Optical Inner Profile Measurement for Pipes and Tubes

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Abstract: This paper summarizes a principle for measurement of inner diameter or profile of pipes and tubes using optical method. Based on this principle, compact probes have been developed for industrial applications such as car industry, heavy industry and civil engineering. In addition to large probes for pipes, tubes and tank-like objects with diameter larger than 1meter, such small size probes as 5mm ∼25 mm in diameter has been produced including prototypes and commercialized products. We report availability and utility of our principle and probes we developed with some experimental results.

Keywords: Inner diameter, inner profile, pipes, tubes, optical section.

Introduction

There are various requirements for measuring the inner diameter and/or inner profile of pipes, tubes and other objects similar in shape. Especially in mechanical engineering field, serious problems come from automobile industry because the inner surface of engine blocks or other die casts are strongly requested to be inspected and measured by non-contact methods (not by the naked eyes inspection using a borescope). Another fact is well known that the rehabilitation and maintenance of sewers are of importance to water and waste utility in urban life[1]. For these problems, hitherto, optical inspection using borescopes have been used. However visual observation and inspection and manual annotation of defects are not sufficient because these methods suffer from a lack of quantitative information and is not appropriate for computer analysis of the recorded data. In addition to the applications in mechanical industry, even in the medical and dental fields there come requests for measuring the inner profile of the stomach, trachea and oral cavity. If the inner diameter is large enough like water pipes or drain pipes, complicated and large equipment may be applicable. However, small pipes with a diameter ranging from 10mm to 100mm are difficult to be inspected by such a large instrument as is

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used for sewers inspection. And we planned to develop an instrument which has no moving elements such as a rotating mirror for scanning a beam. Here we describe our fundamental principle and show some results that were obtained by our smaller and compact probing instruments.

1 Principle

In most of methods conventionally reported, rotary mirrors or prisms have been used to scan the pointed beam over the inner wall. And the locus of the scanned beam is tracked by a CCD camera to capture the inner shape as is shown in Fig.1. In these trials, basically,
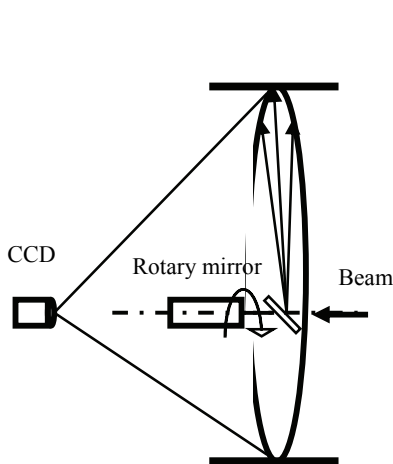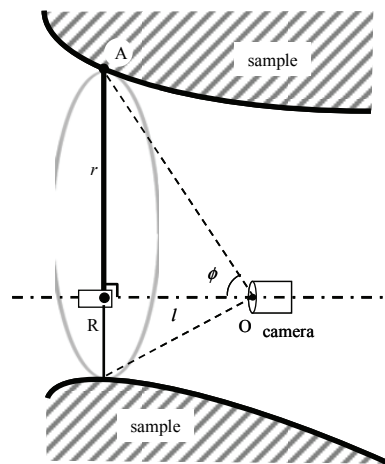

Figure 1: Measurement using scanning mirror

Figure 2: Measurement using R: ring beam device

triangulation is applied to analyze the profile of the inner wall or to find damage of the pipe. However we intend to construct a simpler and easier system for the similar purpose. The first revision is focused on forming a ring beam without using such a mechanically moving device as a rotary mirror (shown in Fig.1) and on realizing simple and stable "optical sectioning". Here we propose to use a ring beam device to optically "cut" a pipe-like object to know the inner profile as is shown in Fig. 2. Here the RBD (ring beam device) is incorporated in stead of a rotating mirror. We can observe the inner defects like cracks, and at the same time we can get the optically sectioned profile of the inner wall by the CCD camera in Fig. 2. This figure shows the basic arrangement for the above-mentioned purpose. In this figure, 1 indicates the device for generating the ring beam. The beam from

a LD (laser diode) is changed to the ring beam like a disk. Appearance of RBD is seen in Fig. 3 and an example of optically sectioned inner profile of a pipe is shown in Fig. 4 where a defect is also observed downward. .
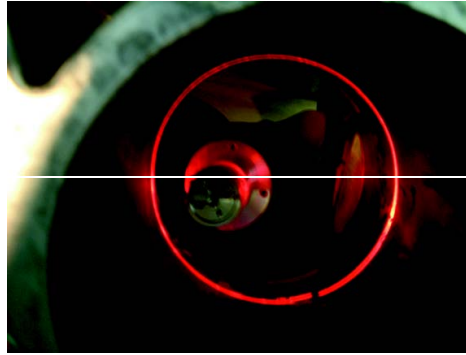

Figure 3: RBD (ring beam device)

Figure 4: Cross section of a pipe

The 3D coordinates of the point on the cross section is analyzed from this pattern using the parameters given in the optical arrangement. Naturally alignment of the RBD (with a LD and mirror inside) and the camera is the most important and, if there exist misalignment (such as ϕ and θ: angular errors, Δz, l and Δz dimensional errors), radius error Δr is caused that is expressed by the next expression,

More discussion on this alignment error is described in our previous paper[2].

2   Development of a measuring probe

On the basis of the above mentioned principle, we have constructed various types of compact instruments. Figure 5 shows an internal design of a prototype probe and Fig.6 is appearance of a probe with a diameter of 10 mm and length: 80mm. The probe consists of a small ring beam device and a miniature camera. The ring beam device with a laser diode (wave length: 650nm, power: 1mW), and a miniaturized conical mirror are built in. These components should be carefully adjusted in alignment,. In addition, a miniature camera is incorporated with a wide-angle lens and a 1/4 CMOS sensor. Both the ring beam device and the miniature camera are jointed precisely inside a cylindrical glass pipe.

Here the electric power for LD is supplied through an enameled wire or transparent electrode such as ITO.

Let's briefly check two matters. Strictly speaking, because of this glass pipe, some amount of error is caused. This problem has been discussed and estimated theoretically in the paper[3]. At the same time, we examined influence of refractive index

of a cylindrical glass, and we showed it not serious except rare cases. Another problem is how to move this probe along the reference line. If the probe is moved not in parallel with the reference line, that is, the optical axis is not in parallel with the reference guide line, the section of the pipe is not perpendicular to the line and obliquely cut section is obtained. Another paper[4] discusses this influence in detail.
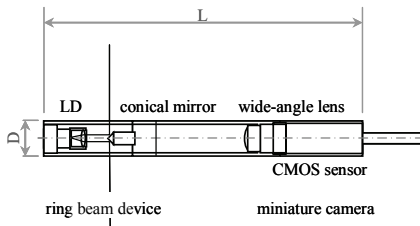

Figure 5: Inside structure of a probe

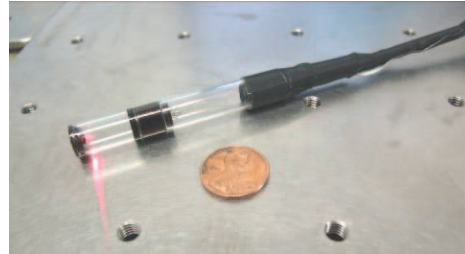
Figure 6: Appearance of a probe

In the case of a probe with 10 mm diameter, such inner size from15mm to 40mm is covered, and a commercialized probe (with 1inch diameter and 145mm length) is available for inner size from 40mm to 100mm. For a larger object we have made a probe in trial with 80mm diameter and 480mm length that a container 600mm may be measured by using a green laser (wave length: 532nm). As the ultimate case, we are currently

developing an extremely small probe with 3mm diameter, and we have succeeded in producing it experimentally by using a small diameter optical fiber.

At this stage of work,, we are checking accuracy of our probe, using a reference ring gage (Mitutoyo Corporation). In the case of the gage that is assured to be 25.000±0.002 mm, the average of the radius determined from our first checking is 25.05±0.08 mm.

3   Applications

At first we aligned this probe in the same optical axis with the miniature CCD camera and moved it along the reference guide line.

Figure 8 shows a boot-like sample object which is used for mixing two kinds of liquid, and the inner profile is required to be checked if it is formed as is designed. A hole shown

In the figure is used for installing a pressure meter or a thermometer to check liquids.

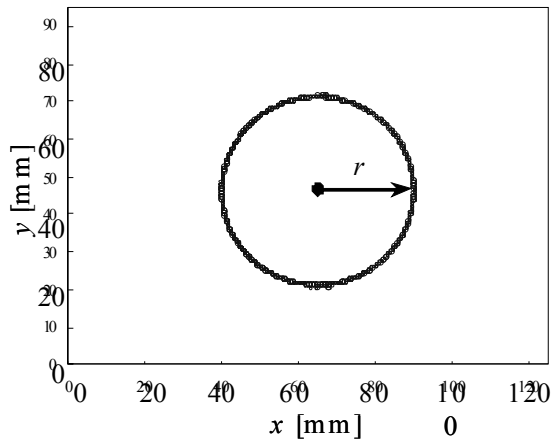A measured result of profiles is shown in Fig. 9 where six profiles are extracted

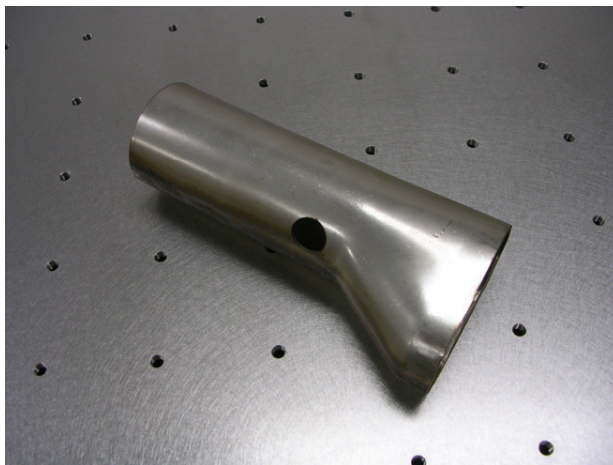Figure 7: Calibration result using a reference

Figure 8: Irregular shape test sample

from cross-sections that are captured by every 5mm. When a series of sections are arranged, we can get a total expression of inner form of the tube as is shown in Fig. 10.

Finally let's show another expression of measurement result of an irregular shape object in Fig.11 (a). One profile of this object is shown in (b), and the total inner appearance is expressed in (c). This may look like outer surface, but inner surface

(a) 5mm   (b) 35mm   (c) 65mm

(d) 95mm   (e) 125mm   (f) 155mm
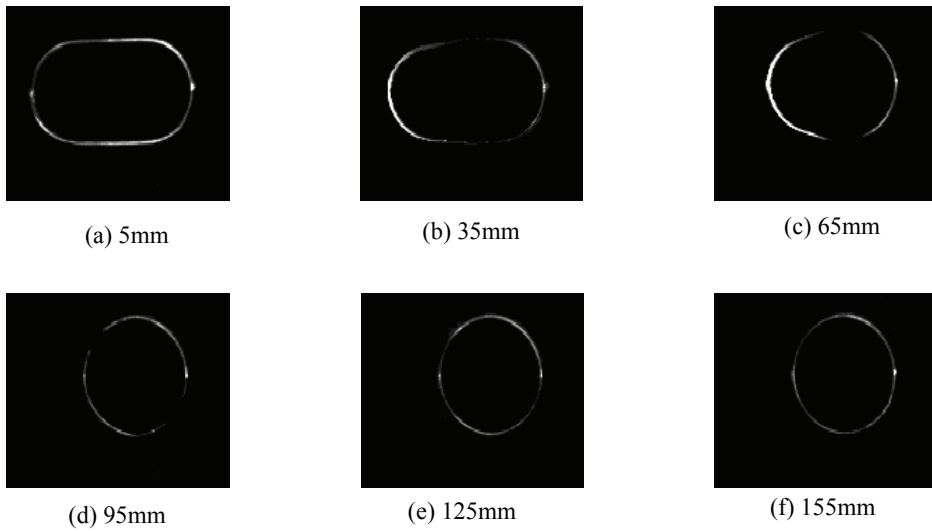
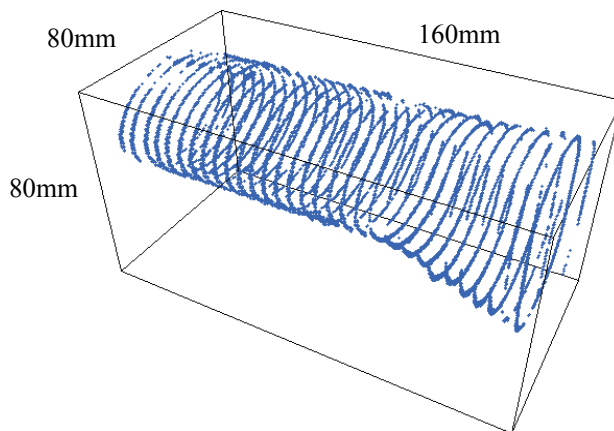Figure 9: Optical sections captured by every 30mm
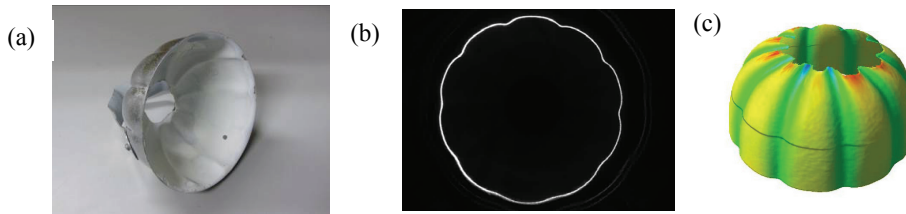

Figure 10: Total expression of sections by every 5mm

Figure 11: Measurement of an irregular object (a), inner profile (b) and total inner surface (c)

is shown in truth.

4 Conclusions

We proposed a principle for measuring inner diameter and/or profile of pipes and tubes.

At the same time some sizes of probes have been developed based on our principle. We showed availability of our principle and demonstrated experimental result that were obtained using our probes.

References

1. T.A. Clarke: The development of an optical triangulation pipe profiling instrument `http://www.optical-metrology-centre.com/Downloads/Papers/Optical{\%}203D{\%}20Measurement{\%}20Techniques{\%}201995{\%}20Profiler.pdf{\#}search={\%}22Clarke{\%}20{\%}20{\%}20{\%}20optical{\%}20triangulation{\%}22`

2. T. Yoshizawa, M. Yamamoto, T. Wakayama: Proc. SPIE Vol.6382 pp.63820D1-5 (2006)

3. T. Wakayama, H. Takano, T. Yoshizawa: Proc. SPIE Vol.6762 pp.67620D1-5 (2007)

4. T. Wakayama, T. Yoshizawa: Proc. SPIE Vol.7066 pp.70660D1-6 (2008)

5. T. Yoshizawa, T. Wakayama: Proc. SPIE Vol.7855 pp.78550B1-8 (2010)