycle requirements.

Beru AG has already developed an appropriate solution to meet these market needs. The second generation ISS quick-start system with electronic control described here does not require pre-heating period, even at very low temperatures, setting the required glow plug temperature to correspond with the engine's operating point. At the same time it meets the increased OBD requirements, particularly in the USA.

The heater flange, which is much used in the vans and light truck sector to pre-heat intake air, will move into the passenger vehicle light-duty sector. Thus, quick start with very low emissions can be achieved with ISS glow plugs, together with very comfortable engine concentricity. A system is currently in series manufacture, which actuates the ISS glow plugs and the heater flange via a control unit.

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