

Influence of a Multispark Ignition System on the inflammation in a Spray-guided Combustion Process

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ABSTRACT

This study describes tests with a fast clocked multispark ignition system intended to improve the stability of inflammation during charge stratification. The advantage of this ignition system is the capability it provides to adjust the number of sparks, the duration of single sparks and the intensity of the primary current. The basic engine test parameters were first set in an optically accessible pressure chamber under conditions approximating an engine. Two strategies were examined to analyze their effect on inflammation in stratified charge mode.

On the one hand, the multispark ignition (MSI) system allows implementing an intermittent spark sequence in the spark gap between the spark plug electrodes. On the other hand, precisely timed pulsing of spark energy into the plasma channel during charge motion can generate a very large deflection of the ignition spark. Both ignition strategies were analyzed in an indicated single cylinder engine's combustion chamber at different operating points to determine the respective tolerance limits of the engine operation and inflammation process.

The results demonstrate that the multispark ignition system may be employed to extend the range of ignition without misfire by a factor of up to five in stratified charge mode. Furthermore, electrical quantities were measured to compare the ignition energy of a multispark ignition system and a conventional ignition system.

In addition, the potentials for using the ignition voltage analysis as a method of measurement to determine local air/fuel ratios at the spark plug are highlighted. Being refined in this project, this method of measurement is based on the analysis of the disruptive voltage in different modes of operation and the thermodynamic conditions derived from the ignition point.

INTRODUCTION

Among the various methods to reduce gasoline consumption, direct injection holds great potential. A spray-guided combustion process with charge stratification can maximize reductions in consumption, particularly in part load operation. The high temporal dynamics of such a combustion process increases the requirements on mixture formation and the ignition system.

As part of a project supported by the Deutsche Forschungsgemeinschaft (German Research Foundation), tests are being conducted to analyze and improve the inflammation of spray-guided combustion. To this end, different operating points are being analyzed in optical and engine tests under comparable boundary conditions to characterize the spray generated by an A-nozzle piezo injector and to establish the requirements for a multispark ignition system (MSI). This research is being supported by Daimler AG and Robert Bosch GmbH.

Among other things, prior studies have demonstrated that multiple injections significantly increase the period of stable inflammation, the speed of flame propagation and, finally, efficiency in stratified charge mode. An improvement of the homogenization of the local air/fuel mixture is one reason for this and a reduction of the charge motion generated by the spray in the ignition volume at the ignition point is another.

In addition to injection timing, spark ignition also holds significant potential to improve the stability of inflammation and to extend the period of reliable ignition. When the flow conditions at a spark plug's electrodes are known, the type of ignition system employed and its parameterization can be used to systematically influence the ignition spark.

This study explores and explains the effects of a multispark ignition system developed by Daimler for two fundamentally different system configurations.

By way of introduction, **Figure 1** presents a longtime exposure of a deflected ignition spark with spark plug electrodes in a flow. Clearly, the spark plasma's exposure range can be extended beyond the original spark gap. The following elucidates this configuration's effects on inflammation in stratified charge mode.

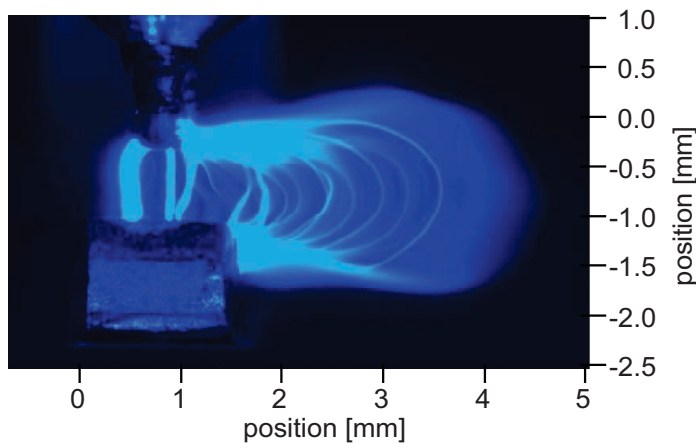


Figure 1 Longtime exposure of the spark plug and the deflected ignition spark

OPTICAL SPRAY ANALYSIS

The droplet velocities during injection into the spark gap are determined in an optically accessible injection chamber with phase Doppler anemometry (PDA) [2]. This setup serves as the basis for experiments to visualize the spark and adjust the different ignition strategies. PDA is a standard method of measuring droplet diameters and velocities with high spatial and temporal resolution. The measuring principle is based on the elastic diffusion of light on an assumed spherical particle.

Figure 2 is a schematic of the test setup. Two intersecting laser beams form the measuring volume by developing interference fringe through superposition. When a droplet traverses the measuring volume, the receiving optics detects its diffused light and the signal evaluation electronics calculates the droplet velocity. For more on the theory of the PDA method, the authors refer readers to the relevant literature [3, 4]. The HiDense (Dantec) PDA device is used to take the measurements and is specially designed to measure the kinds of dense sprays that appear in direct injection engines. The device is able to determine two velocity components. Their orientations and the position of the measuring point are indicated in **Figure 3**.

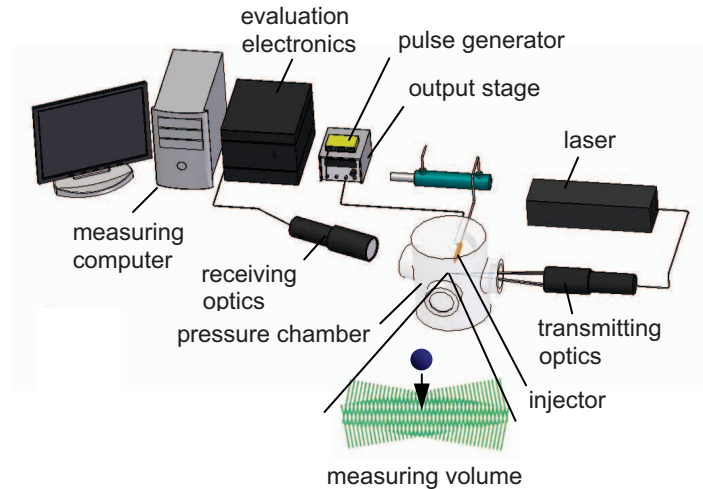


Figure 2 Test setup of the pressure chamber with PDA equipment

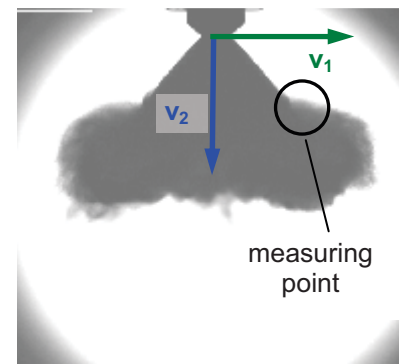


Figure 3 Orientation of the velocities and position of the measuring point

An Ar⁺ laser with a maximum power of 5 watts is used as the light source. The wave length 514.5 nm (green) is employed for channel 1 (velocity component v_1) and the wave length 488 nm (blue) for channel 2 (velocity component v_2). The diameter of the measuring volume is 46 μm .

The PDA tests are conducted in an injection chamber with a constant flow and a volume of 10 liters. The chamber pressure is 6 bar absolute at a temperature of 20 °C. The fuel pressure of 200 bar is generated by a nitrogen gas bottle and a pressure transmitter.

The subsequent figures present the mean velocities v_1 and v_2 measured for the engine operating point $n = 2000$ rpm and IMEP = 3 bar and the respective resulting velocity v_{res} . **Figure 4** presents the results for a simple injection and **Figure 5** for a triple injection.

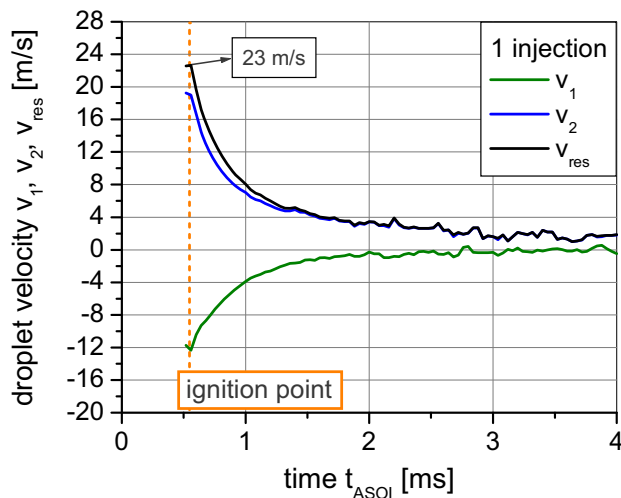


Figure 4 Droplet velocities in the ignition volume at $n = 2000$ rpm and IMEP = 3 bar

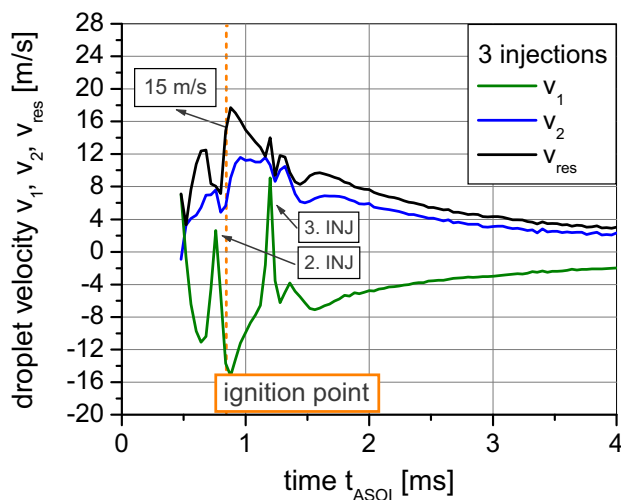


Figure 5 Droplet velocities in the ignition volume at $n = 2000$ rpm and IMEP = 3 bar

The values plotted are above 0.5 ms ASOI (after start of injection) since the number of particulates detected earlier is very low because the sprays are too dense and, thus, in conjunction with the high velocity gradients, make any meaningful calculation of mean values impossible.

The spray's arrival time at the measuring point after the start of injection is approximately 250 μ s [2]. Values of $v_1, v_2 > 40$ m/s are measured for the two spray front velocities for both types of injection and are therefore not represented. Clearly, the velocities for simple injection (Figure 4) dropped significantly at the time 0.5 ms ASOI. A reverse flow causes the velocity v_1 to assume negative values. Both velocity components drop to zero over the further course of time. The second and third injection

during the triple injection (Figure 5) are recognizable in the increase of velocity v_1 at the times $t = 0.8$ ms ASOI and $t = 1.2$ ms ASOI.

Each injection is followed by a reverse flow with a negative velocity v_1 . Further injections, on the other hand, have only little influence on the velocity component v_2 . The comparison of simple and triple injection at the particular ignition timing reveals that the resultant droplet velocity v_{res} at the place of ignition during multiple injection is only approximately $\frac{2}{3}$ of what it is during simple injection.

OPTICAL ANALYSIS OF THE MSI SYSTEM

The tested, fast clocked multispark ignition system (MSI) with energy-adapted ignition coil is a development ignition system of Daimler AG [5]. It can be operated with a variable voltage supply of up to 42 V and additionally has a closed loop primary current control. The special ignition coil is recharged time controlled in the range of μ s. The sparkovers occur at a standard spark plug. Thus, the MSI system does not affect the charge motion inside the engine's combustion chamber.

This multispark ignition system can vary the following parameters to systematically influence the ignition spark:

- Primary current (up to 40 A)
- Recharging time (break)
- Turn off time (burning duration of the spark)
- Spark duration (spark rate)

The following explains the influence the alteration of these parameters has on sparking and spark deflection in stratified charge mode. The findings of the PDA tests presented in the preceding sections demonstrated that the spark gap in stratified charge mode is subject to stronger charge motion as a result of the fuel being injected under high pressure.

The charge motion is quantifiable for every operating point by defining the development of the droplet velocities in the ignition volume over time. This is used to adjust the MSI system. In the process, the resulting droplet velocity is reproduced in a pressure chamber by means of a gaseous medium.

The chamber pressure is set so that ignition occurs at the same density as in the engine. The ignition spark generated under these conditions is visualized with a high speed camera (LaVision HighSpeedStar 6) at a frame rate of 50,000 Hz. At the same time, the MSI system's electrical quantities (ignition voltage and secondary current) are measured in order to be able to correlate the electric signals and the visualized sparks.

IGNITION STRATEGY 1

Figure 6 presents the development of these electrical quantities over time for one parameterization of the MSI system (ignition strategy 1). The calculated characteristic of the ignition energy over time is plotted additionally. Ignition occurred here for the engine operating point $n = 2000$ rpm and IMEP = 3 bar under the conditions of stratified charge mode during a single injection. Accordingly, the chamber pressure was $p_{Ch} = 6.2$ bar and the flow velocity in the spark gap $v = 23$ m/s. Nitrogen (N_2) was used as the chamber and flow medium.

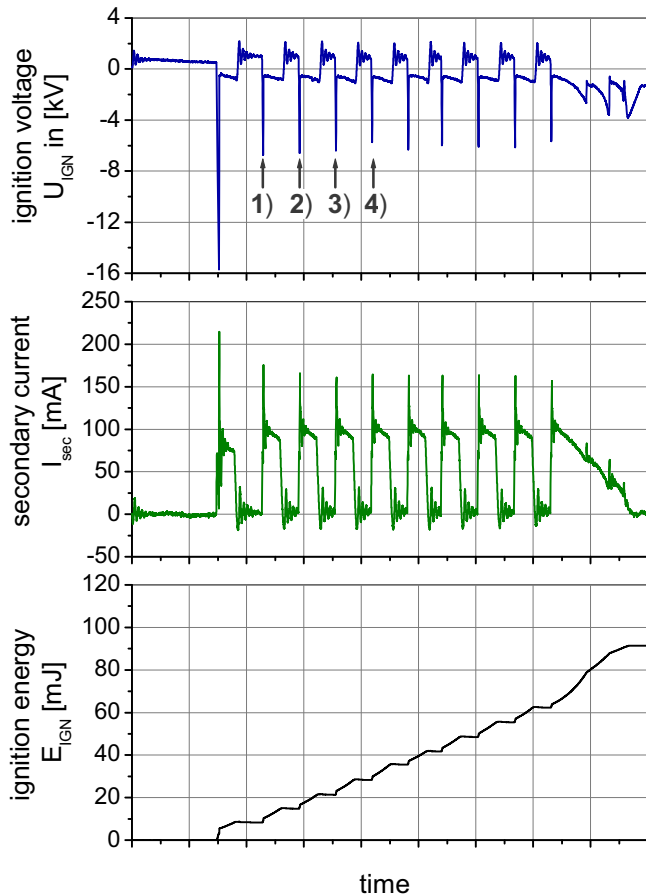


Figure 6 Characteristic curves of the MSI system for ignition strategy 1, flow velocity in the spark gap $v = 23$ m/s

In this case, the MSI system was parameterized so that the ignition spark was extinguished after every spark breakdown and the next breakdown (follow-up sparks) occurred in the spark gap, i.e. between the spark plug electrodes, when energy was reintroduced. Altogether, a spark sequence of ten sparks was recorded, the flowing medium only slightly deflecting the individual sparks during the duration of combustion because of the parameterization. The images of the ignition sparks at the times marked in Figure 6 (diagram ignition voltage,

numbers 1 through 4) presented in **Figure 7** illustrate this correlation.

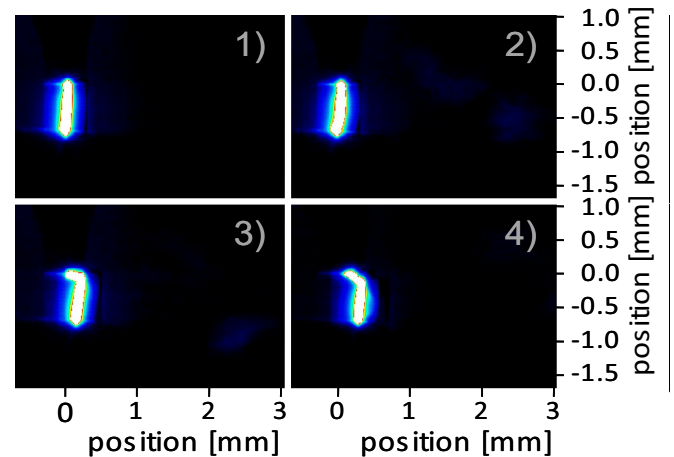


Figure 7 High speed visualization of the spark plug for ignition strategy 1 at the four times marked in Figure 6

IGNITION STRATEGY 2

Figure 8 plots the development of the MSI system's electrical quantities over time for the completely different ignition strategy 2. In this case, the parameterization was selected so that, under identical chamber conditions, the flow velocity deflects the ignition spark in a curve.

The MSI's shutoff and recharging times must be shortened so that renewed energy input causes a spark breakdown (follow-up sparks) in the discharge channel ionized by the previous ignition spark. This enables deliberately extending the effective range of the spark plasma beyond the actual spark gap. **Figure 9** presents the corresponding images of the ignition spark for the times marked (1 through 4) in Figure 8.

A comparison of Figures 6 and 8 reveals that the MSI's timing must be faster by approximately a factor of 3 to make ignition strategy 2 possible. At an identical spark burning duration, this produces a spark sequence of approximately thirty follow-up sparks. The ignition energy converted over time during the duration of spark burning is 90 mJ for both of the ignition strategies examined and therefore on the same level.