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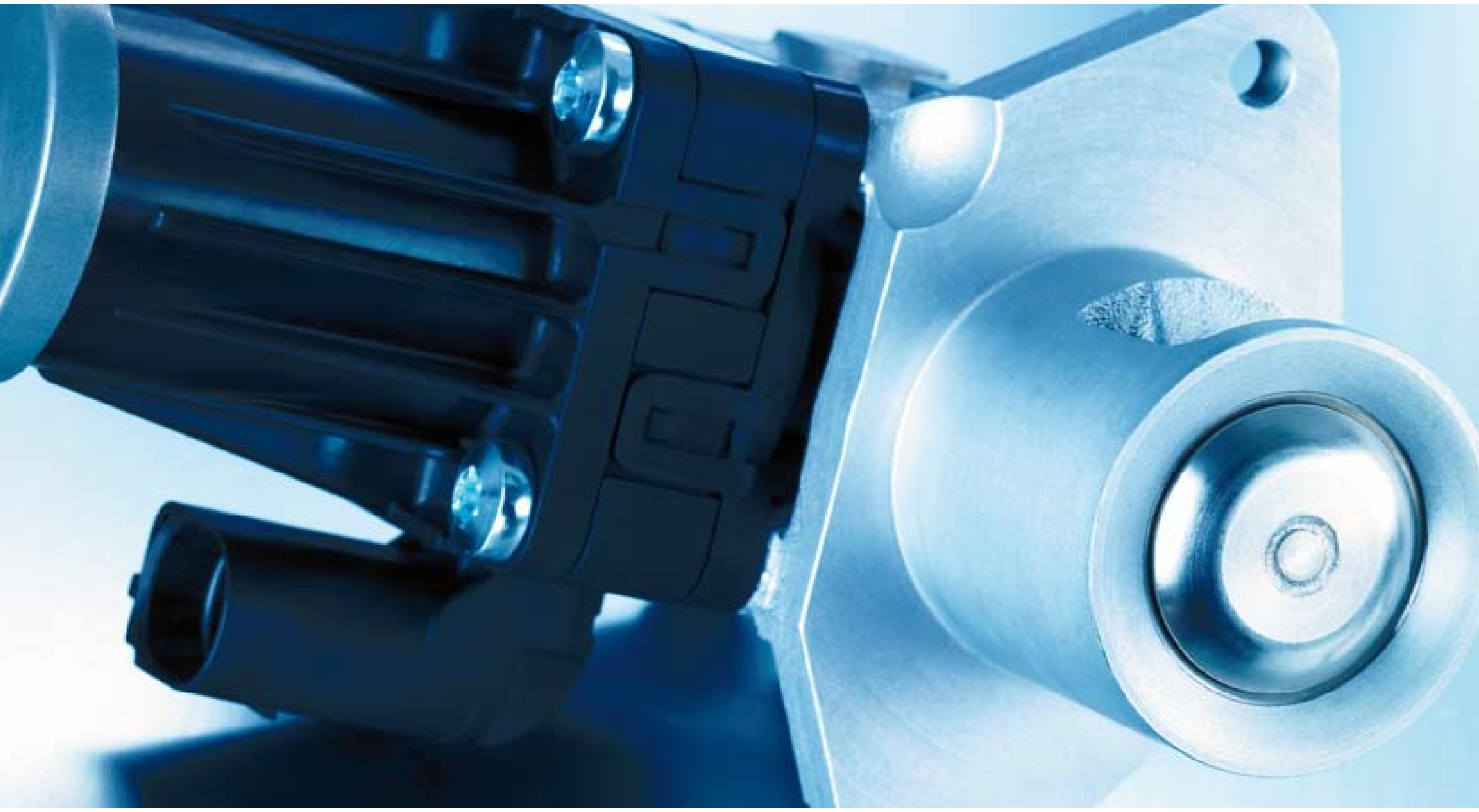


Exhaust Gas Recirculation –

Reducing Emissions with Exhaust Gas Recirculation Systems

PIERBURG

Pierburg exhaust gas recirculation – contributing to a clean environment for more than 30 years

For more than 30 years, Pierburg has produced large quantities of series EGR valves and thereby accumulated considerable experience in their development and manufacture. During this time, the pneumatically actuated EGR valves from Pierburg have matured into robust components used by nearly all engine manufacturers.

Pierburg EGR valves are modular in design. This enables individual, customer-specific variations for different installation conditions with retention of the electric and pneumatic drive. Following this principle, Pierburg has established the preconditions for widely-ranging options as well as the possibility of integrating the EGR valves in the throttle body and intake manifold. This flexibility of application facilitates use in a broad selection of engine designs.

Meeting the demands of future emission limits requires tight tolerances in the EGR system, which cannot be achieved with open-loop EGR systems. Therefore, in the future, only EGR systems with a closed-loop control circuit will be used. For diesel engines, a distinction is made between position control and air flow control, while gasoline engines with intake-manifold fuel injection generally use position control.

With direction-injection gasoline engines, the high rates of exhaust gas return and consequent strong influence on engine parameters by the recirculated exhaust gases make additional control strategies and diagnosis options using an intake manifold pressure sensor or mass air flow sensor advisable.

The state-of-the-art in emission technology for modern gasoline engines is electronically controlled fuel mixture generation, which maintains a fuel-air mixture of $\lambda=1$ under all operating conditions.

The downstream, controlled 3-way catalyst reduces pollution to a very high degree. Exhaust gas recirculation on the gasoline engine is a very effective internal measure in the engine for minimizing NO_X emissions at the source. Due to fewer load-cycle losses, exhaust gas recirculation results in lower

fuel consumption and consequent reduction of all harmful substances, including carbon dioxide emissions, which play a key role in the greenhouse effect.

Since the lean operation of gasoline engines with direct injection precludes the use of 3-way catalysts, the reduction of nitrogen oxide emissions upstream of the catalytic converter requires the highest EGR rates possible. Exhaust gas recirculation reduces nitrogen oxides in the emissions before the catalytic converter up to 70 percent, but the air flow is also considerably weakened. The resultant increase in exhaust temperature causes better conversion on the catalyst and consequently further emission reduction. The reduced flush rate of the $DeNO_x$ catalyst resulting from fewer raw emissions has an additional indirect user benefit as a consequence.

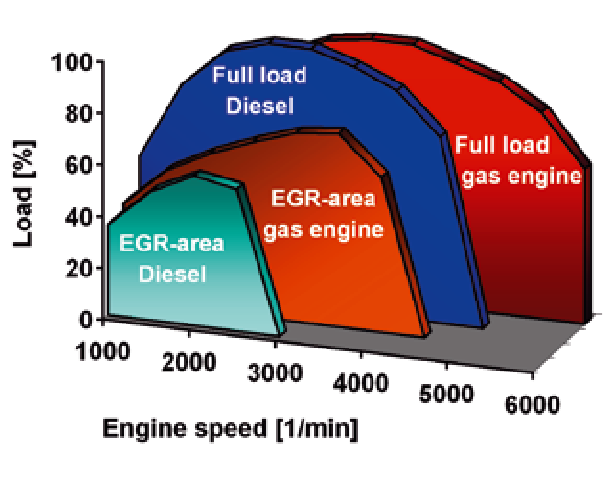


Fig. 1: The following diagram shows the EGR ranges of conventional gasoline and diesel engines.

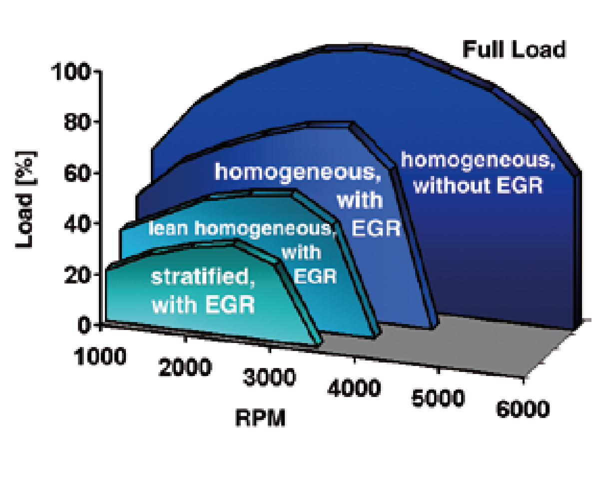


Fig. 2: For gasoline engines with direct injection the highest EGR rates possible are desirable in stratified charge operation and in the homogeneous lean burn operation range for reduction of nitrogen oxides as well as at $\lambda = 1$ for efficiency improvement.

Today, electronically controlled injection systems are used in diesel engines, in which oxidation catalysts contribute to the reduction of hydrocarbons and particle emissions. Exhaust gas recirculation is the only practical solution available for reducing NO_x in diesel engines aside from measures in the engine such as staggered injection. By significantly lowering the temperature of the recirculated exhaust gases, EGR cooling contributes to the effects of exhaust gas recirculation and leads to further reduction of nitrogen oxides.

Effects of exhaust gas recirculation

Nitrogen oxides are formed in the combustion chamber of the engine at high combustion temperatures. Exhaust gas recirculation reduces NO_x emissions at the source by lowering the combustion temperature in both gasoline and diesel engines. EGR systems have long been acknowledged as effective tools for reducing nitrogen oxides in diesel engines. In gasoline engines, exhaust gas recirculation is used primarily for dethrottling of the engine under partial-load conditions to reduce fuel consumption; reduction of nitrogen oxide emissions is only a secondary application. Due to the lean burn, the EGR rates of diesel engines are several times greater than EGR rates of gasoline engines with intake-manifold fuel injection.

Electric gasoline engine EGR valves

In order to meet future ecological and economic challenges with state-of-the-art combustion engines, these require calibrated exhaust gas recirculation systems in the engine performance map. External exhaust gas recirculation is not only used for minimizing nitrogen oxides; in gasoline engines it also reduces fuel consumption. This results in additional requirements for modern EGR valves. Based on many years of experience with EGR valves, Pierburg has developed electric EGR valves that are distinguished from pneumatic valves by the following characteristics:

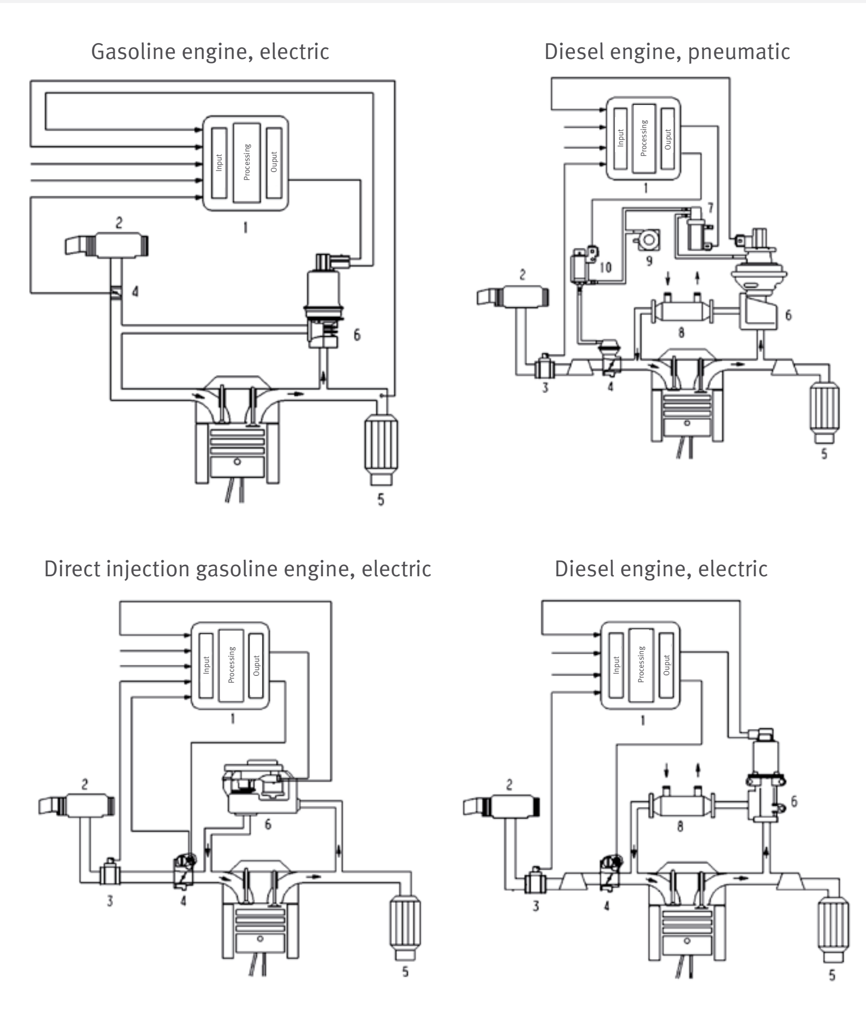
- highly dynamic for fast adjustment of the operating point
- good metering throughout the entire performance range
- linear characteristic
- high EGR rates
- simple, direct control
- high reliability and operational performance
- no servo energy (no pneumatics)
- low NO_x emissions
- reduced fuel consumption in gasoline engines
- low overall installed size and weight

	Diesel EGR system	DI Otto EGR system	Gasoline EGR system
Reason for EGR	NO_x reduction Noise reduction	Lower fuel consumption and NO_x reduction	Lower fuel consumption and NO_x reduction
Max. EGR rate	60 %	50 % (30 %, homogeneous)	20 %
Max. exhaust temperature in the EGR-relevant operating range	450 °C Upstream EGR cooler: 700 °C Downstream EGR cooler: 130 °C	450 °C (650 – 20 °C, homogeneous)	650 °C
Other	EGR cooling required for heavier vehicles	EGR cooling under consideration	
Requirements	■ High dynamics (slow closing smoke and/or sluggish response) ■ Good metering	■ High dynamics ■ Good metering (especially during homogeneous operation) ■ Decentral. EGR feed	■ Achievement of high EGR rates at high load (-> electric EGR valves necessary)

Tab. 1: The summary in the table shows the principal differences of the EGR systems for various applications

Fig. 3:

1. Control unit
2. Air filter
3. Air mass sensor
4. Throttle valve
5. Catalytic converter
6. EGR valve
7. Electro-pneumatic converter
8. EGR cooler
9. Vacuum pump
10. Electric changeover valve



EGR valve with proportional solenoid

This EGR valve has a valve head as shut-off element, which opens against the direction of flow of the exhaust gas. The adjustment of the flow rate for specific operating conditions of the gasoline engine occurs via a change of the on/off ratio that effects a corresponding lift of the valve head with the proportional solenoid. Combined with a travel sensor for position feedback of the tappet with exact positioning and good reproducibility, this valve is suitable for use in an EGR system with a closed-loop control circuit. With comparatively low overall installed size and weight as well as low system cost, this rugged design meets all the demands placed on a state-of-the-art EGR valve.

EGR valves for gasoline engines with direct injection

The use of exhaust gas recirculation in the homogeneous operation of gasoline engines with direct injection corresponds to that of conventional gasoline engines. Due to the higher EGR tolerance, however, EGR rates are also higher for homogeneous operation. In stratified charge operation, EGR rates comparable with diesel engines can be achieved.

Functionally, electrically actuated EGR valves for DI gasoline engine applications are identical to EGR valves for gasoline engines with intake-manifold fuel injection or those for diesel engines. Larger cross-sections and more advanced components with regard to handling high thermal loads and contamination insensitivity are characteristic differences.

The use of exhaust gas recirculation in the various operating modes of gasoline engines with direct injection results in the following requirements profile for these EGR systems:

- high dynamics
- good metering
- high EGR throughput
- high temperature resistance
- low leakage
- good uniform distribution
- insensitivity to contamination
- durability
- diagnosis capability
- low system cost

For central EGR feed, the returned exhaust gases are introduced in the intake manifold directly after the throttle valve. Electrically actuated EGR valves with direct current drive are used as a control unit.

A local or "individual cylinder" EGR feed satisfies the aforementioned requirements profile entirely. Here, the EGR introduction occurs in the ram pipes or intake channels near the inlet valves of the engine. Decentral allocation of the returned exhaust gas occurs via the individual EGR channels

Fig. 4: Electric EGR valve gasoline engines with water cooling

Fig. 5: EGR valve with proportional solenoid

(corresponding to the number of cylinders in the engine). A simple partitioning of the EGR lines and exhaust feed in the intake channels causes fill losses through bypassing of the ram pipe via the EGR lines due to influence on the intake pressure pulsations between the individual cylinders under full load. To avoid this undesired effect, consistent separation of the individual EGR channels is necessary during inactive exhaust gas recirculation. Bypassing of the manifold with decentral EGR feed leads to lower thermal load on the components of the intake module and higher efficiency in gas cycles immediately after sudden load variations. In addition to this, contamination of the components near the EGR inlet or downline (throttle valve, intake manifold, elements for swirl or tumble control), typically found in conventional EGR systems, is largely avoided. Rotary sleeve valves are used for reasons of function and cost. These have a corresponding number of control apertures with a shared actuator. With suitable design of the control aperture geometry, nearly any flow characteristics can be achieved and thus good metering even with relatively large cross-sections, in contrast to poppet valves for example. Regulation of the decentral EGR system occurs in a manner similar to conventional EGR valves with position feedback.

Diesel EGR systems

Pneumatically actuated Pierburg EGR systems distinguish themselves from other systems by the following characteristics:

- durability
- flexibility for the package
- lower energy consumption
- low weight
- low cost

The EGR valves are controlled pneumatically. A vacuum-controlled diaphragm box actuates the valve stem in a manner that allows the cross-section of the valve opening to be varied as needed. The modulation of the partial vacuum necessary for this takes place with the electro-pneumatic converter (EPC).

Various sensors are used as reference variables for con-trolling the rates of exhaust gas return in the EGR system. Position control can be achieved in the engine control unit by using a lift sensor. As an alternative, an air flow controller has the advantage of determination directly from the signal that is dependent on the EGR rate. The use of pulsation-compensated air mass sensors with a linearized characteristic is particularly advantageous to achieve sufficient signal resolution in broad operating ranges, i.e. record the response of the AMS output signal to small changes in the EGR rate.

Fig. 6: DC motor EGR valve

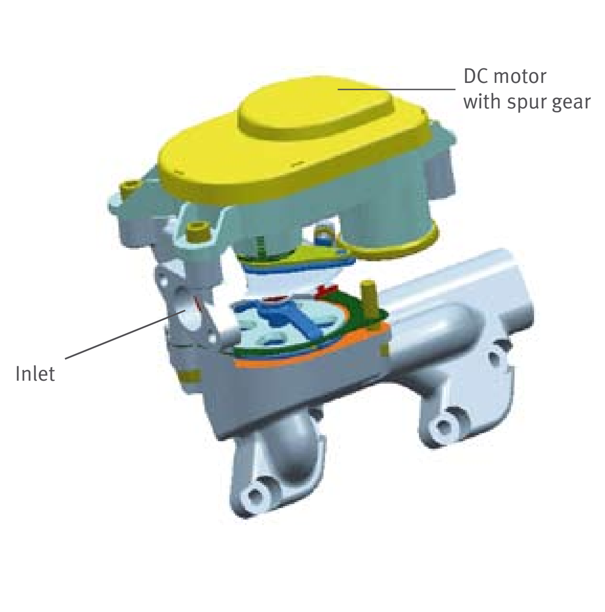


Fig. 7: Rotary sleeve EGR valve

Fig. 8: Pneumatic diesel EGR valve

Fig. 9: Standard EGR valve with charge feedback

Air mass sensors are used along with pressure and temperature sensors for diagnosis of the EGR system to detect possible system malfunctions.

In diesel EGR systems, valve actuators are used to some extent to throttle the air intake, increasing the pressure differential and ensuring high EGR rates. Today, the throttle valve is mostly controlled pneumatically. However, pneumatic actuation of the throttle valve is increasingly being replaced by electromotive means. Both variants can be equipped with sensors for position feedback on request.

Electric diesel EGR valve with pressure compensation

In the diesel engine, the EGR valve must seal securely against exhaust back pressure and charging air pressure and close very quickly in the event of a load increase. Otherwise, puffs of smoke or higher particle output can be expected.

A proportional solenoid was used to achieve high dynamics in the EGR valve. Due to their pressure-compensating design (double seat valve), electrically operated Pierburg EGR valves are distinguished by a very high gas throughput and an insensitivity to pulsations, secure seal against increased exhaust back pressure and good control characteristics.

This allows optimal reduction of nitrogen oxides and some reduction in particle hydrocarbon emissions to be achieved. An additional advantage with respect to noise is that clattering of the valve seat in the area of the opening (caused by exhaust pulsations) is avoided.

Fig 10: Electro-pneumatic converter

Abb. 12: Electric throttle valve

Matching the flow rate to specific operating conditions of the diesel engines is accomplished with duty cycle presets in the diesel control unit (EDC), which sets the appropriate lift of the valve head via the proportional solenoid. Combined with a displacement sensor for tappet position feedback with exact positioning and good reproducibility, this valve is used in a lift-controlled EGR system. In an EGR system with a closed-loop control circuit, in which an air mass sensor is used as a reference variable, the electric EGR valve is used without additional position feedback.

Electromotively operated EGR valve for gasoline and diesel engines with direct injection

Electromotively operated EGR valves, or “EM EGR’s”, are used in gasoline and diesel engines with direct injection. The shut-off element of this EGR valve is a valve head, which opens against the direction of flow of the exhaust gas. It is driven by a DC motor with a downstream planetary drive in which the rotary movement is translated to linear movement with a desmodromic eccentric drive. By reversing the direction of rotation of the DC motor, motor support of the closing force is achieved, ensuring fast, reliable closure with low leakage. Compared to double seat valves with a solenoid, EM EGR valves are distinguished by high adjustment dynamics accompanied by high actuating forces and rugged, contamination-tolerant single-seat valve technology with high throughput. With an overall installed size comparable to that of proportional solenoids, EM EGR’s can achieve higher actuating forces, which allow greater valve cross-sections and thus higher throughputs. This valve is distinguished by its compact design with low weight.

Fig. 14: DC motor Diesel EGR-valve

Fig. 15: EGR-cooler module

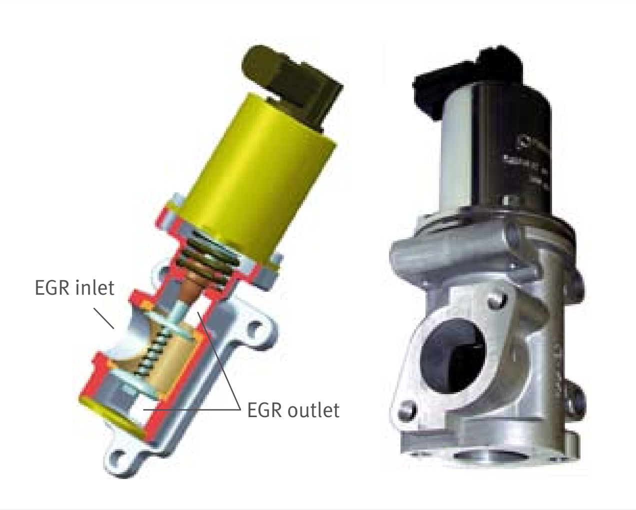


Fig. 13: Electric diesel EGR with position feedback

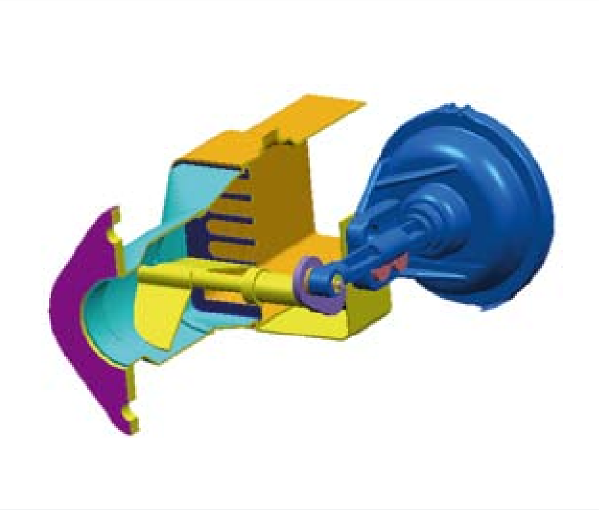


Abb. 16: Bypass valve

As an option, Pierburg EM EGR valves are available with CAN bus capable, integrated electronics containing both the performance electronics and position control. These electronics lead to higher control accuracy, improved dynamics and less application effort for customers.

The control of exhaust gas recirculation and cooling necessitates extensive integration in the design of the EGR system. Proper integration of the EGR system, including the EGR lines, in one module with all components for exhaust gas recirculation (i.e. the EGR valve, EGR cooler and cooler bypass) facilitates a cost-effective and durable solution with optimal functionality. Early involvement of a development partner with appropriate expertise in exhaust gas recirculation ensures the development of an optimum EGR module.

Characteristic	El. EGR valve for gasoline engine	El. rotary sleeve valve	Pneu. diesel-EGR valve	Diesel EGR valve with solenoid	EM EGR Diesel / DI Gasoline
Throughput	<60 Kg/h (Δp=200 hPa)	<200 Kg/h (Δp=200 hPa)	<180 Kg/h (Δp=50 hPa)	<180 – 20 Kg/h (Δp=50 hPa)	<180 Kg/h (Δp=50 hPa)
Valve leakage, Δp=600 hPa	<0.3 Kg/h	<1 – 20 Kg/h	<0.7 Kg/h	<1 – 20 Kg/h	<0.5 Kg/h
Max. ambient temperature	- 40 ... 150 °C	- 40 ... 150 °C	- 40 ... 150 °C	- 40 ... 150 °C	- 40 ... 150 °C
Max. temperature at the actuator	200 °C	180 °C	200 °C	200 °C	200 °C
Permitted exhaust temp. at the EGR inlet	150 ... 650 °C	150 ... 650 °C	150 ... 650 °C	150 ... 550 °C	150 ... 550 °C
Rated current consumption	1 A	1.8 A	1 A (EPC)	1.2 A	1.5 A
Vibration stability, axial / radial	20/30 g	30/30 g	30/30 g	10/30 g	30 g
Weight [kg], approx.	0.7 Kg	0.8 Kg	0.6 Kg	0.9 Kg	0.7 Kg
Actuation frequency	100 ... 150 Hz	140 Hz	250 Hz (EPW)	100 ... 150 Hz	>1000 Hz
Position feedback (potentiometer / contactless)	Yes	Yes	Optional	Optional	Yes, optional integrated control
Attachment position – vertical	± 85°	± 45°	± 85°	± 85°	± 85°

Tab. 2: Technical data for EGR valves

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