Microparticles and plasma stream registration during cylinder compression of a metal liner

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Abstract. In this paper, the authors show the possible way of registration of the microparticles and plasma jets escaping from the inner surface of metal cylindrical liner when the detonation wave reaches it. The liner is allocated within experimental setup and is compressed by detonation products. Jets have been registered by Langmuir gauge which connection circuit was developed by the authors. The authors also developed a technique a method for detecting the signal under study. Average particle (about 4 km/s) and plasma (about 7 km/s) jet velocity is estimated by using the developed technique for copper liner compressed by detonation products. The results of this experiment correlate with those for plane setup.

1. Introduction
Studying of cylinder liner compression by detonation products appears to be of great practical importance in various areas of theoretical and experimental physics. As was previously observed for the plane setup and during the large-scale experiments, when a strong shock wave reaches free surface of the liner, plasma and fine particles stream is formed. The velocity of this jet is almost two times exceeds the particle velocity of liner material [1–3]. There was given estimation of metal liner temperature when a shock wave reached its inner surface [2,3]. To solve a number of problems, in particular, the problem of initiating thermonuclear fusion, it is necessary to monitor the concentration of particles and plasma in a compressing volume. Considering those large-scale experiments quite expensive, the authors advise to register the escaping microparticles and plasma jets under laboratory conditions by means of electrical Langmuir gauge. The same experimental setup was previously used to study the formation of cylindrical detonation wave by the multipoint initiation method [4]. For the experiments described in the following paragraphs a thin-shelled metal liner was placed in the center of the setup. Air was pumped out from the liner and Langmuir gauge was installed along its axis. The fine particles and plasma jets, formed at the time when the shock wave reaches the liner inner surface, are supposed to move towards the gauge. The electrical signal, generated on the stream approach to the gauge, had been registered by means of a special scheme.

2. Experimental
Experimental setup (figure 1) has the form of ring-shaped charge with the outer diameter of 216 mm and wall height of 20 mm and is sited on a metal base. Initiation points are evenly spaced on the outer side of the charge. There are 48 of them in the instant case.
Every point of initiation is the bottom of the plastic tube with the diameter of 5 mm, filled with plastic explosive. One side of the tube contacts with the main charge, while the other side is connected to the detonation cord. Loose ends of the 48 cords are put together and connected to the detonator. The junction point of the 48 cords is on the rear side of the setup. All points are simultaneously initiated after the detonator triggering and the detonation wave passage along the cords. The special aspects of cylindrical detonation wave formation are described in details in the works [4, 5]. In the center, concentrically with the charge, a copper liner of the diameter with 90 mm and wall thickness of 1.4 mm was placed. In order to validate the setup operation, a high-speed registration of the detonation wave exit to the liner and initial stage of the liner compression was performed. The photographs were made by “Nanogate 4BP”, a high-speed camera with time resolution in the nanosecond range. The results of the observation are shown in figure 2.

The photographs of figure 2 illustrate the cylindrical detonation wave formation. At the 42-\(\mu\)s mark, one can observe that the wave is of cylindrical shape and is sufficiently coaxial on its approach to the liner; during the 45-th \(\mu\)s, it reaches the metal liner, while at the 47 and 49-\(\mu\)s marks, the initial stage of the liner compression by detonation products is clearly seen. During the measurements performed with the gauge, the liner was sealed with covers on both ends. Langmuir gauge was installed along the liner axis. Air was pumped out from the liner inner volume where a forevacuum was created.

Langmuir gauge is commonly used for plasma diagnostics. This method is based on the measurement of irradiation current density on one or more electrodes inserted into a plasma depending on its potential. The conductive part of the gauge is made of copper \(d = 0.65\) mm and is inserted in the liner. The electrode is put inside the ceramic tube of outer diameter of 2.4 mm. The copper electrode extension length is 5 mm. Figure 3 shows Langmuir gauge electrical connection diagram.

The electrical layout is connected to PSU with \(-20\) V. The power supplied to the setup by long wires (\(L \approx 6\) m), is shunted by capacitor C1. The ground electrode is connected to the cylinder
Figure 2. History of cylindrical wave exit on the free surface of metal liner (time marks from the moment of the layout trigger).

Figure 3. Langmuir gauge connection diagram.

metal liner. After the voltage division on R1, R3 and R2, R4 resistors, the electrical potential in points A and B comes to the value of $-10\, V$. Point A of the diagram is Langmuir gauge; point B is where the comparing signal is measured. The gauge is inserted in forevacuum of the setup volume. The contact B is placed in an undisturbed zone adjacent to the setup. The signal from the gauge was registered by Tektronix TDS3034 oscilloscope, where two channels of different sensitivity were used with the aim of extending of the regarding range. The reference signal was also supplied to two oscilloscope channels with different sensitivity. On signal processing data measured by the channel 1 were subtracted from the data obtained from the channel 3, and the channel 2 data were subtracted from channel 3 data. Consequently, the electromagnetic interference effect on the recorded signal was removed, due to interference phase coincidence in metering and reference channels. C2 and C3 condensers did not let strong dc signal component at the input of high-sensitive oscilloscope channels.

The gauge with the $-10\, V$ potential is supposed to operate in ion current saturation mode. Due to minor variation of ion current under the conditions of potential change on the gauge,
from the part of the gauge the circuit represents high-resistance power source. The circuit as a whole is matched to the wave impedances with the cables (until the moment the probe closes to the ground by the incoming liner). It helps to avoid high-frequency signal distortion. Effective resistance of the gauge in the scheme is 25 Ohm.

3. Results and discussion

In figure 4, one can see low- and high-resolution oscilloscope records of current signals measured by means of Langmuir gauge.

On the low-resolution oscillogram [see figure 4(a)] point a corresponds to occurrence of a weak signal on the high-resolution oscillogram [see figure 4(b)]. Figure 4(a) oscillogram shows that at the moment b microparticles, that escaped from the liner on shock wave exit on its inner free surface, reach the gauge at the velocity of about 4 km/s. On the impact with the gauge surface these microparticles cause electron emission and current that increases in time. These processes are described in detail in [6].

On the oscillogram with a higher resolution [see figure 4(b)], after a moment of time a there appears a weak increasing current associated with the arrival of positively charged plasma ions emitted from the surface of the liner when the shock wave exits. Leading ionic cluster velocity is evaluated on the basis of initial distance to the liner and the time of signal occurrence at the a point and results to be about 7 km/s.

Similar situation, i.e., occurrence of relatively weak increasing ion current and more intensive current coming from electron emission on particles arrival on the gauge, can be observed during the experiments with plane detonation waves [2].

4. Conclusion

With the scope of evaluation of particles and plasma jets, escaping from the inner surface of metal liner when it is reached by detonation wave, there was proposed a potential registration method using Langmuir gauge. The proposed method was verified under laboratory conditions by the using setup which requires low weight of high explosive. Test results have shown the formation of cylinder detonation wave, which is quite uniform at a certain point when it reaches metal liner placed concentrically with the charge in its center. In the experiments using Langmuir gauge the signals of two different levels were registered. From these signals it can be concluded that microscopic particles come into the gauge, which cause the emission of electrons, as well as the plasma. These jets are characterized by different velocity. The particles stream velocity is about

Figure 4. (a) Low-resolution and (b) high-resolution current signals on the Langmuir gauge.
4 km/s, while the plasma jets velocity is about 7 km/s. Diagnostic method where registration of microparticles and plasma stream escaping free surface of cylinder liner, affected by a strong shock wave, is performed by means of electrical Langmuir gauge can be used for unique large-scale setups. Another advantage of the method proposed in this paper is the absence of particles and plasma stream disturbances.

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