# Formation of Toroidal Explosion Wave for Initiation of Detonation

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## 1 Introduction

Electric-discharge facilities for exciting high-current surface discharges provide ways and means of producing adjacent annular layers of a dense gas-discharge plasma can influence on the gaseous medium in axial regions at a distance equal to the radius of the plasma ring [1-4]. It was shown that gas-dynamic processes, excited by the plasma ring, play a central role in the energy transport from the ring to the gas region adjacent to the axis and that the mechanism governing this process is the generation of toroidal shock wave that begins to amplify as the center of the ring is approached. The cumulation of the toroidal wave arriving at the axis is not a trivial fact, because of arising the mass and energy flow in direction along the axis [5]. It is interesting to know the others possible channels of dissipation of the wave energy that would terminate an increase in temperature in the vicinity of the focus.

In the present paper the experiments and numerical calculations carried out to estimate the possibility of locally heating a gas in the region of focusing of a convergent shock wave are described. The problem was stimulated, in particular, by the applied problem concerned with initiation of the gas detonation and combustion of fuel-air streams in the axial region of the combustion chamber. The fine gas-dynamic phenomena accompanying an annular electric discharge excited in air have been studied. It is shown experimentally that the discharge generates a toroidal shock wave that converges at the axis of symmetry. A mathematical model describing the cumulative process of focusing of a toroidal shock wave has been constructed. The results of measurements of the characteristics of shock processes accompanying the discharge are shown to agree satisfactorily with the results of calculations, which make it possible to estimate the gas temperature that can be attained in the cumulation region at some distance from the center of the ring.

## 2 Experimental layout. Measurement techniques

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The experiments were performed using a setup based on an annular multielectrode discharge system. Fig. 1 shows the discharger ready for mounting and during operation. The diameter of the annular discharger is $D_d \cong 10$ cm. The ring thickness is $2h \cong 1.2$ cm. The discharge is excited in air at atmospheric pressure.

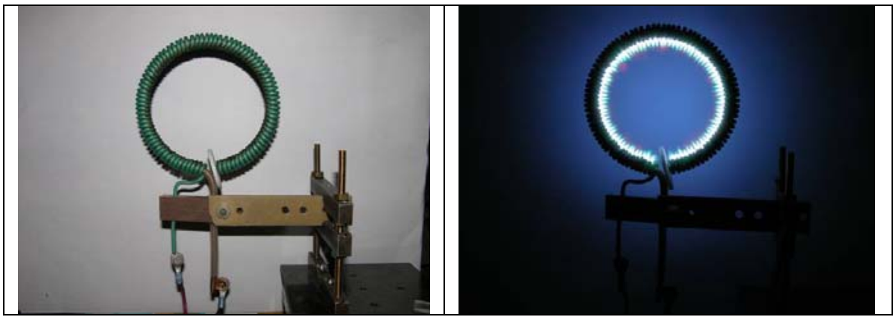

Figure 1.The electric discharger: before mounting at the experimental bench and in operating condition.

Measurements of the dynamics of toroidal shock waves were based on several diagnostic methods. The experimental layout for shadow photography is used to trace the formation and radial collapse of shock waves. The electric circuit is applied for measuring excess pressure at different points at the symmetry axis and also at different positions of the pressure sensor (PCB PIEZOTRONICS model 132A32) in the radial direction. The output from the sensor is fed into a Tektronix TDS 210 oscillograph. The refraction detectors are used to control the axial (Mach) shock waves and perturbations running along the radius. The axial propagation of gas-dynamic perturbations accompanying the focusing of the toroidal wave was studied with the help of the pressure sensor by shifting it along the Z-axis from realization to realization and also with the help of the refraction detector by shifting the diagnostic laser beams along the Z-axis over a distance ΔZ.

## 3 Experimental results

In Fig. 2 are presented typical successive shadow pictures of toroidal shock wave converging at the axis going through the ring center (Figs. 2a-2d).The shock wave reflected from the axis is in Fig. 2e.

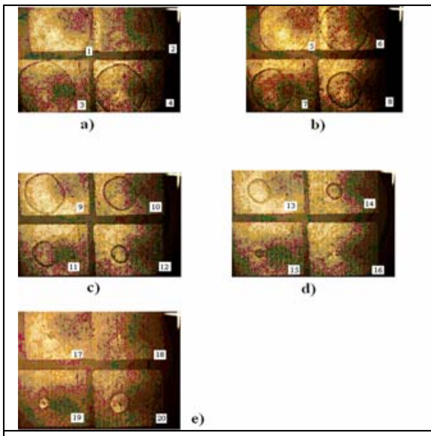


Figure 2. Typical successive shadow pictures of toroidal shock wave.

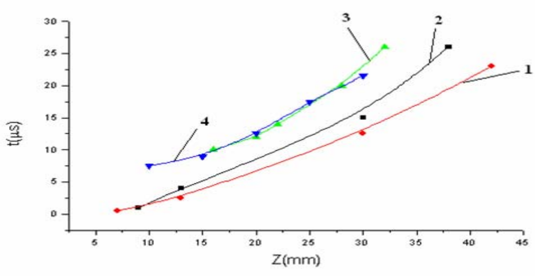


Figure 3. Time dependence of the z-coordinate of the front of the Mach (axial) shock wave at the axis of symmetry:
(1) calculation for $E_0 = 500$ J, (2) calculation for $E_0 = 200$ J,
(3) experiment (measurements with the refraction detector),
(4) experiment (measurements with the pressure sensor).

The results of measurements the z-coordinate of the front of gas-dynamic perturbation at various times are presented in Fig. 3.

# 4 Numerical calculations of the process of focusing of a toroidal shock wave

The gas flow initiated by a toroidal electric discharge with instantaneous energy release in air was numerically studied. The energy release was modeled by a corresponding increase in the internal energy of the gas in a specified discharge region. The system of equations describing the axisymmetrical non-steady flows of an ideal multicomponent gas mixture was used. The equations were solved numerically using the scheme proposed by S.K. Godunov [6] with the nonmoving mesh of variable size. The calculations were performed under conditions of experiments conducted. According to calculations, reflection of a shock wave from an axis of symmetry at first has regular character, which is gradually transformed to the reflection composed of Mach wave with conic shock before it (Fig. 4). The last is formed due to height velocity jet arising near the axis. Fig. 5 shows the calculated pressure distributions along the axis at the times subsequent to the focusing of the wave for discharge energy $E_D$=500 J. The time histories of the wave coordinates at the axis are presented in Fig. 3, where the calculated curves are compared with experimental ones.

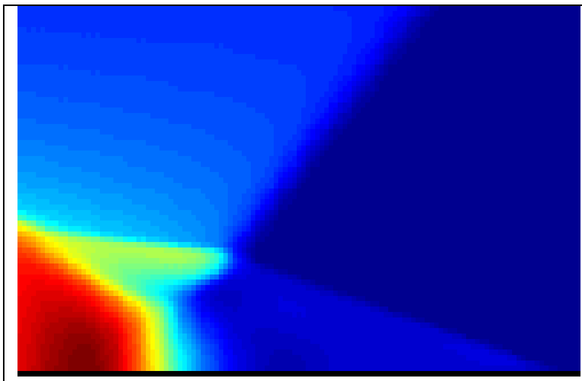

Figure 4. Pressure field illustrating the complicated picture of toroidal shock wave reflection.

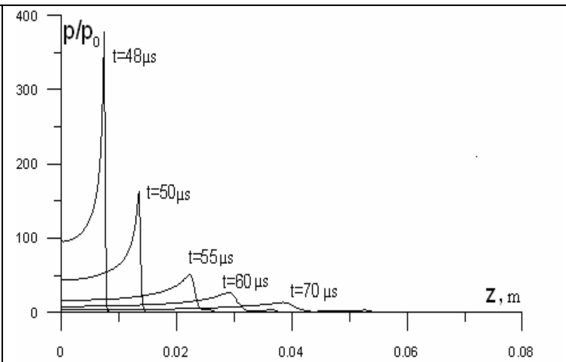


Figure 5. Calculated pressure dependences at the axis on the longitudinal coordinate z for various times.

# 5 Discussion of the results

A comparison of the measured and calculated coordinates of the front in Fig. 3 shows good agreement. However, the experimental points lie over the calculated curve. The satisfactory agreement in Fig. 3 allows us to conclude that the theory adequately describes the collapse of a toroidal shock wave under study, in particular, considering the axial (along the Z-axis) propagation of a Mach shock wave formed at irregular reflections of the shock wave from the axis of symmetry [7]. It follows from the experiments and calculations that, at energy release per unit length 5 – 10 J/cm, it is possible to heat the gas up to temperatures above several thousands of Kelvin degrees in a relatively small axial region of volume $10^{-3}$ $cm^3$ located some distance away from the discharger. The energy transfer from the discharge to this region occurs through gas-dynamic perturbations generated by the discharge.

The complex study conducted, being of fundamental importance, were stimulated, however, by the applied problem - initiation of the combustion in the axial region of a ramjet aviation engine. Considering the obtained results from this viewpoint, we should mention that the heating of a gas to the ignition temperature of the mixture would realized in relatively small volumes, and the temperature would maintained at a high level for a short (microsecond) time. Now, we are not in a position to assert that the ignition of a fuel-air stream is realizable. However, this possibility must not be ruled out, first of all, in connection with a series of experiments on initiation of the combustion of gas mixtures by laser sparks, by microwave discharges and gliding surface discharges, which have revealed the generation of long-lived high-temperature microscopic plasma objects eventually causing the volume combustion of gas mixtures.

The problem of cumulation of toroidal shock waves in chemically active gas mixtures is of obvious fundamental interest. For this reason, as a next step in our studies, we plan to pass from the air medium to combustible gas mixtures.

# 6 Conclusion

We have performed experiments for studying the generation of a toroidal shock wave by a ring electric discharge in air at atmospheric pressure. These experiments show that the shock wave converges at the axis of the ring. A mathematical model was constructed for describing the process of focusing of the shock wave, and the results of calculations were compared with the experimental results. This made it possible to estimate the energy released in the ring discharge in which the experimental dynamics of the toroidal shock wave convergent toward the axis and axial shock waves (Mach waves) accompanying the cumulative process of focusing is close to the calculated dynamics. The experiment is in good agreement with the theory assuming that the energy is released instantaneously and its value is close to the experimental value. Relying on the calculations, we estimated the gas temperature near the cumulation region at the axis at some distance from the center of the ring. Thus, for a ring discharger of radius 5 cm and with released energy about 200 J, the gas temperature the axis of the ring at a distance of about 1 cm from its center can reach 6000 K.

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