The liner brightness temperature measurement by two channel optical pyrometer

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Abstract. Measurability of liner inner surface brightness temperature by two channel optical pyrometer is shown. Liner is compressed by detonation products in large-scale experiment. Absolute radiant intensity values were obtained by measuring optical system channel calibration involving tungsten and xenon radiation sources. Three ways of surface brightness temperature measurement are presented at wavelengths of 620 and 850 nm. Using the developed procedure copper and steel liners behavior (brightness temperature, average speed) under compression by detonation products are evaluated.

1. Introduction
Experimental studies of metallic liner compression under the action of detonation products are of great practical importance in ultrahigh pressure generation, energy cumulation and high speed explosive device creation. As previously observed, when a strong shock wave reaches free surface of the liner, plasma and fine particles flow is formed. This flow speed is almost double the mass velocity of liner material [1–4]. Besides, there is probability of hydrodynamic instabilities formation that leads to non-uniform compression of the liner. One of the parameters determining the condition of a cylinder liner surface, affected by the shock wave, is temperature change. Temperature measurement in a large-scale experiment involves a certain difficulty. This paper introduces a method for brightness temperature measurement of an axisymmetrically compressed liner, which is known as spectral pyrometry method. Temperature measurement was performed by utilizing optical spectral channel developed in IPCP RAS.

2. Experiment
2.1. Calibration
In order to obtain absolute radiant intensity values, the channel of measuring optical system was calibrated. As standard radiator, we used calibrated tungsten-ribbon lamp SIRSh-8.5-200-1. Radiating tungsten filament temperature was measured by an optical pyrometer EOC-66, wavelength 0.65 ± 0.01 μm, with an accuracy of 6 K. Based on the results of the brightness temperature measurements, the true temperature of the tungsten filament was determined for further tungsten emissivity ε(T, λ) definition while calculating brightness temperature of the measured radiator. Transmittance of quartz, glass, and plexiglas optical windows was taken under Fresnel conditions for normal incidence, considering the relationship between the refractive index and the wavelength. The operating point of the lamp with W thermodynamic temperature
Figure 1. The construction of high-speed optical channel: 1—input port; 2, 2’—focusing lenses; 3—bandpass optical filter; 4—photodiode; 5—high-speed amplifier.

was 2700 K. Methodology described in [5] allows the use of a radiating source calibrated at one wavelength (650 nm) for measurements in a broad wavelength band (250–2700) nm where the function \( \varepsilon(T, \lambda) \) is known. For 850 nm:

\[
T = \frac{C^2}{\ln\left\{\frac{S_i\varepsilon T_{re} + C_{lb}T_{re}\exp\left(\frac{C^2}{(\lambda T)}\right) - C_{lb}T_{re}}{S_i\varepsilon T_{rc}}\right\}},
\]

\( C^2 \)—a constant equal to \( 14384 \times 10^3 \) nm K; \( \lambda \)—experimental wavelength condition for measurement, nm; \( T_l \)—lamp temperature; \( \varepsilon \)—tungsten emissivity; \( T_{re} \)—transmittance of optical windows for calibration; \( T_{re} \)—transmittance of windows for measurement; \( C_{lb} \)—calibration signal; \( S_i \)—measured signal.

Extent of brightness signal measurement error did not go out of \( \Delta T = \pm 200 \) K range.

2.2. Measuring equipment

The measurement was made using high-speed optical channel (figure 1) under the following conditions:

- 3 dB Bandwidth: 0–100 MHz.
- Wavelength: 620 nm, 850 nm.
- Spectral channel width: 10 nm (620 nm), 40 nm (850 nm).
Figure 2. Diagram of the measurement scheme number 1 (wavelength 620 nm): 1—optical fiber; 2—holder; 3—lens; 4—focusing cone; 5—ceramic tube for probes; 6—plexiglas protective window; 7—glass protective window; 8—liner; 9—spot focus.

- The lower limit of the registered temperatures, limited by noise: 1500 K (100 MHz band), 1000 K (at 20 MHz).
- Silica fiber, a step index, diameter of 400 \( \mu m \), length (40–60) m.

Signals were recorded by means of Tektronix 7054 oscilloscope.

2.3. Results

As a result of the liner axisymmetrical compression experiment inner surface temperatures were recorded for copper and steel liners. The measurements were performed in 3 schematics that follow.

2.3.1. Scheme 1

The experiment based upon scheme 1 (figure 2) was run on steel liner, wall thickness 5 mm.

The optical signal was transmitted through the optical fiber 1 (quartz-polymer 350 \( \mu m \)). In the holder 2 a lens 3 (focal length 50 mm, diameter 25 mm) was fastened. The radiating source is located so that homocentric light cone 4 has its focus on the inner surface of the liner 8. Plexiglas windows 6, 7 were positioned between the lens and the focus. The blur circle 9 is of the extent of about 10 mm. Light cone passed above the tube 5, containing the probes. 620 nm wave filter with spectral channel bandwidth of 10 nm was used. Figure 3 shows the obtained results of the brightness temperature.

On the initial segment up to 78 microseconds the results are affected by intensity signal emitted by pulse explosive argon lamp that was used in the experiment. Segment (cd) shows the measured temperature drop when the shock wave reaches inner surface of the liner. One can observe transition from the recording of the argon lamp scattered light to the recording of the thermal radiation signal emitted by the liner surface. When the shock wave reaches the
Figure 3. The brightness temperature for scheme 1 (wavelength 620 nm): cd—exit of the shock wave on the inner surface of the liner.

![Brightness Temperature Graph](image)

Figure 4. Diagram of scheme 2 measurements (wavelength 620 nm): a—viewing angle of the fiber; 1—glass tube; 2—end bushing; 3—glass prism; 4—clamping ring; 5—cylindrical bush; 6—optical fiber.

![Diagram of Scheme 2 Measurements](image)

liner surface in a time ≈ 200 ns, its reflectivity decreases drastically while emissivity factor increases. In earlier experiments conducted in IPCP RAS the abrupt change of the surface reflectance affected by shock wave has already been registered. Temperature values that are
Figure 5. Diagram of scheme 3 measurements: a—viewing angle of the fiber; 1—glass tube; 2—curved portion of the optical fiber; 3—optical fiber; 4—probe; 5—probe cable.

close to the surface brightness temperature are being registered within the timeframe of \( \sim 1 \mu s \). Later observation (following the 79th microsecond) under conditions of its laterality at glancing viewing angle appears impractical to interpret the results as liner movement causes field of view movement along the surface. Due to the conditions of observation at an angle to the surface to interpret the signal after \( \approx 79 \mu s \) is difficult, since the movement of the liner causes the observation area move on the surface. The set-up 1 experiment verifies the spectral pyrometry method for liner temperature measurement. Estimated temperature values were about 3000 K at the wavelength of 620 nm.

2.3.2. Scheme 2

The experiment based upon scheme 2 (figure 4) was run on steel liner, wall thickness 5 mm.

In the center of the liner along its axis the glass tube 1 was placed. The end bushing 2 ensured leaks and provided support for the glass prism of total internal reflection 3, with the edge of 5 mm. From the other side the prism was fixed by the ring 4. The optical fiber was installed in cylinder block with a hole 5 and engaged freely with the tube until it hit the prism. The optical signal was transmitted through the optical fiber 6 (quartz-polymer 350 \( \mu m \)).

In this experiment there was clearly observed an optical signal with a level of brightness temperature \( T \approx 2600 \) K.

2.3.3. Scheme 3

The experiments based upon scheme 3 (figure 5) were run on steel liner, wall thickness 5 mm and copper liner, wall thickness 2 mm.

The optical signal is transmitted through the optical fiber with a diameter of 400 \( \mu m \).

Under the experimental conditions the internal diameter of the glass tube 1 was reduced to 3 mm. Such dimensions made it impossible to place a TIR prism inside the tube. The viewing axis was turned to the liner surface by means of the curved section of the optical fiber 2. The
Figure 6. The brightness temperature for scheme 3 (steel liner, wavelength 850 nm): a—appearance of a signal from an explosive argon lamp; b—output shock wave occurs on the inner surface of the liner; c—signal beyond the limit of the recording range.

Figure 7. Steel and copper brightness temperatures (wavelength 850 nm).
probe 4, which was located on the cable part 5, was placed near the optical fiber. The central filter wavelength had been chosen from the infrared part of the spectrum at 850 nm, bandwidth is of 40 nm.

At the time point a, the signal of explosive argon lamp appears. This signal changes only slightly during the entire measurement time. At the time point b the output shock wave reaches the inner surface of the liner. The brightness rises and at the time point c the signal goes beyond the limiting range of the record. Dotted curve path in figure 6 is obtained by subtracting the argon lamp radiation signal out of the basic signal.

In the experiments based upon scheme 3 (figure 7) with a copper and steel liner we used a spectral 850 nm filter as well as cutoff liquid filter (CuSO$_4$ $\cdot$ 5H$_2$O solution in water). Such a filter transmits almost completely wavelength of the visible spectrum (350–550) nm and absorbs radiation at a wavelength of 850 nm [6]. In this case one can use a complete absence of the argon lamp stray light.

3. Conclusions

During this large-scale experiment we took temperature measurements of the inner surface of metal liner under compression by the detonation products. Depending on the experimental conditions any of the three presented measuring techniques can be used. Selected schemes can be easily adapted to the conditions of the experiment. Using a high-speed optical channel, temperature values of 2600–3200 K were recorded at a wavelength of 620 nm for a steel liners for schemes 1 and 2. Scheme 3 showed temperature changes from 1800 K to 3300 K for steel and copper liners in the central part following the compression at a wavelength of 850 nm. The average speed of liner surface, determined by the optical signal on the area of maximal diameter, is of about 7.1 km/s.

Acknowledgments

This work was supported by program of the Presidium RAS No. 13P “Thermophysics of high energy densities”. The experiments are performed on the equipment provided by the Moscow regional Shared Explosive Center.

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