

Investigations on Supercharging Stratified Part Load in a Spray-Guided DI SI Engine

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ABSTRACT

Given the fact that, in an endeavor to achieve the goals of engineering for a trade-off between cleaning up exhaust emissions and maximizing fuel economy, two main paths are being followed in advancing and optimizing SI-engine operating strategy in the upper part-load range. On the one hand, homogenization and operation in the compression ignition mode seem to offer a promising means of minimizing NO_x emission by keeping the combustion temperature below the formation borderline and accepting a high cylinder-pressure gradient to obtain benefits in fuel economy. On the other hand, there are ambitions to widen the range of stratified operation using a supercharger or turbocharger. This way, efficiency of the engine cycle can be improved by operating at a higher global air-fuel ratio and, with this, a higher polytropic exponent, thereby taking the efficiency chain to a higher level.

As seen in wall-guided stratified combustion systems in the past, there is a trade-off between NO_x mass flow / PM emission and fuel economy. However, it has not been possible to achieve efficient homogeneous lean-burn operation with this type of engine.

Now, the spray-guided engine is seen to provide a much greater potential for optimizing mixture formation by using an advanced injection system that offers the greatest scope for avoiding wall impingement on the piston surface while delivering well-atomized fuel spray, even under high backpressure conditions.

INTRODUCTION

Running a gasoline engine on a leaner-than-stoichiometric air-fuel ratio is one of the most efficient measures for increasing overall efficiency in the low

part-load range. On the one hand, this is associated with an effective de-throttling and thus an increase in charge-cycle efficiency. On the other hand, it provides benefits in the context of wall heat losses, particularly in the field of expansion.

The stratified-charge DISI engine combines the improvements gained from reducing charge-cycle losses and increasing thermal efficiency, representing the single measure with the greatest potential for cutting consumption. Despite these theoretical advantages, the first-generation of direct-injection spark-ignition engines hitherto introduced into mass production have only been able in part to meet the ambitious expectations placed on the potential for reducing consumption. With these air-guided or wall-air-guided engine concepts, fuel-saving stratified-charge combustion is limited to a small engine load map area. The map area permitting stable engine operation with a stratified charge is limited in these engines by properties of the injector and the dependence of mixture-formation processes on piston position to low loads and low engine speeds. In addition, wetting the combustion-chamber walls with fuel leads to a significant loss of energy, further narrowing down the potential of fuel saving.

A further difficulty inherent to all lean combustion processes lies in exhaust-gas aftertreatment from the aspect of nitrogen oxide emissions. For this purpose, most engines use NO_x adsorption catalysts in conjunction with intermittent rich-lean combustion. While the engine is running on a lean mixture, nitrogen-oxide emissions are adsorbed in the adsorption catalyst until adsorption capacity is reached. The engine is then switched over to rich-burn operation with higher fuel consumption to regenerate the adsorption catalyst. Nitrogen-oxide emissions rise at higher loads in particular and the regeneration frequency has to be

increased. To reduce this regeneration frequency and achieve charge stratification at higher loads as well, engine development in this field must focus on reducing nitrogen-oxide emissions inside the engine.

As an alternative to direct-injection, stratified-charge engines, engines have been developed with a homogeneous cylinder charge across the entire map area, partly with supercharging. Permitting the use of efficient 3-way catalytic converters, these engines mainly achieve their fuel-consumption benefit from the effects of downsizing [1].

Second-generation direct-injection SI engines make it possible to use a far greater load map area in stratified operation. These processes are configured as spray-guided combustion processes. Given the proximity of injector and spark plug in a spray-guided combustion system, the piston surface is no longer required for guiding the injected fuel, as is the case with wall-guided processes. Hence, mixture formation is largely independent of piston movement and can thus take place later on in the compression stroke, making it possible to achieve combustion with greater thermodynamic efficiency. By the nature of the process, no defined charge motion is necessary any more either for guiding the fuel cloud. Consequently, this can be used systematically for controlling mixture preparation and combustion. Combining supercharging and charge stratification provides the capability of further improving the spray-guided combustion process. Supercharging is able to increase the air-fuel ratio, improving the thermal efficiency of the combustion process. Supercharging, and the associated greater mass of air in the cylinder, can furthermore extend the stratified-charge load map to include higher loads, leading to a fuel saving compared to naturally aspirated mode (Figure 1).

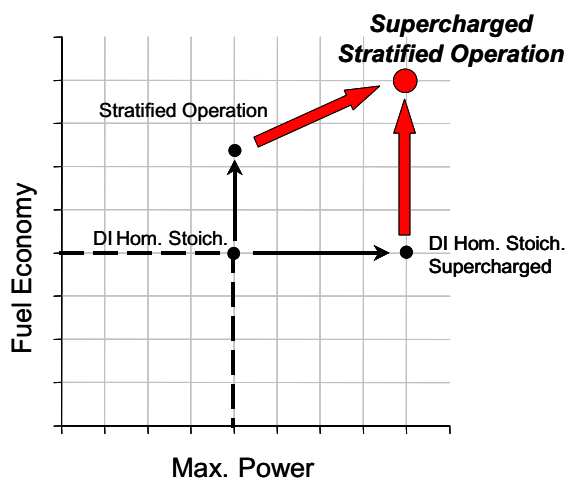


Figure 1: Fuel economy and supercharged stratified operation [2]

EXPERIMENTAL SETUP

The test engine is a single-cylinder research engine employing a spray-guided combustion process. The

crankcase and cylinder unit are based on a single-cylinder production engine from Rotax. To realize the spray-guided combustion system, a 4-valve cylinder head with centrally positioned injector was designed and constructed specifically for this base engine at the *Institut für Kolbenmaschinen in Karlsruhe* (Figure 2).

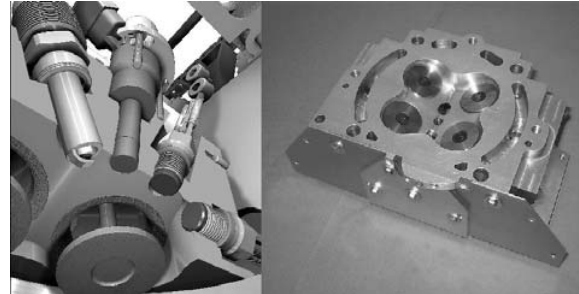


Figure 2: Cylinder head layout

To counteract slow burn-out of the lean air-fuel mixture in stratified operation, the cylinder head was designed with a relatively high squish-area component of approx. 20%. The main technical specifications for the test engine are shown in (Table 1).

Operating mode	4-stroke gasoline
Displacement	652 cc
Bore x stroke	100 mm x 83 mm
Con-rod length	149 mm
Compression ratio	11.0:1
Intake-valve head diameter	31 mm
Exhaust valve head diameter	31 mm
Timings	IO: 12 °CA before gas exchange TDC IC: 122 °CA before ITDC EO: 150 °CA after ITDC EC: 16 °CA after gas exchange TDC

Table 1: Engine data

The test engine is supercharged by an externally driven Roots compressor. In this context, intake-air temperature is kept constant by a charge-air cooler. The externally driven supercharging system was selected for these investigations so as to be in a position to assess the full potential of stratified-operation supercharging across the charger's entire operating range. For any application using an integrated charging device, the relevant system must be designed to suit the combustion process concerned. If an exhaust-gas