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For Bosch business partners

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Gasoline injection

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Gasoline direct injection operating modes

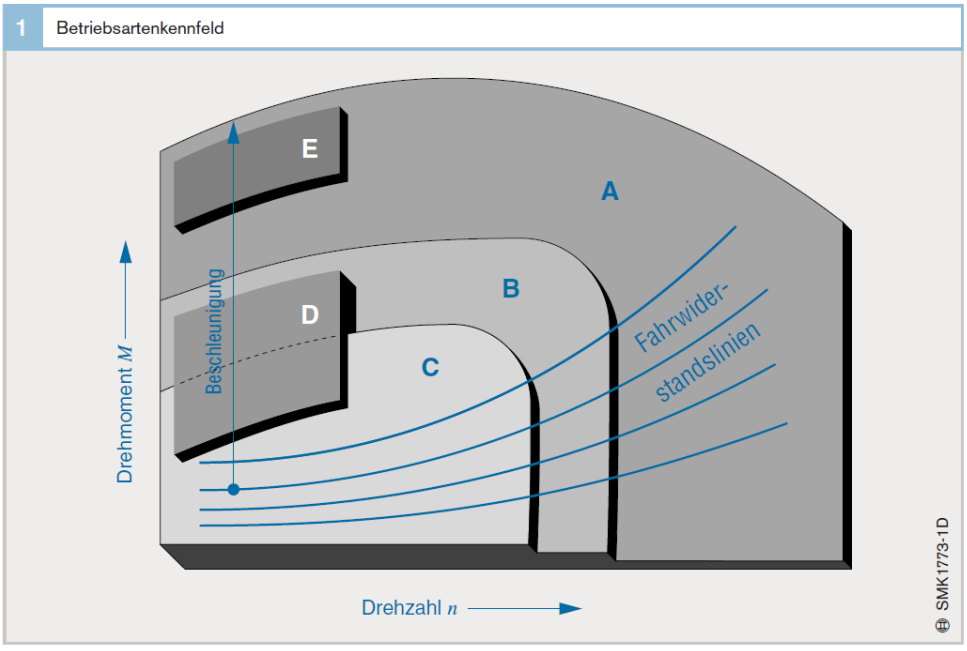
Gasoline direct injection

Engines with gasoline direct injection form the fuel/air mixture in the combustion chamber. Only the combustion air flows through the open inlet valve on the induction stroke. Special injectors inject the fuel directly into the combustion chamber.

Operating modes

The different operating modes used with gasoline direct injection are described in the following. The appropriate mode is set by the engine management system on the basis of the engine operating point.

1 Betriebsartenkennfeld



A
Homogeneous mode with $\lambda = 1$; this mode is possible in all ranges
B
Lean mode or homogeneous mode $\lambda = 1$ with EGR; this mode is also possible in ranges C and D
C
Stratified mode with EGR

<u>Modes of operation with double injection:</u>
C
Stratified CAT heating mode; same range as stratified mode with EGR
D
Homogeneous stratified mode
E
Homogeneous knock prevention mode

DE	EN
Betriebsartenkennfeld	Operating mode map
Drehmoment M	Torque M
Beschleunigung	Acceleration
Fahrwiderstandslinien	Motion resistance curves
Drehzahl n	Speed n

Homogeneous (HOM)

In homogeneous mode, the quantity of fuel injected is added to the fresh air with an exact stoichiometric ratio of 14.7:1. The fuel is injected on the induction stroke to provide enough time for homogenization of the entire mixture. In parts of the operating map, use is also made of slight excess fuel (λ < 1) to protect catalytic converter components or increase power at full load. This mode must be employed if a high torque level is required as it makes use of the entire combustion chamber. On account of the stoichiometric fuel/air mixture, the level of untreated pollutant emissions in this mode is low and can be completely converted by the three-way catalytic converter. The combustion process in homogeneous mode largely corresponds to that with manifold injection.

Stratified (SCH)

In stratified mode the fuel is not injected until the compression stroke, as only some of the air is to be used for mixture formation. This produces a mixture cloud, ideally surrounded by pure fresh air. The start of injection is extremely important in stratified mode. The mixture cloud not only has to be sufficiently homogenized at the moment of ignition, it also has to be located at the spark plug. As there is only a local stoichiometric mixture in stratified mode, the mixture is lean on average on account of the surrounding fresh air. More sophisticated exhaust gas treatment is required, as the three-way catalytic converter cannot reduce any NOx emissions in lean mode. Stratified mode can only be employed within certain limits, as soot and/or NOx emissions rise considerably at higher loads and the fuel consumption advantages over homogeneous mode are lost. At lower loads, stratified mode is restricted by low exhaust gas enthalpy, i.e. the exhaust gas temperatures drop to such a low level that the catalytic converter cannot be maintained at operating temperature solely by the exhaust gas. The speed range for stratified mode is limited to roughly 3000 min−1, as the time available above this threshold is no longer sufficient to homogenize the mixture cloud. The mixture cloud is leaner at the boundary with the surrounding air. This leads to an increase in untreated NOx emissions in this zone on combustion. In this mode the situation can be remedied with a high exhaust gas recirculation rate. The recirculated exhaust gas lowers the combustion temperature and thus reduces the level of temperature-dependent NOx emissions.

Homogeneous lean (HMM)

The engine can be operated with a homogeneous lean mixture (λ > 1) in a transition range between stratified and homogeneous mode. In homogeneous lean mode, fuel consumption is lower than in homogeneous mode ($\lambda \leq 1$), as the charge cycle loss is reduced due to the reduction in throttle action. The NOx emission level is however higher, as the three-way catalytic converter cannot reduce these emissions in this range. The use of additional NOx storage catalytic converters is in turn associated with loss of efficiency on account of the catalytic converter regeneration phases.

Homogeneous stratified (HOS)

In homogeneous stratified mode, the entire combustion chamber is filled with a homogeneous lean basic mixture. This mixture is produced by injecting a basic quantity of fuel on the induction stroke. A second injection operation (double injection) takes place on the compression stroke. This results in a richer zone in the area of the spark plug. This stratified charge is readily flammable and the flame can ignite the homogeneous lean mixture in the rest of the combustion chamber. Homogeneous stratified mode is activated for several cycles whilst switching between stratified and homogeneous mode. This enables the engine management system to set the torque more accurately during switchover and the NOx emission level drops thanks to the very lean basic mixture (λ > 2). The distribution factor between the two injection operations is roughly 75%. In other words, 75% of the fuel is injected

during the first injection operation which provides the homogeneous basic mixture. Steady-state double injection at low engine speeds in the transition range between stratified and homogeneous mode reduces soot emissions as compared to stratified mode and fuel consumption as compared to homogeneous mode.

Homogeneous split (HSP)

Homogeneous split mode is a special form of homogeneous stratified double injection. It is employed after the starting phase to attain catalytic converter operating temperature as quickly as possible. Thanks to the stabilizing effect of the second injection operation on the compression stroke, ignition can be greatly retarded (15...30° crankshaft after ignition top dead center). A considerable proportion of the combustion energy then no longer goes into increasing torque but rather raises the exhaust gas enthalpy level. The exhaust gas heat flow is such that the catalytic converter is ready for operation just seconds after starting.

Homogeneous knock prevention (HKS)

By employing double injection at full load, there is no need for "retardation" of the ignition timing in this mode to avoid knocking as this is prevented by the charge stratification. The more favorable ignition angle also yields a higher torque. In reality the potential offered by this mode of operation is extremely limited.

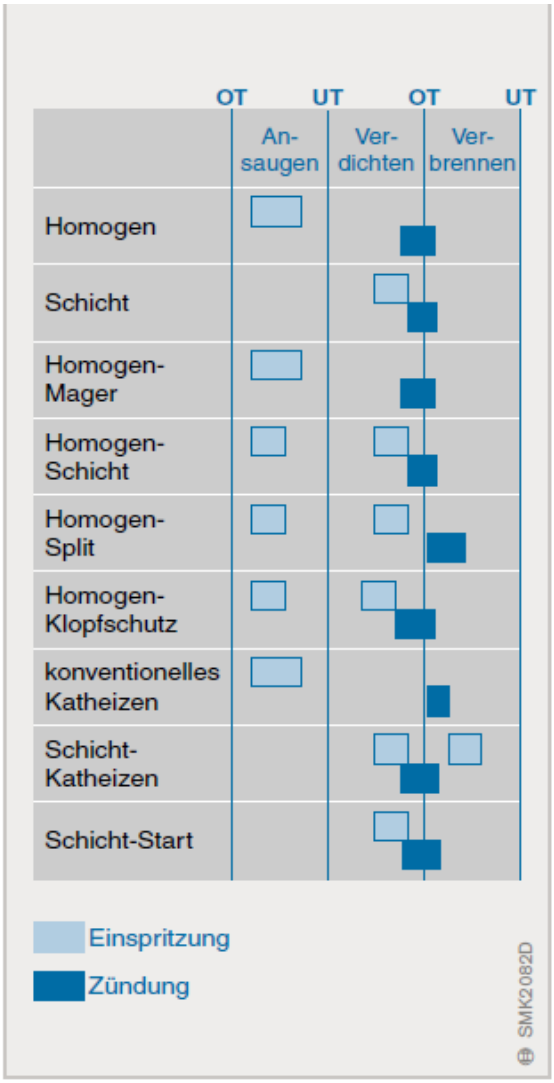
Stratified CAT heating (SKH)

A further type of double injection permits rapid warm-up of the exhaust system, however the exhaust system has to be optimized for this application. In stratified mode with a large amount of excess air, injection first takes place on the compression stroke (as with stratified mode) and then again on the power stroke. Combustion of this portion of the fuel is very late and leads to considerable heating of the exhaust end and the exhaust manifold. This mode is however only of very limited use for a cold engine and homogeneous split mode is far superior is such cases. A further important application is heating of the NOx catalytic converter to temperatures in excess of 650°C to initiate desulphurization of the catalytic converter. Double injection is essential for this purpose, as such a high temperature level cannot be attained in all operating situations with conventional heating methods.

Stratified starting

With stratified starting, the start quantity is injected on the compression stroke and not in the conventional manner on the induction stroke. The advantage of this strategy is that the fuel is injected into air which has already been compressed and thus warmed. As a result a greater proportion of the fuel vaporizes than in cold ambient conditions, where far more of the fuel injected remains in the combustion chamber in the form of a liquid film on the wall and does not take part in the combustion process. Far less fuel therefore has to be injected with stratified starting, thus considerably reducing the level of HC emissions on starting. As the catalytic converter is not able to take effect at the moment of starting, this mode is of great significance with a view to developing low-emission concepts. To make mixture formation possible in the short time available, stratified starting is performed at a fuel pressure of approximately 30...40 bar. The high-pressure pump is already able to provide such pressure levels at cranking speed.

Injection and ignition timing in the various operating modes



DE	EN
OT	TDC
UT	BDC
Ansaugen	Induction
Verdichten	Compression
Verbrennen	Combustion
Homogen	Homogeneous
Schicht	Stratified
Homogen-Mager	Homogeneous lean
Homogen-Schicht	Homogeneous stratified
Homogen-Split	Homogeneous split
Homogen-Klopfschutz	Homogeneous knock prevention
Konventionelles Katheizen	Conventional CAT heating
Schicht-Katheizen	Stratified CAT heating
Schicht Start	Stratified starting
Einspritzung	Injection
Zündung	Ignition