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FLOW OBSERVATION BY ROD LENS AND LOW-LIGHT VIDEO (VIDEOTAPE SCRIPT: JANUARY 4, 1977)

D. E. Lord

G. W. Carter

R. R. Petrini

August 10, 1977

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ABSTRACT

This report presents the script of a demonstration videotape made to show the possibilities of coupling rod lenses to low-light video systems to observe internal flow conditions. The illustrations accompanying the text were photographed directly from the video screen. Some updated comments appear as footnotes to the original script and a description of the multiscan low-light television system developed to measure velocity is included in the epilogue. The combination of rod lens and low-light video system makes it possible to observe dynamic events in hitherto inaccessible volumes. The pressure and temperature capabilities of the rod lens make it applicable to many engineering uses. This system, in conjunction with electronic image enhancement systems, provides a new dimension in engineering analysis.

PROLOGUE

The rod lens is a long cylindrical optical system with a small cross section. It can be as small as 1 mm in diameter and 10 cm long or as large as 2.5 cm in diameter and 10 m long. These lenses are not fiber optic bundles; they are solid lenses arranged in different configurations. Most have a built-in bundle of glass fibers that transmit light to the object. They may also be used with other illumination. Because of these innovations, the modern rod lens provides brilliant images by keeping internal light losses to a minimum.

Although the rod lens is an improvement over the borescope, under most conditions it does not transmit enough light to record dynamic events. Therefore, we thought a low-light-level TV camera with a 40,000 light gain coupled to the rod lens would provide the extra sensitivity necessary for dynamic conditions while

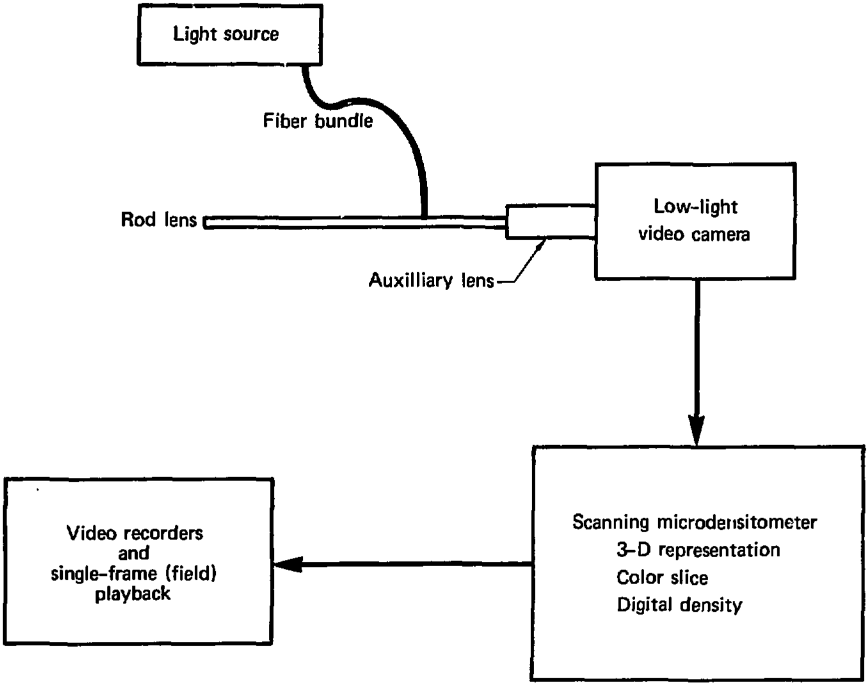

Fig. 1. Endo/optronics analysis system.

retaining the geometric access advantages of the rod lens. The system also includes a conventional video recording and single-field playback capability (Fig. 1).

Lawrence Livermore Laboratory (LLL) first tried the system in the fall of 1976 on a two-phase flow system. We were able to directly observe the turbine/drag-bar-type flow-measuring instrumentation. The rod lens system showed lack of mixing as the reason for the apparent malfunction of the test section instrumentation.

We then demonstrated the rod lens on a 1/5 scale model of a Mark I Boiling Water Reactor pressure suppression system (~2-m-diameter) for the Nuclear Regulatory Commission (NRC). The LLL plan called for high-speed cameras and large access windows. We felt the video system would be complimentary and even advantageous because of its instant-replay capability and ability to immediately single-frame (field) the results. We also suggested a three-camera grouping for optimum observation. Both high-speed cameras and video systems are used.

The NRC requested that we demonstrate the system with possible applications to reactor safety monitoring. We did this by building a pipe test section and observing various flow conditions within it and then recording the results on videotape.

This report is the updated script of that videotape with photographs made directly from the video screen. It is provided mainly for those people who expressed an interest in the subject matter but who do not have facilities for videotape presentations.

VIDEOTAPE SCRIPT

The purpose of this tape is to communicate and demonstrate the uses of the rod lens in conjunction with low-light-level television systems. Our immediate use is pressure suppression testing for the Nuclear Regulatory Commission at LLL.

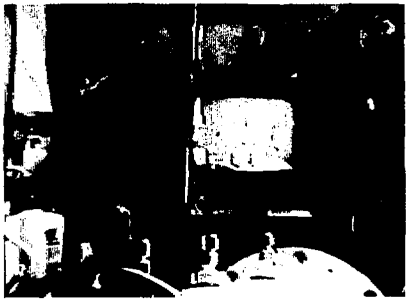

Fig. 2

Typically, the rod lens can be as small as 2 mm with a 0.1-m length to larger diameters and lengths of several meters. The one you see here is 5 mm in diameter and 0.5 m long (Figs. 2, 3, 4).

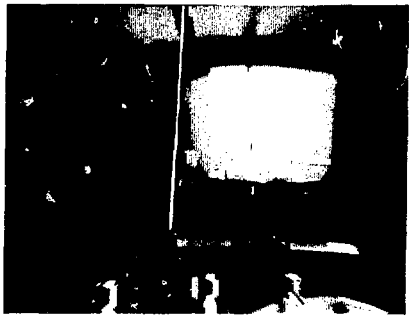

Fig. 3

The rod lens has uses ranging from the simple but straightforward "what's going on inside?" to sophisticated measurements and analysis of flow systems, both liquid and vapor phases.

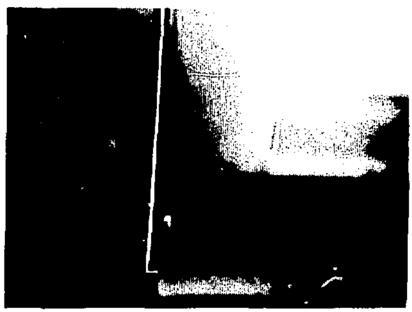

Fig. 4

The system offers instant-replay capability and the rod lens can be introduced into pipes through standard tubing fittings (Figs. 5, 6, 7), where observation windows or glass pipe sections are not practical or even possible. It also affords unlimited angles and magnification of observation not possible with windows as well as non-fogging operation.

Fig. 5

The rod lens is a British patent of Professor Hopkins and is manufactured in Germany; the Japanese also manufacture similar systems.

The light transmission properties of a rod lens are further enhanced and made applicable to dynamic flow conditions by a low-light-level TV camera of USA manufacture with a light gain of 40,000 times. The particular rod lens system we use has a bundle of glass fibers built into the OD of the rod to carry light from an illumination source to the object. Reflected light is returned through the rod lens system not the fiber bundle.

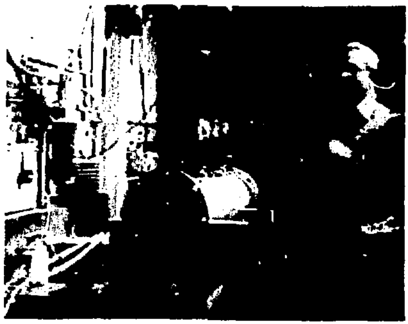

Fig. 6

This tape is divided into 4 segments:

1. The fixture used to test flow conditions.
2. Examples of what can be seen inside the pipe.
3. Analytical measurements.
4. Present limitations and future improvements.

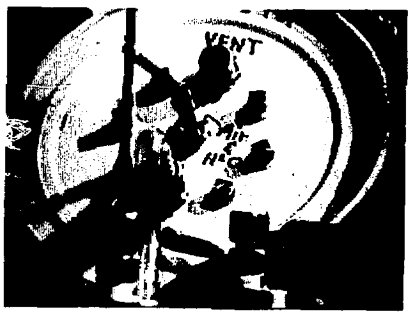

Fig. 7

The fixture you have been watching in assembly is a 1-m-long section of pipe about 200 mm in diameter (Figs. 8, 9). It is designed to be about one-third filled with water and to handle simultaneous liquid and vapor flow. The liquid part is fitted with an immersion heater and is also used as a reservoir of hot water which can be sprayed into the top or vapor section of the pipe by the simple air-operated T-section pump. Droplet size can be regulated by air pressure and liquid line construction. The rod lens is introduced into the pipe section through standard tubing pressure fittings. In this case we also introduce two thermometers through the additional fittings to monitor liquid and vapor temperatures. Here we use a 90° rod lens which allows 360° rotation and 360° observation. It can also be moved vertically to examine underwater conditions, subsurface, above surface, and vapor flow conditions.

The test section is assembled and the internal view checked by rotating the lens (Fig. 10).

Fig. 8

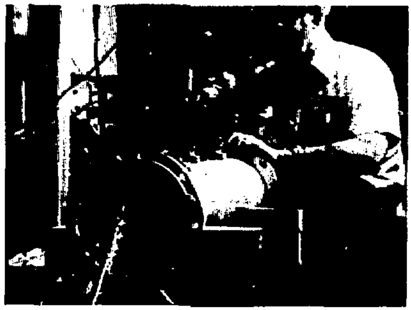

Fig. 9

Fig. 10

The immersion heater and internal features are well illuminated and can be observed in detail (Fig. 11).

Fig. 11

Now the 54°C water is admitted — note the change in index of refraction and the reflection from the overhead water surface.

The vertical position of the lens is raised and we observe the surface film and the vapor above it (Fig. 12). As air flow and droplet spray are introduced the vapors increase and take on the appearance of a snowstorm (Fig. 13).

Fig. 12

We have added a lens between the rod lens and the TV camera. This gives us a two times magnification and allows us to fill the TV screen. Ordinarily, because of the tremendous depth of field of the rod lens such additional lenses are not necessary. However, this additional lens also allows us to choose our depth of field and subsequently the features we wish to observe.

Here (Fig. 13) we are observing convective vapor flow above the surface of the water.

Fig. 13

This short sequence (Figs. 14-18) again shows some interesting effects as we break the surface. The temperature is 90°C. Again we go from underwater to breaking the surface to vapor flow. Note the relative calm of the underwater condition compared to the convective violence of the vapor phase.

Fig. 16

Fig. 14

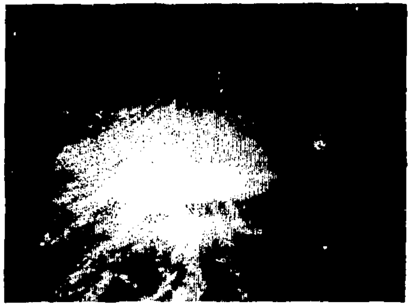

Fig. 17

Fig. 15

Fig. 18

Here we have vapor flow, blown by air, at shallow depths of field (Fig. 19). As we change the depth of field the end plate of the test section comes into sharp view and the vapor droplets tend to blur out (Figs. 20, 21). Note that as the depth of field increases the vapor becomes very transparent. It is worth noting that there is a relationship between steam quality and opacity that can be exploited by electronic/optical analysis. Now we return to the shallow depth of field (Fig. 22).

Fig. 20

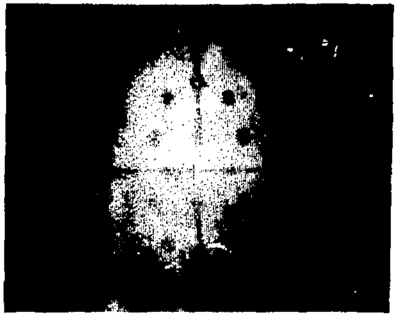

Fig. 21

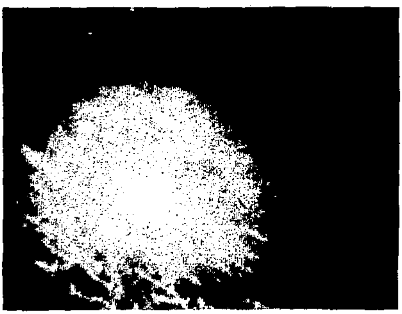

Fig. 19

Fig. 22

Below the surface, a look at the immersion heater gives us an idea of the nucleate boiling process (Fig. 23). Bulk temperature of the water here is 90°C. Normal continuous operating temperature of the standard rod lens is 180°C. We have used them in short-time applications, however, to 350°C. The hot spots on the heater are evident as is the convective flow around it. The larger vapor bubbles cling to the cooler regions.

Here we're observing some of the snowstorm produced by air-blown water vapor (Figs. 24, 25, 26).

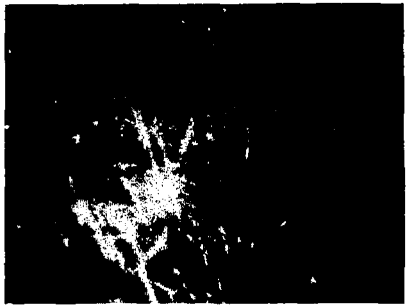

Fig. 24

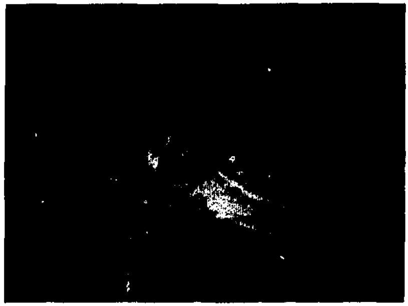

Fig. 25

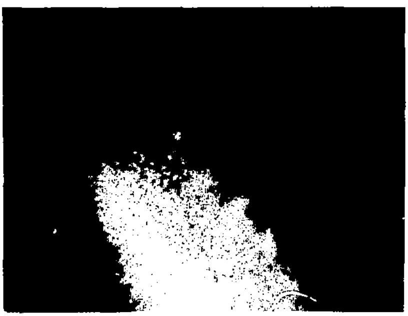

Fig. 23

Fig. 26

There are several ways to analyze the results of the flow systems you have seen. The first and simplest is to practice single framing or slow framing to measure the bubble or droplet size and its velocity (Figs. 27, 28). The events must be slower than the TV scanning rate to achieve "stop action" measurements.

This section illustrates some of the several flow experiments we have conducted. In some we have gone to different backgrounds to help contrast. In most you can recognize the blurred image of the end cap of the pipe section in the background.

Fig. 27

In order to size particles with reasonable accuracy it is necessary to calibrate the field volume of view through the system. This can be done with precision grids at different positions within the view volume.

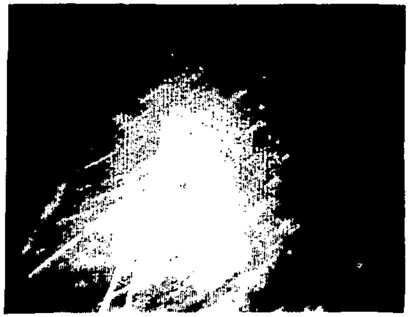

Fig. 28

There is another method of velocity measurement that is tied to the scanning speed of the TV system and is generally referred to as "measuring the head of the comet." Measuring the tail of the comet, the TV screen and camera retention, gives us the trajectory of the particle. The angle of the head of the comet, the brightest line segment, with respect to the TV scan lines gives us an idea of the particle velocity that produces that bright line. This comes from a single particle interacting with the TV scan system and is analogous to photographing aerial fireworks or stars at slow shutter speeds.

It is easier to measure such velocities if we can keep the bright comet heads at uniform intensity and size indicating motion primarily in the x-y plane. The rod lens can be angled perpendicularly to the primary flow pattern to produce such effects.

Fig. 29

Most of the vapor droplets in this tape fall in the 10- to 50-μm range. Velocity measurements are limited to maximum 10 to 100 m/s depending on the angle of observation and its relationship to the scan of the TV system.

These techniques are developmental but have already been demonstrated as feasible.

Here are some examples of slow framing of flow conditions (Figs. 29, 30).

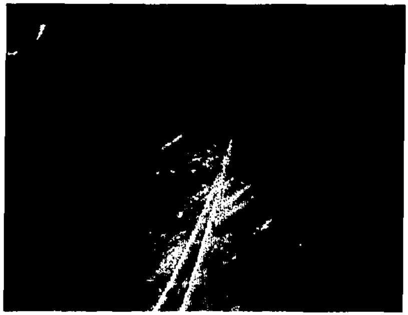

Fig. 30

The views of flow systems and their distinctive particulate matter are really shown in three dimensions in the sense that the particle intensity and size are a function of the particle distance from the lens. To make precision measurements in this dimension we use a scanning microdensitometer. This system provides an x-y-z view with the z axis being light intensity and size measurement. The x and y are the physical dimensions of the display. This, with appropriate calibrations, allows us to measure the particle vectors within the observed volume (Figs. 31, 32, 33). The cursors, the bright lines on this display, allow us to set a point or line of calibrated measurement for particle-size determination. This also allows integration of the total number of particles crossing the lines.

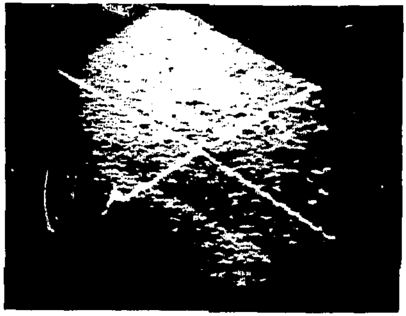

Fig. 31

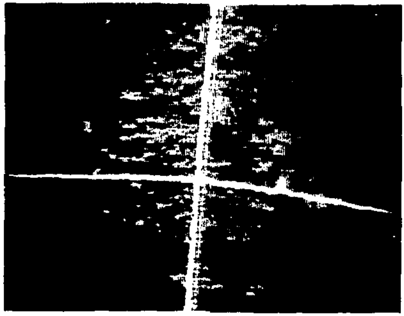

Fig. 32

The short demonstrations in this tape illustrate droplets, bubbles and large drops, and the single and slow framing processes that can be used.

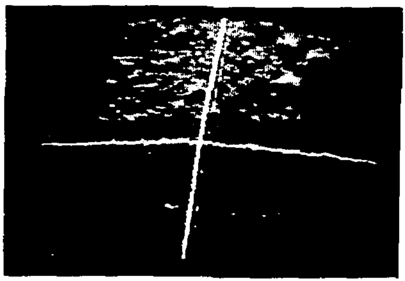

Fig. 33

At the present time the basic rod lens has temperature and pressure limitations. Continuous temperature is about 180°C because of the low-melting alloy seals and epoxy lens mounting. It appears that materials changes could increase the continuous-operating temperature to 500°C or better. An alternative is to use an optical protective thermowell. The pressure is now limited to several hundred psi (3-4 MPa).* However pressure is not a difficult problem because of the small size of the lens tube.

*We have since tested the 5-mm lens to 17.5 MPa external pressure without failure.

There are limitations in resolution and framing rate imposed by the video system.

The standard video scan and the 30 frames/s† rate can be improved for those applications that require it. However, the present systems make reasonably accurate measurements available *now*! In our opinion rod lenses coupled to low-light-level video systems have great application to many engineering measurement problems both static and dynamic. Flow condition is one of these problems. The use of analytical electronics imaging systems for data processing is the additional link that allows us to put numbers on our observations.

†60 fields/s on single field machines.

EPILOGUE

Since this videotape was made we have procured a modified 4400SIT Cohu video camera that allows a four-fold increase in framing rate. It does this by reducing the vertical field of view and sweeping the *smaller central area as many as four* times during a standard frame. The camera is switchable from the standard full frame to two, three, and four smaller frames. Figures 34-37 show the motion of a 2.54-cm ball pendulum in each of the four framing options. The increased framing rate allows us to gage particle velocities and dynamic events with considerably greater precision than standard video systems. We are presently studying the *interactions* of the *images* of particles/missiles with the TV scanning system. Faster velocity

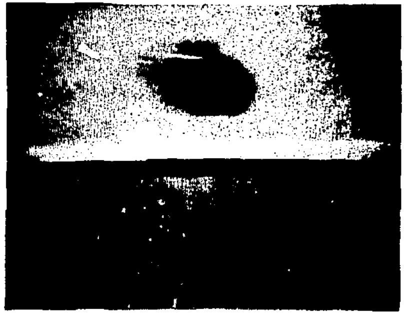

Fig. 35

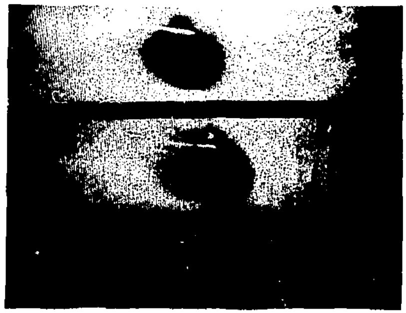

Fig. 36

Fig. 34

Fig. 37

measurements require interpretation depending on size, distance from the camera, and other factors.

We have also found that this rod lens low-light TV system can observe both dynamic combustion processes and active fabrication processes.

Copies of the original videotape may be obtained on a loan basis by contacting the authors, or permanent copies may be purchased through commercial sources.

ACKNOWLEDGMENTS

Our sincere thanks are extended to Drs. John Pitts and Ed McCauley, and Vic Karpenko, all of LLL, whose early appreciation of this system contributed to its development. And most certainly to Drs. Tong, Fabic, Hsu, Slegers and McPhearson of the Nuclear Regulatory Commission whose interest and support allowed this preliminary study to be made.

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