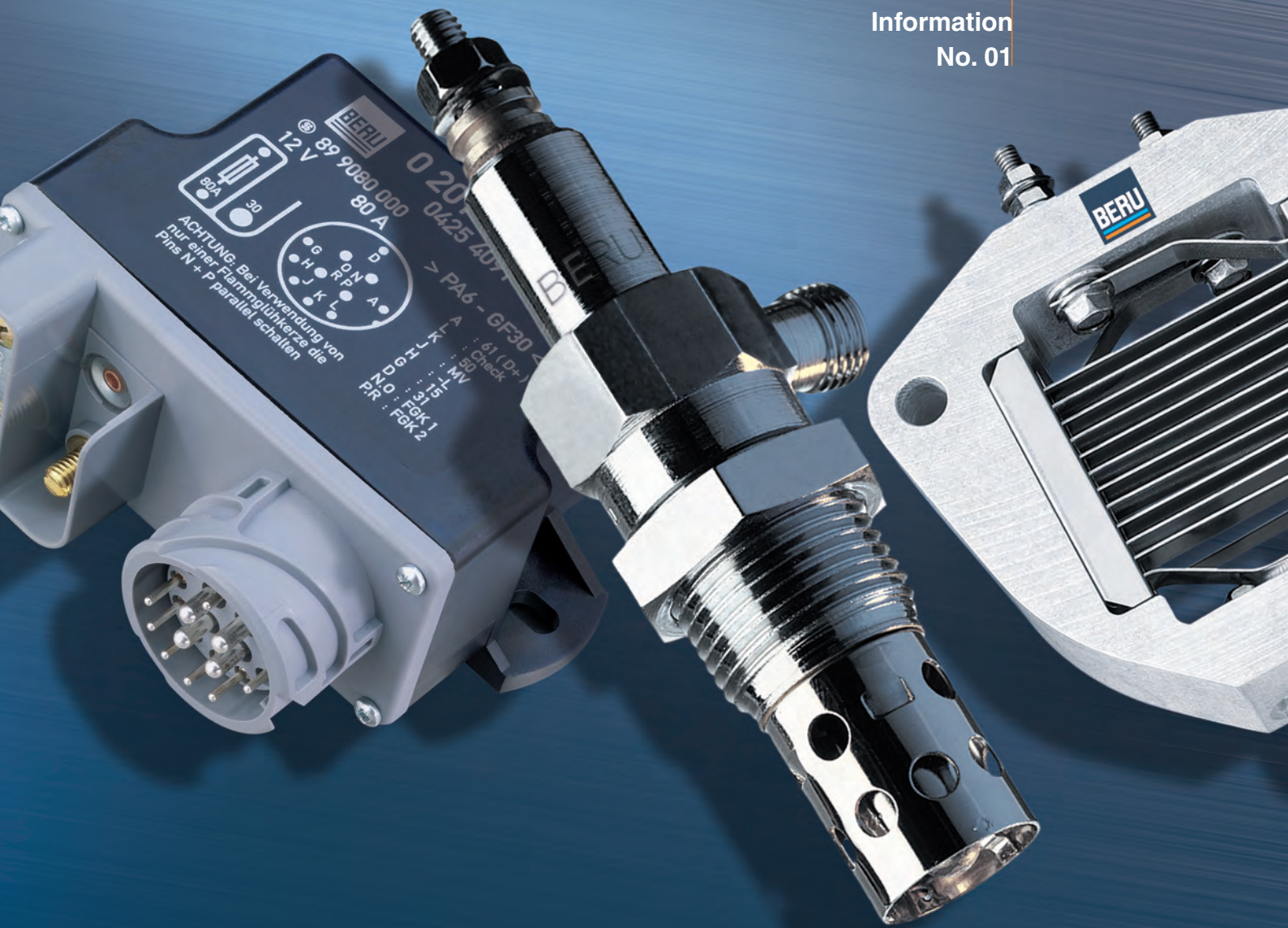


# Cold start aids for commercial vehicles

Technical  
Information  
No. 01



# Foreword

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The development of the automobile is also the success story of the Beru company. Today automobiles would be inconceivable without the Diesel engine, originally thought to be only an especially economic drive for commercial vehicles and tractors. And this triumphal procession of the compression ignition engine was decisively codetermined by Beru – also documented by numerous innovations and patents.

In the more than 90 years of its existence the Beru company has advanced from pure spark plug manufacturer to one of the most important suppliers for cold-start system technology. For more than 70 years Beru glow plugs and starting systems guarantee a reliable cold start of the Diesel engine – even at extremely low temperatures.

A team of glow system engineers works in the Beru headquarters in Ludwigsburg on the permanent optimization of starting quality and exhaust gas values. The corresponding systems for intake air preheating are provided in every truck. The electrically operated heating flanges for the well-known flame starting system have been further developed and supplement the product line.

This Technical Information provides a first overview of the range of supplies and services of the Beru AG in the Diesel cold-starting sector. Our team is pleased to be at your disposal for more information and technical details.



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# The theory of the diesel cold start

## The starting process

To enable the injected fuel to ignite in the compressed air it must be heated to a level above a specific threshold temperature. This requires a number of engine revolutions. Below this temperature the engine cannot be started without a starting aid.

## Starting aid

There are a number of alternatives which offer themselves as an aid to starting: for example initial ignition by a glow plug in the main or precombustion chamber (prechamber or swirl chamber) or air heating by electrical heating elements such as filament glow plugs, heating flange or combustion systems, e.g. rod flame glow plugs in the induction manifold. This would ensure a reliable start by introducing warm air even at low temperatures. In addition, the exhaust emissions and the noise created by the Diesel engine would be reduced during the start and warm-up phase.

## Necessity of the „cold-start aid“

It is true that the Diesel engine is also known under the term of „self-igniter“. However: Under wintry conditions the start is made difficult or even impossible without a starting aid.

A look at the combustion process explains this. If one presupposes optimization of injection position, spray and timing, then viewed simplified only the temperature at the end of the compression still plays a decisive role.

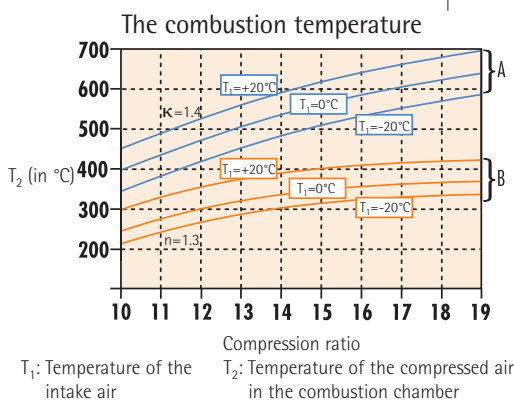
According to engine, normally 450 °C - 500 °C are sufficient for reliable ignition.

Under idealized conditions only the temperature of the induced air and the compression ratio resulting from the design have an influence on the final compression temperature.

However, in practice heat losses at pistons, cold cylinder walls and gas losses through the pistons rings "blow by" lead to the temperatures in the real process drop by approx. 150 °C compared with the ideal temperatures.

Thus it is no longer possible for the engine to start and starting aids must come into use.

Concepts for intake air heating with which even under arctic conditions a temperature sufficient for self-ignition can be guaranteed suggest themselves for the commercial vehicle engine, with its cylinder displacement clearly larger compared to the automobile.



### The adiabatic compression

$$T_1 = T_2 \cdot \epsilon^{\kappa-1}$$

$$\epsilon = \frac{V_H + V_K}{V_K}$$

$$\kappa = \frac{c_p}{c_v} = 1,4$$

für die Luft

- $T_1$ : Temperature of the intake air
- $T_2$ : Temperature of compressed air at the TDC
- A: Adiabatic compression (without losses)
- B: Actual compression (with losses)
- $\kappa$ : Adiabatic exponential
- $\epsilon$ : Compression ratio
- $V_H$ : Displacement volume
- $V_K$ : Compression volume
- $c_p$ : Spec. heat capacity at constant pressure
- $c_v$ : Spec. heat capacity at constant volume for the air

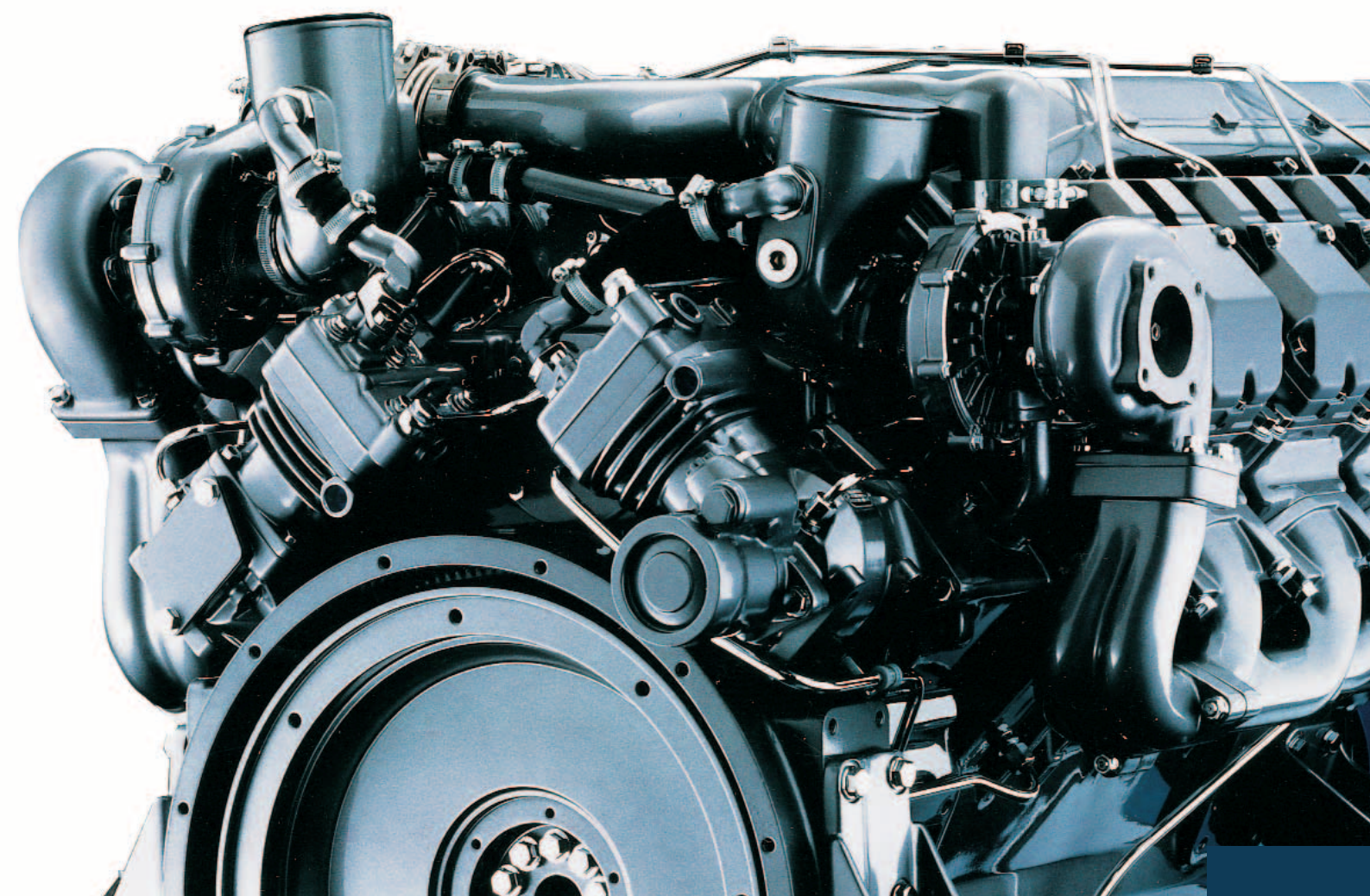
## □ *The clean start*

### Lower emissions during the warm-up phase

In addition to its original task of being an aid to starting, the cold-start systems have another major advantage: They reduce engine exhaust emissions. Beyond the start, they also remain operative during the warm-up phase and consequently reduce gaseous and solid exhaust emissions which can otherwise be seen in the form of white and blue smoke due to incomplete or delayed combustion. Depending upon the engine type and outside temperatures, this phase lasts up to 8 minutes.

### Corresponding future standards of exhaust levels

A further reduction of exhaust gas emissions is aimed at and accomplished in the three-stage plan of the European exhaust gas legislation. Therefore, increasingly stricter limits for the gaseous and solid components of exhaust emissions will also apply in three steps to commercial vehicle engines. The leading commercial vehicle manufacturers already offer engines whose performance has been optimized accordingly. Virtually all of these low-pollutant engines are also equipped with a cold-start system.



# Overview

□ *Different cold-start systems*

The high heating output required by engines with large displacement has led in the past to extensive penetration of the market by cold-start aids. The necessity for reducing nitrogen oxide at the beginning of the 1990s while retaining the mechanical injection systems led necessarily to lower compression and later start of delivery. The simultaneous requirement for acceptable starting quality has further encouraged the propagation of cold-start systems.

<p><b>„Direct starting aid“</b> Glow plugs</p> <ul style="list-style-type: none"> <li>■ Fast heating up</li> <li>■ Long life</li> <li>■ Compact dimensions</li> <li>■ Immediate starting</li> </ul>	<p><b>Flame start systems</b></p> <ul style="list-style-type: none"> <li>■ High heating output</li> <li>■ Low electrical power consumption</li> <li>■ „one fits all“</li> <li>■ Very effective for suppressing white smoke</li> </ul>	<p><b>Intake air preheating</b> Filament glow plugs</p> <ul style="list-style-type: none"> <li>■ Simple to apply</li> <li>■ Proven design</li> <li>■ Long service intervals</li> </ul>	<p><b>Heating flange</b></p> <ul style="list-style-type: none"> <li>■ Fast heating up (especially PTC)</li> <li>■ Long life</li> <li>■ Very effective for improving emission</li> </ul>
<p><b>Special features</b></p> <ul style="list-style-type: none"> <li>■ Restricted to smaller piston displacements</li> <li>■ Without cylinder head modification no retrofitting of existing engines without starting aid since then possible</li> </ul>	<ul style="list-style-type: none"> <li>■ The application must be matched in each case to the individual installation circumstances.</li> </ul>		

In the meantime the trend to units with electronic control with less swept volume, but also more powerful thanks to higher supercharging and injection pressures, predominates among commercial vehicles.

Today partially even less than 2 kW heat output are sufficient to improve drastically starting and emission even in the 8 liter engine.

## Choosing and adapting a cold-start system

### Careful planning pays off

When choosing the size and performance of the cold-start system and on installation the following aspects must be considered:

- Size of the engine displacement
- Installation and flow conditions in the intake manifold (especially for flame start)
- Required heating output
- Afterburn time
- Fuel pressure (for flame start)

### Calculating the required heating output

The volume of heat required to preheat the intake air can be calculated using the basic thermodynamic equations (see below). The calculation of the heating output must be performed for two different conditions: on one hand for the cold start, the starting mode with starter speed and on the other hand for the afterburn mode with correspondingly higher speed and air mass throughput.

### Test procedure

Once the decision has been made for a specific cold-start system output and a prototype has been manufactured, extensive tests are then carried out on the engine test field, in the cold room and finally also in the vehicle.

### The basic thermodynamic equations

Heat amount for heating up a mass:	$Q_{12} = m \cdot c_{pm} \int_{t_1}^{t_2} (t_2 - t_1)$
Assumptions:	$\rho \approx 1,51 \frac{\text{kg}}{\text{m}^3}$ $c_{pm} = 1,004 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$
Heat output:	$P = \frac{Q_{12}}{t}$ $P = \frac{\text{intake air mass}}{\text{seconds}} \cdot c_{pm} \cdot \Delta t$

$\rho$ : Density

$c_{pm}$ : average spec. heat capacity at constant pressure

P: Output

### Starting tests in the cold room



# The flame start system

## Change in the fuel flow volume

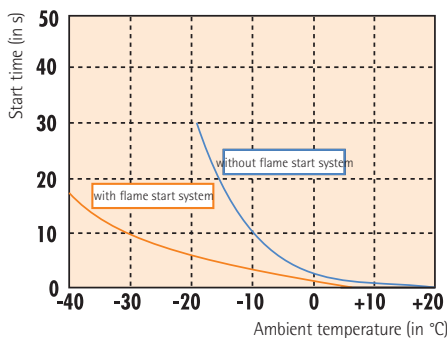
Plug heating output formula

$$P = H_U \cdot \dot{V} \cdot \rho \left[ \frac{\text{kJ} \cdot \text{m}^3 \cdot \text{kg}}{\text{kg} \cdot \text{s} \cdot \text{m}^3} \right]$$

Resolved according to fuel flow volume  $\dot{V} \left[ \frac{\text{cm}^3}{\text{min}} \right] \approx \frac{\text{required heat output [kW]}}{0,6017}$

Assumptions:  $H_U = 41031 \frac{\text{kJ}}{\text{kg}}$   $\rho$  Diesel density = 850 to 888  $\frac{\text{kg}}{\text{m}^3}$   
 $H_U$  = lower heating value

Start time as a function of ambient temperature



## Fuel volume and plug heating output

Once set, the fuel flow volume for the flame start system can be altered only by using a different plug. Smaller or larger nozzles must be selected, depending upon the required flow volume and the available fuel pressure. In this context, the pressure can vary depending upon the delivery point, it fluctuates between 0.2 and 1.7 bar, in Rails up to 6 bar. Normally the fuel is extracted either on the fuel filter overflow valve, from the return or alternatively after the pre-feed. In some circumstances a pressure reducer is required.

Including the warming-up phase in the heating has shown how advantageous the high output is. Thus in all cases a clear reduction of the gaseous emissions, primarily of the unburnt hydrocarbons, is achieved. Even in engines with large displacement a significant increase in temperature on the intake side could be achieved.

The volume of fuel which the flame glow plug requires can be calculated approximately on the basis of the required heat output. This is obtained, providing the ideal conditions of total combustion apply, by applying the above formula. A single-rod plug can burn up to 10 ccm/min, correspondingly twice the amount for two-rod flame glow plugs.

## Correct positioning

To prevent flame blow out when the engine is warming up or unburnt fuel from draining away when the engine is idling, both the correct fuel supply to the plug as well as its correct position in the inlet pipe are crucial. Before carrying out the installation the flow conditions and flow velocities at the installation site should be checked thoroughly. It is also important to use a plug with a suitable protective tube. In addition, in individual cases the amount of air required by the plug and the air available for combustion in the engine must be calculated by computer, particularly for engines with a piston displacement of less than 0.6 liters.



□ *The components of the flame start system*

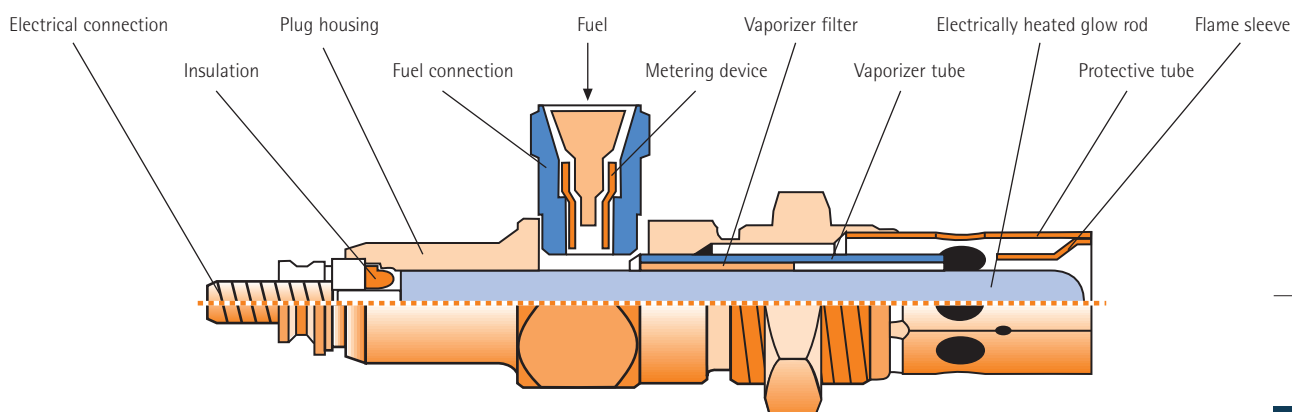
A flame start system consists of:

- one or more flame glow plugs
- a temperature sensor or temperature signal
- a solenoid valve
- a control unit
- an indicator light
- possibly a pressure reducer for the fuel supply
- optionally other accessories

□ *The flame glow plug*  
Design and function



In the front section of the vaporizer tube of the flame glow plug, the vaporized fuel mixes with the intake air and then ignites on the heater rod. In this context, the protective tube also serves to steady and stabilize the flame. The fuel volume burnt by the flame can be varied with the metering unit. The volume is determined by the throttle orifice in the metering unit and the existing fuel pressure. The specific fuel flow for each type of engine is determined on the test bench and this value used as a fixed factory setting for each flame glow plug.



# The flame start system



## □ The flame glow plug

### Technical data

Heat outputs: 2-10 kW with graduations of one kW  
 Preheating time: voltage-dependent, approx. 15-35 sec.  
 Ignition temperature: 950-1,050 °C

### Preheating time

Today the preheating time is approx. 20 seconds if the flame glow plug is operated with 11 or 23 volts. A rapid heating rod is used in the flame glow plug as heating filament. Because of the regulating properties of the material used, the current is limited in such a way that the high temperature does not damage the heating filament even if it is in operation for a number of minutes during the warm-up phase.

### Various types of plugs

Single-pole flame glow plugs are normally used; two-pole plugs are used on special vehicles. We also install 2-rod flame glow plugs in some larger engines requiring a high heat output.

## □ Accessories

### Connections and useful aids

Solenoid valve and rod flame glow plug are connected by a pipe consisting of commercially available components, e.g. self-cutting ring screw union for metal tubes or ring connection for plastic tubes. The link with the fuel system is also provided by such connections. Prefilters for solenoid valves and flame start glow plugs as well as a throttle unit for pressure reduction are available from Beru.

### Electrical isolation adapters for series installation

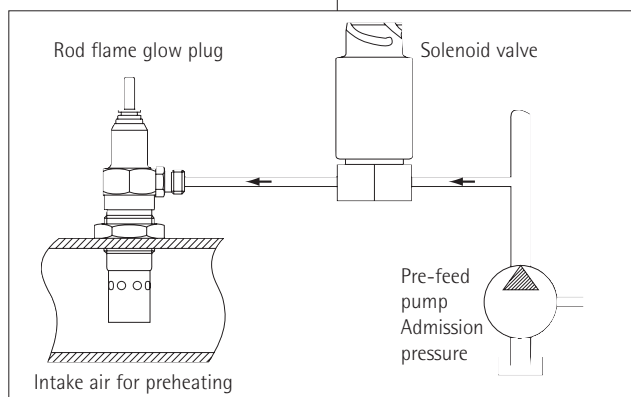
Electrical isolation adapters are now available as a special feature, enabling flame glow plugs to be used for series installation for ground potential-free applications. This kit consists of an glass-insulated isolation plug which is screwed into the inlet pipe, an insulating washer and lock nut each with three M5 threads for connecting the ground wire (also available for two rod flame glow plugs), in the case of steel or copper wires with an additional insulated connection nipple.





### ■ The solenoid valve

**The right valve for every customer**



According to requirements, different solenoid valves are used, either 2/2 or 3/2-way valves. Both are available for 12 and 24 volt on-board power sources and for a duty cycle of 100% according to VDE. All solenoid valves are opening types and are closed in deenergized condition (so-called SG valves). If current flows the valve opens to provide fuel to the flame glow plugs. Our customers are also free to choose the type of connector they require (flat blade, circular sealed connector, AMP mini-timer, etc.). There are numerous options for fuel connections. The fuel connection point for the 2/2-way valve can for example be positioned behind the pre-feed on the fuel filter overflow valve. The 3/2-way valve by contrast is frequently installed in the virtually pressureless return line. They are designed as overflow cut-off valves or pressure regulating valves, increasing the pressure to approx. 0.2 bar or limiting it in the other case via the spring expansion characteristic to approx. 0.5 bar. The fuel feed line to the valve and the plug can be provided by metal or plastic fuel lines; the connections are designed as banjo fitting or self-cutting screw union connections.

### Technical data

Rated voltage: 12 V; 24 V  
 Starting voltage:  $\approx 7$  V;  $\approx 15$  V  
 Drop out voltage:  $\approx 3$  V;  $\approx 7$  V  
 Switching duration: up to 15 min  
 Permissible ambient temp.:  $-55$  °C to  $140$  °C (no current)  
 Method of operation: currentless closed  
 Installation position: arbitrary  
 Connection: single or twin-pole  
                   various connector designs  
 Degree of protection to DIN 40050: IP 60 to IP 69 K  
 Flow volume: 4 l/h to 11 l/h at 0.05 bar  
 Interference suppression: no/yes  $\leq 100$  V  
 Operating medium: Diesel or gasoline  
 Electrical power consumption: 6 to 48 W



□ **Flame start control unit**  
**Design and function**

The flame start control unit controls and monitors the function of both the flame glow plugs and the solenoid valve. It determines their use as well as the flame time depending upon the engine coolant temperature. Many models have an indicator light to let the driver know the system is ready to start or if there are any malfunctions.

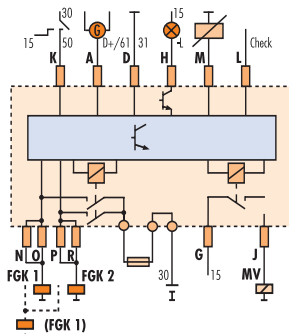
**Technical data**

Rated voltage: 12 V; 24 V  
 Operating voltage: 9 to 16 V; 19 to 32 V  
 Output current (term. FGP 1..2): ≤35 A maximum ≤15 A nominal  
 Output current (term. SV): ≤4 A  
 Output current (term. L): ≤3 W  
 Operating temperature: -40 °C to +80 °C  
 Connection: round plug; bayonet lock  
 Glow stop: at a coolant temperature of 25 °C +/-5 °C (switching off the function)

**Corresponding to the specifications of the vehicle manufacturers**

In addition to the known control units for 24 volts, Beru has now developed a control unit for 12 volts. Thus Beru offers all components for flame start systems from a single source. And important for our customers: All devices comply both in the scope of functions and in design and connection system with the requirements of renowned vehicle manufacturers.

Circuit diagram of a flame start system with two glow plugs



Pin	Pin assignment of the connections	Pin	Pin assignment of the connections
A	D+/61 generator	G	15 ignition
M	T <sub>1</sub> temperature sensor	D	31 ground
L	Check	N/O	FGK 1 (glow plug 1 of 2)
K	50 canking signal	P/R	FGK 2 (glow plug 2 of 2)
J	SV solenoid valve	N/P	FGK 1 (only where one plug in use)
H	-L indicator light (-)		

## Electrical air preheating



### ■ The filament glow plug

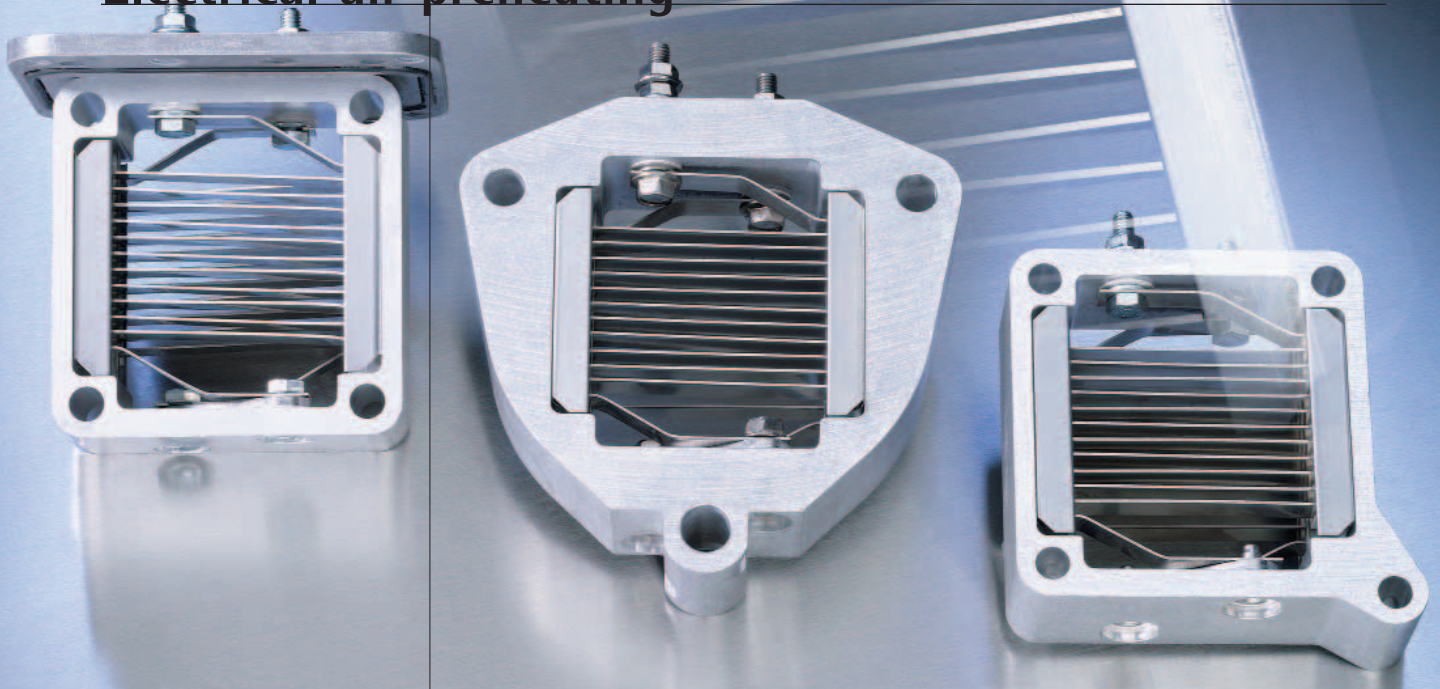
#### Design and function

As already described, a small intake air temperature rise is sufficient for the engine in cold condition for a clean start. The open, hot wire filament delivers sufficient thermal energy to the passing intake air to guarantee this in the starting process and the warming-up phase. The warm air is generated by the electrically operated systems. The hot filament is held and stabilized by a ceramic support.

#### Technical data

Rated voltage: 5,5 V; 24 V  
 Preheating time: approx. 30 sec  
 Switching duration: up to 15 min  
 Permissible ambient temp.: -55 °C to 150 °C (no current)  
 Temperature of the heating element: up to 1,150 °C permissible  
 Installation position: arbitrary  
 Connection: single or twin-pole, various versions  
 Electrical output: 400W to 600W heat output

# Electrical air preheating



## ■ Unregulated heating flange

**Design and function**  
„without self-regulation“

Here, a supplement to the electric preheating, the version as flange or module solution. The band held in a frame with lateral ceramic support is the heating element. The advantage of the band is the better heat transfer to the air flowing past. It has almost completely ousted the flame start in commercial vehicle engines up to 10 l.

**Technical data**

Rated voltage: 12 V; 24 V  
 Preheating time: max. 30 sec  
 Switching duration: up to 15 min  
 Permissible ambient temp.: -55 °C to 150 °C (no current)  
 Temperature of the heating element: up to 1,150 °C permissible  
 Installation position: arbitrary  
 Connection: single or twin-pole, various versions  
 Electrical output: 1.1 to 2.5 kW heat output

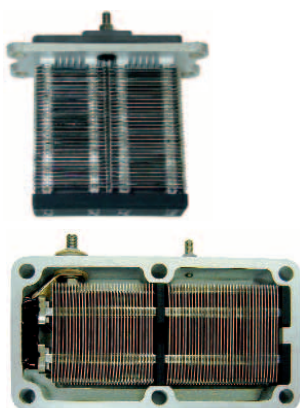
## □ Regulated heating flange

**Design and function**  
„with self-regulation“

A further alternative for air preheating is the version with self-regulating ceramic heating elements as flange or module solution. The electrically conductive ceramic elements are packed into rods and conduct the heat through the leaves. Low temperatures also enable their use as interior heating.

**Technische Daten**

Rated voltage: 12 V; 24 V  
 Preheating time: approx. 10 sec.  
 Switching duration: up to 15 min  
 Permissible ambient temp.: -55° C to 150 °C (no current)  
 Temperature of the heating element: up to 250 °C  
 Installation position: arbitrary  
 Connection: single or twin-pole, various versions  
 Electrical output: up to 2.5 kW heat output



## Electronic control

Flame start control unit



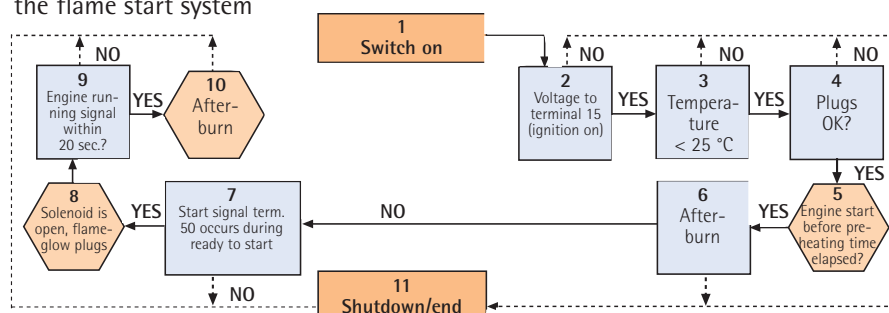
Compared with very simple concepts, which are operated without electronic control and only by means of glow plug starter switch, the extension of the system in the form of a control unit represents a considerable gain in convenience and reliability.

In combination with our flame glow plugs, electronic control units have been in our product line for a long time, but time and load control can improve operating convenience for heating flanges as well.

Extending beyond the offered solutions, we are able to develop and produce application-related problem solutions for original equipment manufacturers.

Here we would be pleased to give advice in all cases in which integration into the electronic engine control system is considered.

Functional flow chart of the flame start system



## Quality assurance



□ *Products of the highest quality*

■ *Computer-aided, continuous running test bench*

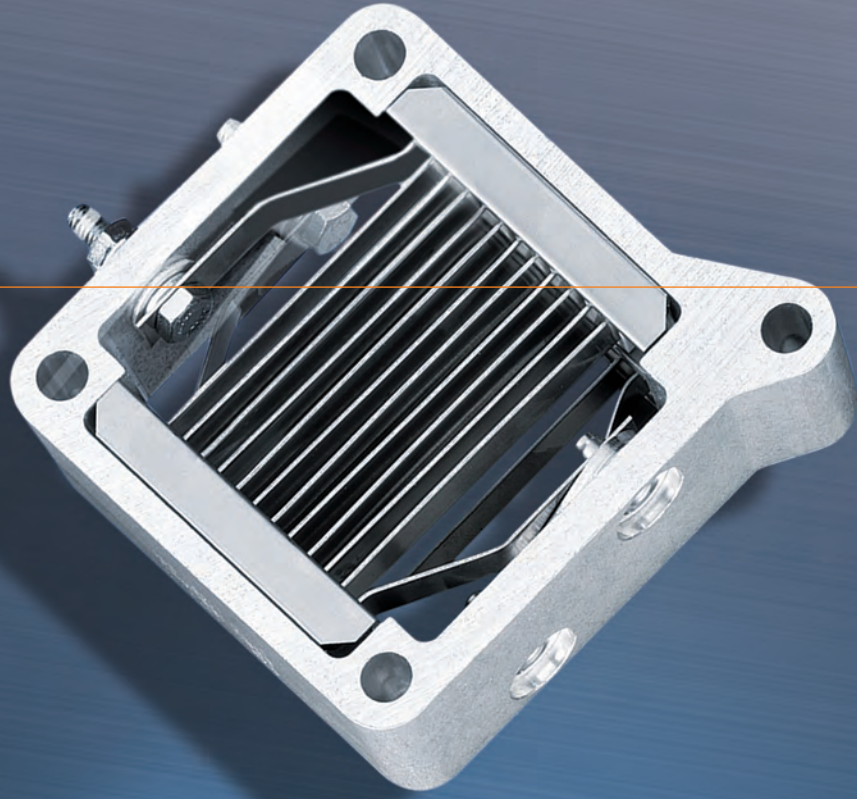


■ *ISO 9001: Beru goes one step further*

Chemicals quality control laboratory, quality control laboratory for mechanical and electrical testing, quality control laboratory for dimensional measurement engineering, X-ray test facility, vibration test laboratory, environmental simulation, climate testing laboratory ..., these are just a few of our facilities which help to ensure that only products of the highest quality bear the name of Beru.

A continuous running test bench is used for the operational optimization and further development of flame glow plugs and for regular testing in series production. It can be used to simulate the starting of an engine and simulate the battery voltage, the air speed in the inlet channel and the diesel fuel feed line. The fully-electronic control and monitoring system of the Beru test bench allows for 24 hour operation. Thanks to the facility for on-line data recording, we are able to provide computer-aided analyses more quickly.

All Beru plants comply in development, production, sales and management with the DIN ISO 9001:2000 quality standard. This certificate stands for development, design and manufacture according to customers' specifications and attests optimum methods for manufacturing products. Moreover Beru is committed to the permanent improvement of its products and services – to assure one hundred percent customer satisfaction.



# BorgWarner



A BorgWarner  
Business

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