Multispark initiation of ring gas charges in water

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Abstract. The experimental results of studying in-water initiation of propane-oxygen charges in the form of ring bubbles by using 2, 4 and 6 electrical sparks have been presented. In discharge gaps, sparks were initiated from the single capacitor storage of energy 2 J and were located along the ring perimeter of diameter 52 mm at the same distance from each other. The difference between the processes of energy release in the combustion of gas charges has been revealed in the analysis of force pulses measured by the piezo-dynamometer with time resolution of 2.6 µs. It has been shown that for the same gas charges in the initiation of gas by multispark discharges, thrust characteristics have both qualitative and quantitative advantages. As the number of sparks increases from 2 to 6, the amplitude of force pulses rises to 30% and a specific pulse increases to 20% for the same gas charges.

1. Introduction
The term “multispark initiation” is used in the description: of initiation of combustion [1, 2] and initiation of transition-to-detonation combustion [3]. In this work, the methods and approaches of multispark electrical initiation of gas charge combustion without transition to detonation are considered to develop efficient devices for initiation of hydrocarbon mixtures for pulse water movers and to increase the efficiency of hydrocarbon combustion for internal combustion engines.

The application of methods of in-water gas combustion for the sake of thrust generation was considered previously in [4–6]. When increasing the mover’s dimensions, the initiation of gas charges by 1-spark discharge may cause the formation of force moment sufficient for the fracture of structure elements of the mover. For these reasons, it is necessary to perform a synchronous mixture initiation by using sparks uniformly distributed in the bubble volume. The present work is devoted to the solution of this problem.

2. Experimental setup
Figure 1 demonstrates a principal scheme of experimental setup. In the Plexiglas cuvette with dimensions of 30x30x50 cm (1) filled with water, the model of gas-pulse water mover made in the form Plexiglas or PTFE disk of 100 mm diameter and 10 mm thickness (2) was located. To produce ring gas charges, a channel in the form of longitudinal semi-ring (3) (figure 2) with torus generating lines of diameters $D = 52$ mm and $d = 10$ mm was made in the lower part of disk 2. Along the bottom of ring channel, the pairs of discharge electrodes with the gap between them in the range from 0.3 to 1 mm were located at equal distance, the quantity of pairs $N = 2, 4$ and 6. The discharge pairs were connected in series. The disk was fixed co-axially with a plastic rod of diameter $d = 30$ mm (4). The rod (4) was ball-coupled to piezo-dynamometer (5) which measured force pulses in gas charge combustion. The dynamometer was located on a horizontal rigid beam (6). The time resolution of piezo-dynamometer
was 2.6 µs. To protect the measuring complex from water, a transparent plastic cylinder (7) was fixed on the disk (2). Gas discharges were blown out into the ring channel of the disk by using a syringe.

Figure 1. Principal scheme of experimental setup.

The discharge gaps were connected in series to the secondary winding of pulse transformer TDS-90 (8). The capacitor ($C = 4 \mu F$) was discharged to the primary winding of transformer by using a thyristor key with remote control (9). The time of turning on the thyristor was 50 µs. All the experiments were performed provided that the initial voltage values of the capacitor were equal to $U = 1kV$. All the measured parameters were registered by using the oscillograph TDS-210 (10) and were recorded by the computer. Both initiation and combustion processes were recorded by using mirror (11) and digital video camera MotionXtra HG-LE (12). In the experiments, gas charges of stoichiometric propane-oxygen mixture ($C_3H_8 + 5 \cdot O_2$) of volumes $V_g = 4, 5, 6 \, cm^3$ were used.

Figure 2a. Photographs of disk with 6-spark discharges. 

Figure 2b. Photographs of disk with ring gas charge in water (bottom view).
3. Experimental results

Figures 3 and 4 demonstrate the examples of records of combustion initiation (figure 3) and attenuation of combustion (figure 4) for stoichiometric propane-oxygen mixture in a ring channel at the interface between water and gas. The records are presented for two variants of initiation of the same charges: a) initiation of combustion by 2-spark charges, b) initiation of combustion by 6-spark charges.

Figure 3. Records of combustion initiation of propane-oxygen mixture of volume 6 cm$^3$: a) for 2-spark charges, b) for 6-spark charges.

Figure 4. Subsequent stages of combustion of propane-oxygen mixture of volume 6 cm$^3$: a) for 2-spark charges, b) for 6-spark charges.

Figure 5 shows the examples of oscillograms of force pulses obtained in the combustion of the same gas charges of volume of 5 cm$^3$: in the initiation of combustion by using 2-spark sources (dashed line) and in the initiation of combustion by using 4-spark sources. This figure also illustrates correlation of time intervals corresponding to the processes of ignition, combustion and its attenuation.

The results of performed series of experiments by using 2, 4 and 6-sparks show that the amplitude of force pulses rises as the number of sparks increases up to 30% for the same gas charges due to a more rapid combustion of the whole volume of gas charge. Figure 6 demonstrates the results of measurements of specific pulses ($P_1$) depending on the number of spark charges for gas charges of volume within the range from 4 to 6 cm$^3$. In figure 6, the scatter in values of specific pulses is clearly seen. This may be related to variation of cross-sectional diameter of the produced gas bubble. As the cross-sectional diameter of the bubble decreases, the velocity of registered luminosity front decreases up to its disappearing. The velocity spread of motion of luminosity front was within the interval from 100 to 165 m/s.

Note that the maximal luminosity of gas in the ring corresponds to the moments when wave fronts encounter (see figures 3, 4), for example: a) from 479 to 579 $\mu$s is for 2-spark initiation, b) from 363 to
513 µs is for 6-spark initiation. It is important to note that the maximal values of force (figure 5) coincide with the minimal values of gas luminosity since for 2-spark initiation ($V_g = 5 \text{ cm}^3$) it corresponds to $t = 1044 \mu s$, and for 4-spark initiation it corresponds to $t = 841 \mu s$.

Figure 5. Oscillograms of force pulses in the combustion of the same gas charges ($V_g = 5 \text{ cm}^3$) for 2-spark initiation (dashed line) and for 4-spark initiation; $\tau_i$ is an induction period, $\tau_N$ are the intervals of encounter of luminosity fronts for $N$ sparks.

Figure 6. Results of measuring the specific pulses for gas charges of volume within the range from 4 to 6 cm$^3$ in the initiation by using 2-, 4- and 6-spark charges.

The results of measuring specific pulses (figure 6) clearly show a considerable spread of measured parameter. This is related to the complexity to form a bubble of constant cross-section diameter on the solid surface. In the additional experiments, it has been found that the decrease of measured pulses is
due to variation in the cross-sectional size of ring bubble, i.e., due to formation of constrictions. In the zones of decrease of bubble cross-section, the combustion stopped abruptly at the initial stage. In this connection, it was necessary to compare the measured parameters by the most values of generated force pulses, which is the rule of selection, or by the controlled quality of the bubble. Thus, according to the chosen rule of selection, the difference between 2-spark and 6-spark initiation attains 20% for the presented measurements or specific pulses.

Note that the maximal values of specific pulses corresponded to the charges of volume $V_g = 6 \text{ cm}^3$ and the minimal values corresponded to the charges of volume $V_g = 4 \text{ cm}^3$. It is easy to explain this fact based on the theory [1]: as the cross-section of ring charge decreases, heat losses rise.

4. Short analysis of results

It follows from the obtained experimental results that by increasing the number of sparks of gas charge initiation, the efficiency of fuel combustion in this model of water mover rises due to the decrease of time of gas combustion in a given volume without increasing the velocity of both flame distribution and combustion front. Here, the electrical energy in the capacitor was unchangeable whereas the number of spark discharges with serial connection changed.

The records presented above show that the ignition of the whole mixture volume by 6 electrodes occurs from 166 to 182 µs earlier. This fact is observed in the oscillograms of measurements of force pulses (figure 5).

For the sake of quantitative estimation, it is possible to compare the efficiency of fuel combustion and the given number of spark sources by using measurements and calculations of time of luminescence fronts encounter $\tau_N$ ($N$ is the number of sparks). Based on the distance between spark gaps along the ring channel ($l$), and average values of velocity of luminescence fronts ($v$), the time of fronts encounter will be determined as $\tau_N = l/2v$.

For example, taking into account that $v \approx 130 \text{ m/s}$:
- for 2-spark initiation $\tau_2 = 314 \text{ µs}$,
- for 4-spark initiation $\tau_4 = 156 \text{ µs}$,
- for 6-spark initiation $\tau_6 = 104 \text{ µs}$.

The obtained results point to the fact that to attain more efficient fuel combustion determined according to the parameters of specific pulses, it is necessary to perform synchronous gas combustion by the initiators uniformly distributed in the whole charge volume owing to minimal time values of encounter and intersection of combustion fronts between the combustion sources. The luminescence fronts are not always perpendicular to the axis of combustion propagation. For example, it is seen in figure 3a (429 µs). The flame-like luminescence fronts intersecting the counter ones at angles from 30° to 45° were observed. Previously, the effect of flame-like luminescence was mentioned in [5] as “swallow tails”. To explain these effects, it is necessary to perform additional research and develop the experimental setups.

Conclusions

The obtained experimental results have shown that a multispark initiation of gas charges may ensure rapid and efficient combustion of a given volume of gas charge by increasing specific pulses of thrust. The amplitude of force pulses rises with an increase of spark number up to 30% for the same gas charges and the specific pulse rises up to 20% as the number of sparks increases from two to six.

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