

# Visualization of explosion phenomena using a high-speed video camera with an uncoupled objective lens by fiber-optic cables

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## Abstract

Visualization of explosion phenomena is very important and essential to evaluate performance of explosive effects. Explosion phenomena generate blast waves and fragments from cases. We must protect our visualizing equipment from the impulsion. When the flash X-ray system is used at an explosion site, the tube heads, from which X-ray is irradiated, are surrounded with steel plates to protect from blast waves and fragments.

The high-speed video camera HPV-1 has been applied to visualize many types of explosion effects at many universities and laboratories. The control unit of the video camera is separated from the camera head with cables, but the lens is coupled with the camera head.

We had an idea of trying to separate the lens from the camera head, actualizing shootings with the video camera under the severe blast environment. We employed a fiber-optic cable of 1.8 m length to separate the front lens from the camera unit. Two lenses inserted a tandem ring were set to connect the cable with the camera unit.

We obtained some clear images from this newly comprised camera system at normal temperature and pressures, using a dichroic halogen lamp as the light source. Furthermore, we tried shootings under emission by detonation at an explosion site. We could also obtain clear images using appropriate additional light sources.

We decide that this system is very useful for shootings at a dangerous place, e.g. explosion site and from the direction of unachievable under normal circumstances.

**Keywords:** High-speed video camera, Fiber-optic cable, Moving image, LSC jet formation.

## 1. Introduction

Several means of visualizing explosion phenomena have presented. Streak Cameras, High-speed video cameras and flash X-ray systems have been mainly applied to obtain images of explosion. Dome-type explosion sites have been placed at many universities, institutes and companies in Japan, because of reducing explosion noise and vibration. Several explosion sites have windows for observing the inside of the dome. When streak cameras and high-speed video cameras are used, images of explosion are obtained

to shoot through the windows. Because, if the cameras set in the site, fragments and blast waves from explosion would ruin the mechanism.

Flash X-ray systems have been used to visualize hyper-velocity phenomena, such the jet of shaped charges. The system consists of the console, pulsars and X-ray tubes. The tubes, which are surrounded and enclosed by steel plates for protection, are located close to explosion samples in the dome to irradiate X-ray and get an image on a film.



Fig. 1 Overall setup of laboratory-scale shooting tests.

High-speed video camera HPV-1 is fabricated by Shimadzu Corporation and has been applied to visualize explosion effects at many universities and laboratories. The control unit of the video camera is separated from the camera head with cables, but the lens is coupled with the camera head.

We had an idea of trying to separate the lens from the camera head, actualizing shootings with the video camera under severe blast environment. A fiber-optic cable was employed to separate the front lens from the camera unit.

In this paper, preliminary tests at a laboratory and explosion tests at a dome-type explosion site are described. Moving Images from these tests are clear and give us a lot of information to evaluate explosion effects.

## 2. Theoretical

An objective lens of cameras provides an image. The positional and brightness information of the image does not deteriorate in a fiber-optic cable. An image transferred using a fiber-optic cable might cause light loss by more than 50 percent. High-speed image sensors are absolutely necessary to achieve high speed imaging processing. The ISIS-CCD (In-situ storage image sensor – charge coupled device) of the high-speed video camera HPV-1 has high sensitivity<sup>1)</sup>. We decided that the high speed imaging system will put into practice using the camera with an uncoupled objective lens by fiber-optic cables.



Dichroic halogen lamp Zoom lens 16 mm – 100 mm

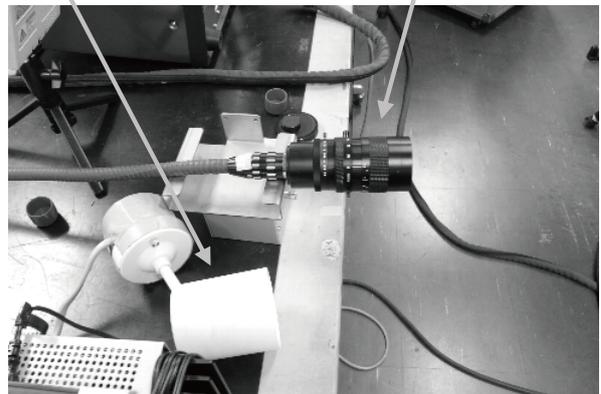


Fig. 2 Camera head and C-mount lens in detail.

## 3. Experimental

### 3.1 Laboratory-scale experiments

Fiber-optic cables can transmit images and signals to an arbitrary direction and distance. As a result of investigation for a couple of months, the Schott Fiber Optics' wound image bundles were selected for image transfer. The cable, which the Schott describes as a bundle, is 1.8 m length and 0.032 m diameter, sheathing a stainless steel hose with a polyolefin cover.

A setup of laboratory-scale shooting tests is shown in Fig. 1. A part of a camera head and a C-mount lens are minutely shown in Fig. 2. The camera head is connected the Schott's fiber-optic cable with the lens 1, tandem rings and the lens 2. The C-mount lens, which has zoom ratio from 16 mm to 100 mm, is connected the cable. A dichroic halogen lamp as the light source is shown at the side of the boom lens.

The condition of shootings is as follows; the frame rate is 30 fps (frame per second), the exposure time 1 / 2 second, the gain 10 or 7, and the illumination intensity 1,200 lux at the surface of the photographic subject. The allocation of the shooting tests is shown in Table 1.

### 3.2 Experiments at an explosion site

Our experiments at an explosion site were conducted at the explosion pit A in the Shock Wave and Condensed Matter Research Center, Kumamoto University<sup>2)</sup>.

Table 1 Shooting condition.

No	Tandem lens ratio	Lens 1 mm f	Lens 2 mm f	Tandem rings	C-mount lens mm f	Field angle mm	Target-lens distance m
1	4:1	105 1.8	28 2.8	77 → 72, 72 → 62, 62 → 49	16 2.8	395	1.2
2	4:1	105 1.8	28 2.8	77 → 72, 72 → 62, 62 → 49	100 2.8	65	1.2
3	3:1	105 1.8	35 2.8	77 → 72, 72 → 62, 62 → 49	16 2.8	470	1.3
4	3:1	105 1.8	35 2.8	77 → 72, 72 → 62, 62 → 49	100 2.8	100	1.3
5	3:1	85 1.4	28 2.8	77 → 72, 62 → 49	16 2.8	460	1.2
6	3:1	85 1.4	28 2.8	77 → 72, 62 → 49	100 2.8	80	1.2

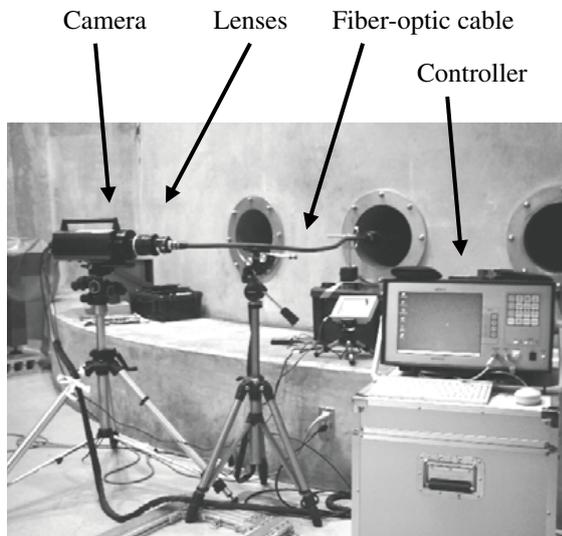


Fig. 3 Configuration of camera, lens and fiber-optic cable.

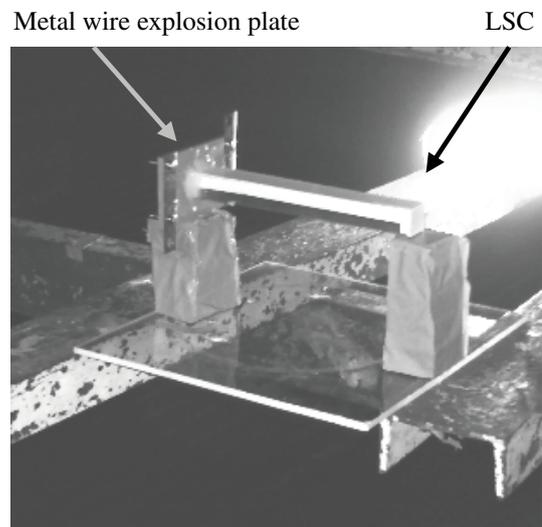


Fig. 4 Test setup of a LSC explosion.

After a process of trial and error, we determined that the lens 1 was 105 mm f 1.8, lens 2 28 mm f 2.8, fiber-optic cable 1.8 m length and C-mount lens 75 mm f 2.8. The size of tandem rings was 3 groups: 77 to 72, 72 to 62 and 62 to 49 mm. A neutral density (ND) filter was fixed at the front of the C-mount lens. The density was selected to be equivalent to approximately 5.0 m length cable, because some explosion sites without windows only have lead-in holes and the length of the hole is commonly 5 m. The configuration of the camera, lens and fiber-optic cable are shown in Fig. 3.

The condition of shooting is as follow; the frame rate is 1 Mfpt, the exposure time 500 ns.

At first, we experimented if a good image is obtained by the light from a metal wire explosion, even where the fiber-optic cable is added. Xenon flash light system was used as an auxiliary light source from back and front of the photographic subject. Finally, we determined that the light from the explosion is enough to obtain clear images, using some mirrors for reflection.

Linear shaped charges (LSCs) were selected as a main object of shooting. A copper plate 1 mm thickness was formed M-shaped. Liner angle is 90 degree, charge width 20 mm, and total length 200 mm. PETN (Pentaerythritoltetranitrate) was loaded inside of the formed metal and the charge weight was approximately 59 g. The loading density was 980 kgm<sup>-3</sup>. The LSC covered with a plastic case. Metal wire explosion was applied to initiate the LSC. Several three-ply copper wires, one of which is 0.175 mm diameter, were attached on a polyvinyl chloride plate. The plate was set on the end face of the LSC. The capacitor 12.5 μF capacitance was charged up with 40 kV, then the electrical charge was discharged to the copper wires. PETN was initiated by the discharge. The test setup is shown in Fig. 4. The light from the initiation was enough to get clear images and several mirrors were used to have the light reflected.

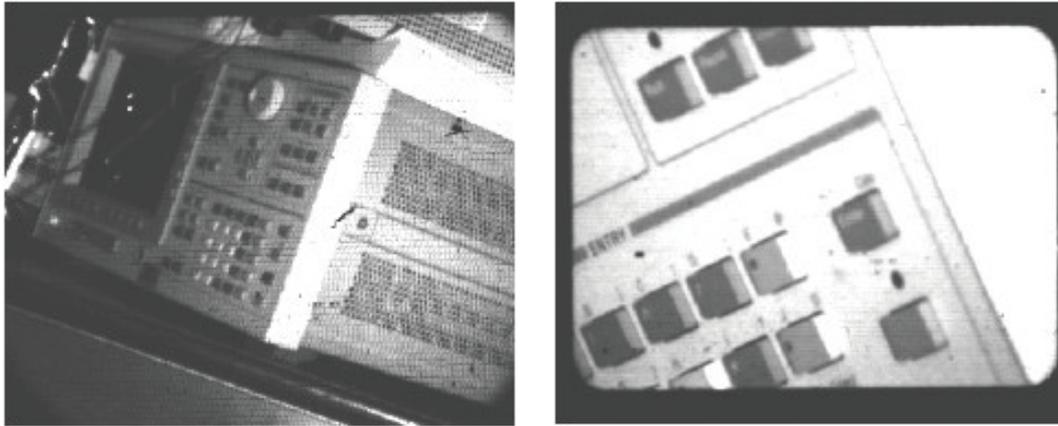


Fig. 5 Still images of No. 1 test and No. 6 test.

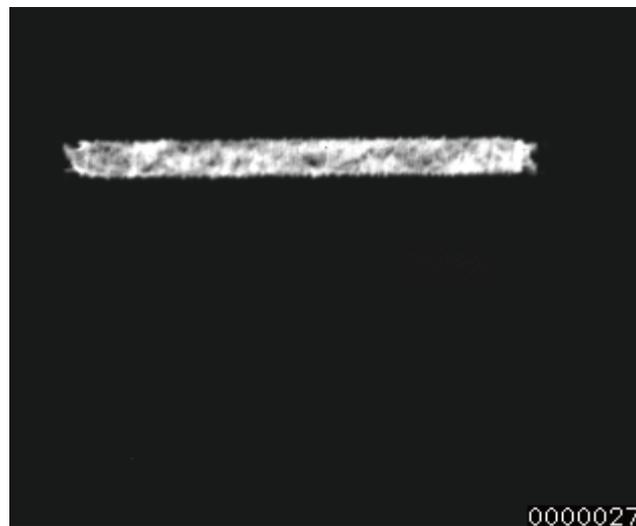


Fig. 6 An image of a metal wire explosion test.

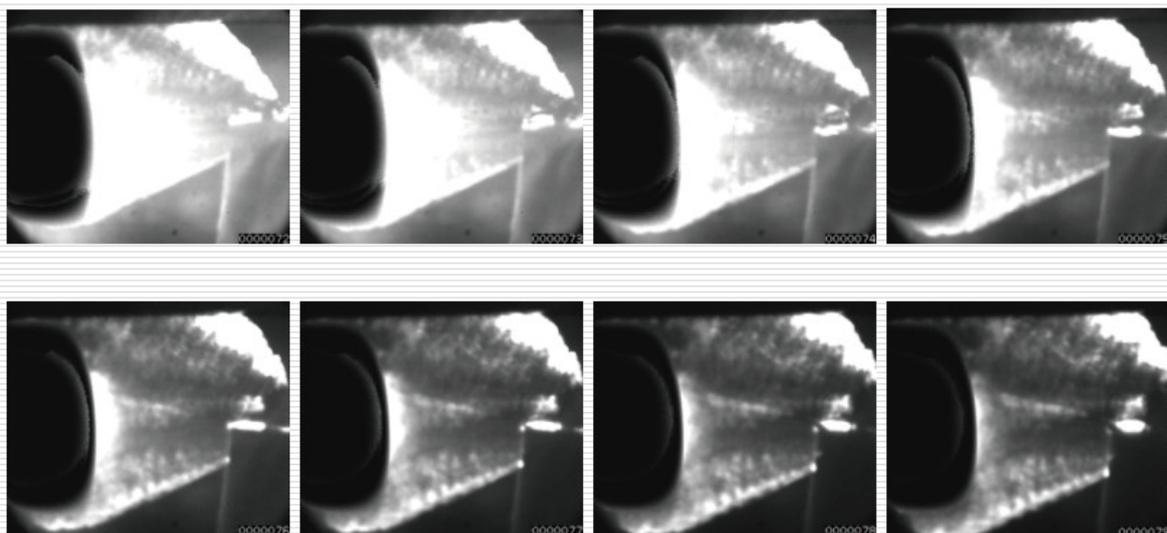


Fig. 7 Time-lapse images from 72 to 79  $\mu$ s.

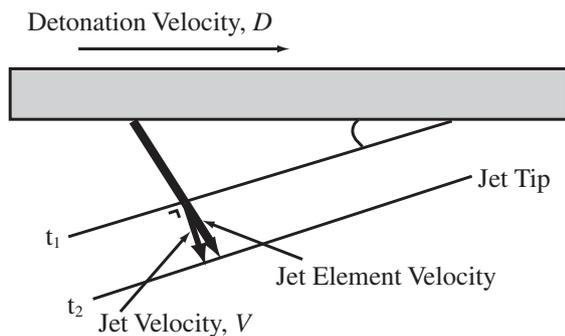


Fig. 8 Moving schematic of LSC jet.

## 4. Results

### 4.1 Results at laboratory scale

We could obtain still images to use the new configuration of lenses with a dichroic halogen lamp as the light source. The still images of No. 1 and No. 6 tests are shown in Fig. 5. We confirmed that shooting through the fiber-optic cable could be available.

### 4.2 Results at the explosion site

We obtained clear moving images after trial-and-error shootings. Image of a metal wire explosion is shown in Fig. 6 as a time-lapse picture at 27  $\mu\text{s}$  from the trigger time of the camera.

Image of the LSC explosion is shown in Fig. 7 as several time-lapse pictures from 72 to 79  $\mu\text{s}$  from the trigger time of the camera. Elongation of LSC jet was clearly observed in these pictures.

## 5. Discussion

Although we obtained moving images for elongating of LSC jet, we should confirm whether or not the tip velocity of the jet accords with the conventional theories. We also had other information from the moving images about the detonation velocity of PETN.

At an early stage of the moving image shown in Fig. 7, the detonation front of PETN was observed because the top part of the LSC has no confinement or no cases of metal plates. From two pictures at 38 and 45  $\mu\text{s}$ , we measured that the detonation front proceeded 40 mm. Therefore, the detonation velocity of PETN was 5,720  $\text{ms}^{-1}$ . We could confirm that the value was reasonable, comparing it to several published data.

A schematic illustration of LSC jet movement is shown in Fig. 8<sup>3)</sup>. The detonation velocity of LSC represent  $D$  and the jet tip proceeds with time at a certain angle  $\theta$ . The jet tip velocity  $V$ , therefore, is given as

$$V = D \sin \theta \quad (1)$$

We measured that the angle was 30 degree and the detonation velocity was 5,720  $\text{ms}^{-1}$  as mentioned above. We substituted these values the equation (1) and obtained that the jet tip velocity was 2,860  $\text{ms}^{-1}$ .

From two pictures of the moving image at 64 and 83 $\mu\text{s}$ , we measured that the jet tip proceeded 52 mm. We, therefore, calculated that the jet tip velocity of the LSC was 2,740  $\text{ms}^{-1}$ . Although calculated value was slightly different, we concluded that a moving substance in the moving image was the jet generated by the LSC.

## 6. Conclusion

We established a unique high speed shooting system that can obtain several images at a dangerous circumstance, and from unachievable directions, by separating the front lens from the high speed video camera unit.

We also found that a light from explosion is enough to get clear images, with some mirrors for reflection, even where a long fiber-optic cable is added between the objective lens and the camera unit.

Numerical simulation should be conducted to evaluate the moving images of a high-speed video camera. We already reported that the SPH (Smoothed particle hydrodynamics) solver of commercially available AUTODYN-3D did not deliver reasonable results in the simulation of CSCs (Conical shaped charges)<sup>4)</sup>. We have a plan for conducting calculations using the multi-material Euler solver of AUTODYN-3D.

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## 光ファイバーケーブルで接眼レンズを分離した 高速度ビデオカメラによる爆発現象の可視化

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爆発現象の可視化は爆風や破片から撮影機材を防御する必要があることから、特殊防護仕様のX線照射部を持つフラッシュX線撮影システムが主として使用されてきた。しかし、撮影できる画像は数枚で現象の連続的な解析は不可能であった。高速度ビデオカメラによる連続撮影を実現するためには、対物レンズとカメラ本体を光ファイバーケーブルで分離し、レンズ部分だけを爆発現象近くに置くことが必要となる。室内での試写と爆発ピットでのLSCジェット生成状況の撮影で、レンズ分離方式による爆発現象の高速度撮影が可能であることが確認できた。撮影したLSCジェットの速度は従来理論で算出した値と合致していた。

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