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Compact optical probe for inner profile measurements of pipes

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A new instrument can measure objects with apertures that range from 20mm to 200mm or more, and consists of a laser diode, a conical mirror, and a miniature CCD or CMOS camera.

Inner profile measurements serve an important function in the manufacture of components in many fields, such as mechanical engineering (within the car and aircraft industries) and heavy industries (e.g., for jet engine manufacturing and power plants).[1–3] Conventional methods for measuring the inner diameter of circular holes involve contact-type instruments such as cylinder bore gauges or inside micrometers. When these conventional instruments are used, however, the average diameter of a circular hole is determined from only two or three measured points. This is because it is too time-consuming to find the diameter for many cross sections.

In cases where the inner profiles of non-circular pipes or holes (e.g., tunnels and sewers) need to be measured, optical sectioning methods have been applied. These techniques use a rotating mirror or prism, and are based on the principle of triangulation. Optical sectioning methods, however, are difficult to use for pipes with diameters or cross sections that are less than about 100mm. Furthermore, non-contact measuring methods—that lack rotating or moving parts—are preferable for practical applications.

We have recently developed a new principle for the measurement of the inner diameter and profile of pipes and tubes. The key component that we use in our technique is a ring beam device, which consists of a conical mirror and a laser diode (LD).[4] The fundamental principle that underlies our technique is based on optical sectioning, without the use of any contact-type stylus. During our inner profile measurements (see Figure 1), a laser beam that is emitted from the LD hits the apex of the conical mirror. The beam is then reflected and spreads out to form a ring-like disk. When this disk-like beam reaches the inner wall of the tube or pipe, an optically sectioned profile (i.e., the peripheral cross section of the pipe) can be observed. We analyze the optically-sectioned profile of a pipe-like object's inner wall to give both the inner sectional profile and the inner diameter. We capture the optically-sectioned profile with a CCD or a CMOS camera. As illustrated in Figure 1, we use the principle of triangulation to derive the radial length, $r(\theta)$, at the circular angle (θ). This is given by the expression $r(\theta){=}l\tan\phi(\theta)$, where l is the length of the baseline from the conical mirror to the lens of the camera and $\phi(\theta)$ is the angle of attack, with respect to the measurement point (at θ). We are also developing our simple and small optical instrument for several practical uses.

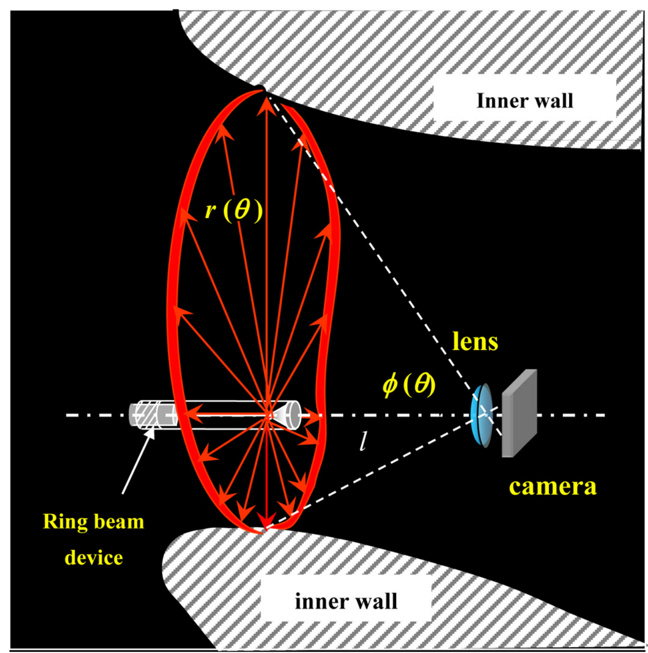

Figure 1. *Cartoon illustrating the principle of inner profile measurement for a pipe or tube. A laser beam is emitted from a laser diode and is reflected from the apex of a conical mirror. The beam reflection spreads out into a disk-like sheet. l: Baseline length between the conical mirror and the camera lens. $r(\theta)$: Radial length at circular angle (θ). $\phi(\theta)$: Angle of attack, with respect to the measurement point at the circular angle.*

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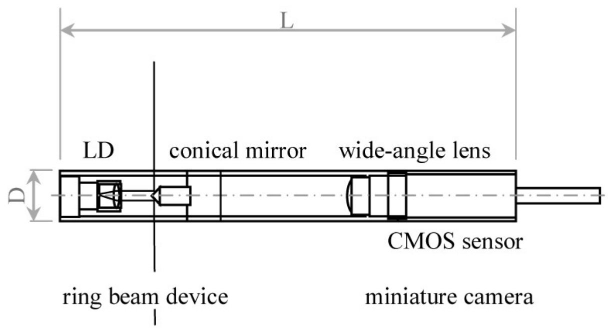

Figure 2. *Inner structure of a prototype inner profile measurement probe. LD: Laser diode. L: Length. D: Diameter.*

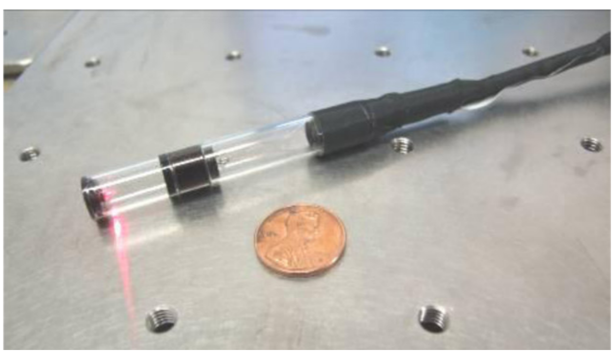

Figure 3. *Photograph of the prototype shown in Figure 2, which has a 10mm diameter.*

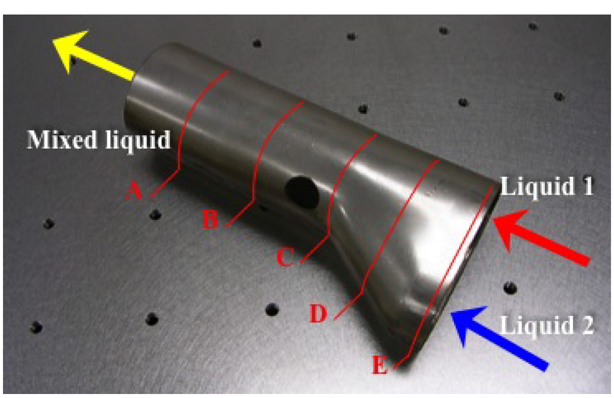

Figure 4. *An irregularly shaped pipe, with non-circular and non-uniform cross sections. This object is made by a hydroforming process and is used for mixing two kinds of liquids (liquid 1 and liquid 2). The drilled hole in the pipe is for fixing a pressure gauge. Optically-sectioned profiles of the pipe (Figure 5) were measured at the points marked A–E, which are 125mm (A), 95mm (B), 65mm (C), 35mm (D), and 5mm (E) from the end of the pipe.*

In our previous experimental studies, we have demonstrated the use of our instrument for a number of industrial purposes.[5–8] For easier practical application in these particular situations, we fabricated both the ring beam device and a miniaturized CCD camera within a glass tube. In our most recent work we have

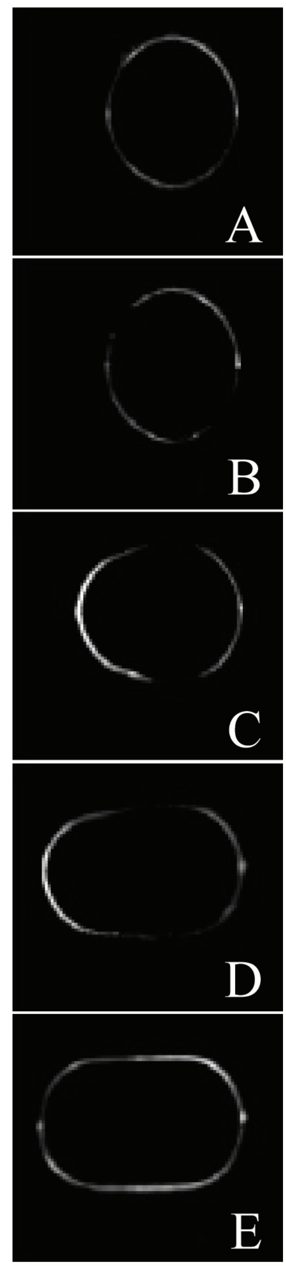

Figure 5. *Inner profiles of the pipe measured at the positions shown in Figure 4. We also measured cross sections of the pipe at 5mm intervals.*

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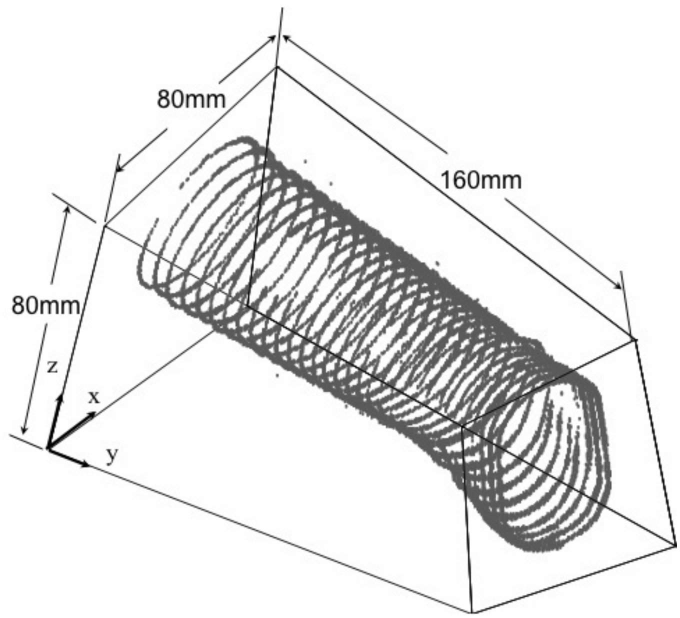

Figure 6. 3D measurement result of the sample pipe.

conducted trials for inner profile measurement and detection of defects and flaws on the inner walls of pipe-like objects.

We have developed a few sizes of compact inner profile measuring instruments. The structure of one of these sample instruments is illustrated in Figure 2 and a photograph of the instrument itself is given in Figure 3. The ring beam device is built within the instrument structure, together with the LD (which has a 650nm wavelength) and a miniature camera. We adjust each component precisely so that they are in good alignment. For this instrument, we incorporated a miniature camera with a wide-angle lens and a 1/4 CMOS sensor. The ring beam device and the miniature camera are jointed inside the cylindrical glass. Power to the LD is supplied through a hairline enameled wire. We have built various kinds of these prototype instruments, with diameters that range from 5mm to 120mm, including some commercialized probes.

It is difficult to measure the inner surface profiles of the pipes with non-circular and non-uniform cross sections (e.g., the pipe shown in Figure 4) using a contact-type stylus. We have thus used this sample pipe to demonstrate the feasibility of our instrument. We measured five optically-sectioned profiles (shown in Figure 5) along the length of the pipe (as marked in Figure 4). These sections were used to produce inner profiles and the 3D expression of the pipe (Figure 6). We were able to obtain the 3D expression of the profile, with an angle interval of 2°, in a quick and efficient manner with our instrument.

We have developed a new optical inner profile measurement technique for tube-like objects. We have experimentally demonstrated the success of this technique with several prototype instruments, which have diameters that range from 5mm to 120mm. We are currently working to make our instrument compatible with practical industrial applications. These include inner profile measurements of objects such as engine bores (80mm diameter), nuclear fuel rod sheaths (18mm), inner shapes of impellers, and knee point cavities for medical operations, as well as various pipes and holes used in the automobile and aircraft industries. We are also developing an even smaller probe that will be applicable to holes with diameters less than 10mm.

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Toru Yoshizawa received his BS, MS, and Doctor of Engineering degrees in precision engineering from the University of Tokyo. He was previously a professor at Yamanashi University, Tokyo University of Agriculture and Technology, and Saitama Medical University. He is one for the founders of the SPIE Japan Chapter and has served as its chairperson for ten years. He is also a SPIE Fellow, and has been chair or a committee member for many SPIE conferences.

References

1. T. Yoshizawa ed., **Handbook of Optical Metrology: Principles and Applications**, p. 744, CRC Press, New York, 2009.
2. T.A. Clarke, *The development of an optical triangulation pipe profiling instrument*, **Opt. 3-D Meas. Techniques 3**, pp. 331–340, 1995.
3. Y. Chugui, L. Finogenov, V. Kiryanov, V. Nikitin, A. Sametov, and P. Zavyalov, *Inspection of holes parameters using a ring diffractive focuser*, **Int'l Symp. Photon. Meas. 2**, pp. 433–443, 2004.
4. T. Yoshizawa, T. Wakayama, M. Yamamoto, and K. Machi, *Development of inner profile measurement probe for pipes, tubes, and holes: case examples and additional topics*, **Proc. SPIE 9276** (9276-11), 2014.
5. T. Yoshizawa, M. Yamamoto, and T. Wakayama, *Inner profile measurement of pipes and holes using a ring beam device*, **Proc. SPIE 6382**, p. 63820D, 2006. doi:10.1117/12.689317
6. T. Wakayama, H. Takano, and T. Yoshizawa, *Development of a compact inner profile measuring instrument*, **Proc. SPIE 6762**, p. 67620D, 2007. doi:10.1117/12.733215
7. T. Wakayama and T. Yoshizawa, *Simultaneous measurement of internal and external profiles using a ring beam device*, **Proc. SPIE 7066**, p. 70660D1, 2008. doi:10.1117/12.794388
8. T. Yoshizawa and T. Wakayama, *Development of an inner profile measurement instrument using a ring beam device*, **Proc. SPIE 7855**, p. 78550B, 2010. doi:10.1117/12.870825