

Investigation of the Flow Velocity in the Spark Plug Gap of a Two-Stroke Gasoline Engine using Laser-Doppler-Anemometry

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ABSTRACT

The two-stroke SI engine remains the dominant concept for handheld power tools. Its main advantages are a good power-to-weight ratio, simple mechanical design and low production costs. Because of these reasons, the two-stroke SI engine will remain the dominant engine in such applications for the foreseeable future. Increasingly stringent exhaust emission laws, in conjunction with the drive for more efficiency, have made new scavenging and combustion processes necessary. The main foci are to reduce raw emissions of unburned hydrocarbons via intelligent guidance of the fresh air-fuel mixture and to improve performance to reduce specific emissions. The flow velocity in the electrode gap of the spark plug is of great interest for the ignition of the air-fuel-mixture and the early combustion phase of all kinds of SI engines. In these investigations, the flow velocity in the spark plug gap of a two-stroke gasoline engine with stratified scavenging was measured under various conditions. Two spatial directions in the spark plug gap were measured without influencing the in-cylinder flow. The measurements were performed using LDA (Laser Doppler Anemometry), a non-intrusive optical velocity measurement technology. For the application of the LDA equipment, the placement of one optical access in the cylinder head was necessary. The access is located in the plane of the spark plug gap coaxial with the crankshaft.

The investigations were done in non-fired operating points; the engine was powered by an asynchronous motor. Variation parameters included the engine speed in a range from idle speed up to 9500 rpm; engine loads and volumetric efficiencies at various throttle valve positions. In addition, the influences of different orientations of the spark plug electrode were also investigated.

INTRODUCTION

Due to its high power density, low weight and compact design, the small two-stroke SI engine is the preferred driving unit for handheld power tools. In consideration of increasingly stricter emission limits, one of the main development areas of these engines is the further reduction of the exhaust gases.

Emissions legislation for handheld power tools limits the emissions of hydrocarbon (HC) and nitrogen oxides (NO_x). The two-stroke SI engine produces only small amounts of NO_x because of the high concentration of residual gas, and operating with a rich mixture. Hydrocarbon emissions are mainly caused by uncompleted combustion and, specifically, by the high scavenging losses, which amount 20 to 25 % of the supplied fuel at rated power [3]. The uncompleted combustion is a result of cyclic changes by the in-cylinder flow and the first phase of the combustion. For these reasons, meeting the HC limit is the main goal throughout the engine development.

Hydrocarbon emissions caused by scavenging losses can be reduced with charge stratification. A stratification of the charge can be realized by a direct injection or by stratified scavenging. Because of the lower production costs, better performance, robustness and stability, stratified scavenging is the preferred solution in modern handheld power tools. The scavenging ports are filled with pure air while the crankcase is filled with mixture. At the beginning of the scavenging process the air flows into the combustion chamber before the rich mixture.

By using stratified scavenging, the scavenging losses can be reduced by a large scale. Under these conditions the optimization of the combustion becomes an important development target. Unstable combustion and high cyclic variations of the in-cylinder pressure in small two-stroke SI engines are mainly caused by cyclic variations of the composition of the charge, the in-cylinder flow, the ignition, the fuel mass and dynamic interactions between consecutive engine cycles. These parameters affect the inflammation process, the burn rate and thus the whole combustion process.

In view of these facts, it is essential to know the flow conditions inside the cylinder in the area of the spark plug. The target of this research was to point out the dimensions of the CA resolved variations in the flow velocity and direction of the charge in the gap of the spark plug in a small crankcase-scavenged two-stroke SI engine.

Figure 1 shows different measurement techniques to visualize scavenging, mixture formation, ignition,

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inflammation and the combustion process. All of these measurement techniques are used by the Institute for Reciprocating Engines to get a better understanding of the in-cylinder processes of both small two-stroke and four-stroke engines. For this research special attention is given to the in-cylinder flow and the flow conditions in the spark plug gap by using Laser-Doppler-Anemometry.

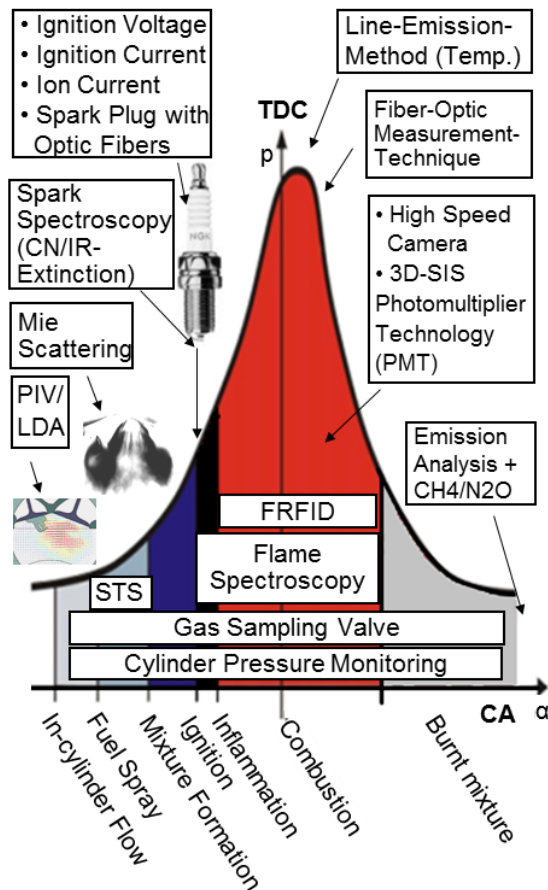


Figure 1 Overview of measurement techniques [4]

MEASUREMENT TECHNOLOGY

Laser-Doppler-Anemometry

Laser-Doppler-Anemometry (LDA), also known as Laser-Doppler-Velocimetry (LDV), is a non-intrusive optical measurement technique to investigate in-situ flow velocities of liquid and gaseous media. The LDA measurement principle is based on the Doppler effect, and provides information about velocities in a small probe volume. This volume is generated by two different laser beams (two-dimensional LDA). Particles moving through this probe volume cause a frequency shift of the scattered laser light, which is detected and finally evaluated to define the flow velocities. A detailed description of the measurement technique is available in [7,8,9]. The LDA system, displayed graphically in Figure 2, generally consists of three major assemblies: the light source, emitting and receiving fiber-optics, and a detector.

The light source of the two-dimensional LDA-system (Dantec) was a 5W Ar-Ion laser (COHERENT Innova 70) operated in multi lines mode. The laser emitted a green ($\lambda=514,5\text{nm}$) and blue ($\lambda=488\text{nm}$) wavelengths. For the investigations the power was adjusted between 150-200mW. The wavelengths were split in the colour separator of the Transmitter Box (Dantec 60X41). After leaving the Transmitter Box, two beams were adjusted in the fiber manipulators (Dantec 60X24) and followed the fiber probe cable to the optical probe at the test bed (engine). The LDA-System for these investigations operated in the backward-scattering mode. That means that the transmitting and receiving fiber-optics (inclusive detector) are in the same optical probe. This has the advantage of only requiring one optical access at the test engine. In order to identify the direction of the flow velocity, a Bragg cell operating at 40 MHz was also part of the LDA-setup. For the adjustment of the optical probe a manual traverse was used.

The LDA-setup was able to process the crank angle information provided by the encoder together with the Doppler-bursts received from the two Photomultipliers. Finally, the Burst Spectrum Analyzer transmitted the data of the two velocities, the crank angle information and some statistics to the PC.

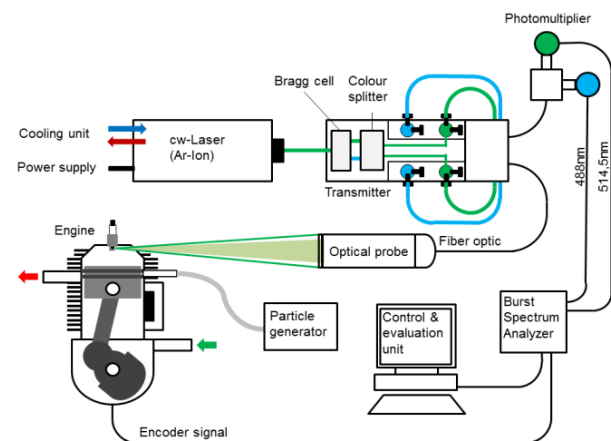


Figure 2 Schematic diagram of the test rig configuration

The principle characteristics of the two-dimensional LDA optics are listed in Table 1.

Table 1: Principle characteristics of the LDA-System

2D-LDA-System (Ø 27mm)	Unit	Technical Data	
		Channel 1	Channel 2
Wavelength	[nm]	514,5	488
Focal length	[mm]	160	160
Beam diameter	[mm]	1,35	1,35
Beam spacing	[mm]	15	15
Beam half angle	[deg]	2,684	2,684
Number of fringes	[-]	14	14
Fringe spacing	[µm]	5,494	5,211
Probe volume - dx	[mm]	0,078	0,074
Probe volume - dy	[mm]	0,078	0,074
Probe volume - dz	[mm]	1,658	1,573

Particle Seeding

The measurement principle required that a convenient particle, whose velocity was representative for the flow velocity, existed within the probe volume. Additional tracer particles often have to be homogeneously mixed with the in-cylinder flow. The density, shape and size of these suspended particles should be such that the particles have little momentum and can faithfully follow the flow. These tracer particles, also used for PIV experiments [10], were copolymer microspheres encapsulating isobutane. The particles had a diameter of 20-40 μm and a density of 20 kg/m^3 . The microspheres had been prepared in a separate cyclone seeding generator. The output of the generator was connected via flexible tube to the engine cylinder. The mass flow of particles to engine cylinder was supported by additional air.

TEST BED SETUP

Test Engine

The handheld power tool used for these experiments was a 70 cc two-stroke research SI engine with external mixture formation. The engine is crankcase scavenged using stratified scavenging. For the research, changes had to be done on the engine setup. Optical access was on the fan side of the engine, parallel to the crankshaft at the altitude of the spark plug gap, as represented in [Figure 3](#). The combustion chamber was sealed with a quartz glass.

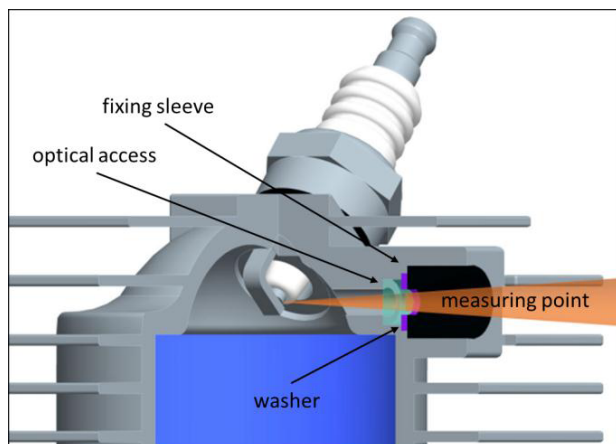


Figure 3: Optical access

Furthermore, an access for the particles needed for the LDA-measurements was set above the intake, shown in [Figure 4](#). It was positioned above the scavenging ports but below the closing edge of the outtake. By using this position it was ensured that the particle flow did not influence the flow inside the cylinder. The particles were brought into the cylinder after outlet port opened, so the pressure in the cylinder was already reduced. After the scavenging ports opened, no more particles were able to flow in because of the higher pressure inside the cylinder.

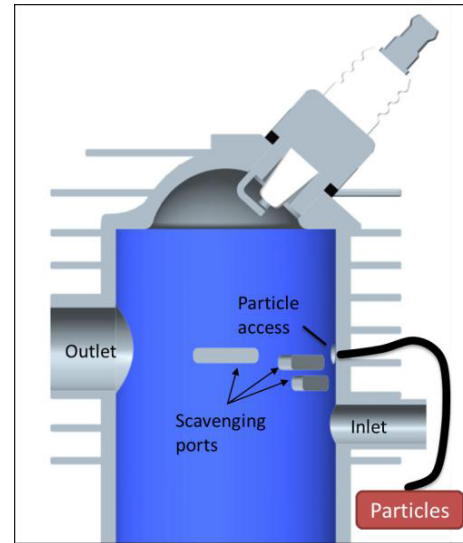


Figure 4 Particle Access for LDA Measurements

Because the investigations were done at non-fired operating points, no fuel-air mixture came into the cylinder. Since the oil would have bonded with the particles, no lubricant was used during the investigations. In combination with the particles, the duration of the measurements was limited because of the missing lubrication.

The engine was powered by an asynchronous motor. The crankshaft was connected to the asynchronous motor with a belt through the use of a pulley.

Measurement Setup

The laser beam was split off in two wavelength, each one with a discrete wavelength. With this structure, two measuring planes were set up in the gap of the spark plug. [Figure 5](#) illustrates the size of the measuring volume. It has the shape of an ellipsoid. The proportion of the measuring volume depends on the wavelength of the laser beam. The green laser beam with a wavelength of 514.5 μm has an expansion of 74 μm x 74 μm x 1573 μm and a volume of 0.0045 mm^3 . The blue laser beam with a wavelength of 488 μm has an expansion of 78 μm x 78 μm x 1658 μm and a volume of 0.0052 mm^3 . A spark plug gap of 0.6 mm was used.

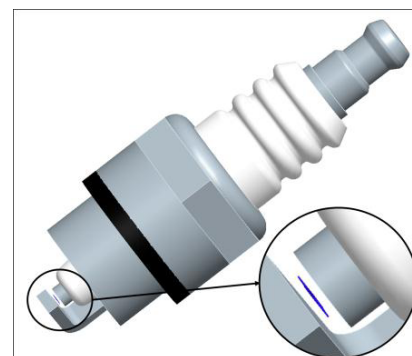


Figure 5: Measurement Volume in the spark plug gap

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