Inner profile measurement and flaw inspection of pipes and tubes

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Abstract:
Inner profile measurement is an important matter in such fields as mechanical engineering including car and aircraft industries, and heavy industry relating to jet engines and power plant. In addition, we can find many applications in medicine and/or surgery related field. Here we describe recent development of our measurement principle for inner diameter and profile of pipes and/or tubes. The key device in this technique is a ring beam device which consists of a conical mirror and a laser diode (LD). And the fundamental principle is based on optical sectioning without using any contact type stylus. The optically sectioned profile of an inner wall of a pipe-like object is analyzed to give the inner profile in addition to the inner diameter. This optical instrument with simple and small configuration has been under development for practical uses. In our experimental works up to now, the availability of this instrument has been evaluated in many cases. This ring beam device consisting of a conical mirror and a LD is assembled in a glass pipe and the beam emitted from the LD is deformed, after reflected by the top of the conical mirror, into a disk-like circular light sheet. We show measurement result of pipes, and, at the same time, report a few examples that are developed for practical purposes. Both the ring beam device and a miniaturized CCD camera are fabricated into a glass tube for easier practical applications. We have already reported the fundamental principle of this measurement system and showed some applications. Here we report our trial to extend our technique to checking defects and flaws on the inner wall of pipe-like objects.

1. Introduction

Damage and cracks due to fatigue of gas and water tubes are pointed to be a social problem world-widely. And check and inspection of pipes and sewers are required to prevent serious disasters. Therefore speedy and simple inner profile measurements of pipes have been concerned from the viewpoint of safety managements to avert various accidents. Besides these social concerns, there are different requests for measuring the inner diameter and/or inner profile of pipes, especially, in automobile industry (various pipes and manifolds in addition to engines, for example). The inner surface of engine blocks or other castings is strongly required to be inspected. In addition to these industrial necessities, there are different requests for checking inner profiles of human organs such as tracheae, large bowels and stomach in medicine and oral cavity in dental field. Most of methods hitherto in use [1] are classified into contact methods with any kind of mechanical stylus or touching probe. However, contact methods are not appropriate for inner profile measurement because of long measurement time and fear of damage. In this situation it is strongly demanded to inspect inner profile by using optical methods. Conventionally bore-scopes and endoscopes have been utilized, but these are useful merely for visual examination by naked-eyes. Some optical methods have been proposed which incorporates a rotating mirror or prism to scan the inner surface. One technique using a rotating mirror is well-known that was used for checking the inner wall of sewers in London [2]. And another principle using a DOE and a conical mirror is reported [3]. However, to realize similar and simple system, we have proposed an idea for inner profile measurement using a ring beam device consisting of a conical mirror, a laser diode, and a CCD camera in 2006 [4].The fundamental technique is based on optical sectioning, and, in the previous paper, we suggested possibility of inspection of defects as well as inner profile measurement of pipes Now, in this paper, our recent instrument with smaller size is also shown. This instrument, as small as a cigarette, is incorporated with the ring beam device and a small CMOS camera. The optically sectioned profile is analyzed to calculate the inner profile. In this experiment, a bore of an engine block is used to measure the inner profile and to find flaws of inner surface.

2. Principle

2.1 Inner profile measurement

Figure 1 shows fundamental principle for inner profile measurement. A laser beam from the LD (laser diode) hits the apex of the conical mirror, and then the beam reflects and spreads to form a ring beam like a disk. When this disk-like beam comes to the inner wall of the pipe, we can observe optically sectioned profile, i.e. peripheral cross section of the pipe. This profile is captured by a CCD/CMOS camera. According to the principle of triangulation, the inner diameter of the profile can be expressed as

$$r = l \tan\varphi \qquad (1),$$

Here, r means the radial length AR, l is the length of base line from the conical mirror to the lens of CMOS camera. The angle φ is angular separation between OR and OA. In the previously papers [3,4], we have discussed alignment between the conical mirror and the camera, and we checked error caused by misalignment. From he practical viewpoint, we should note the same profile is given regardless of the device position, that is the ring beam device is not necessary to be centered. Here, just to be sure, we show the influence of refraction index of a cylindrical glass. The ray from the LD is traced as is shown in Fig. 2. Then, optically sectioned profile is to be captured by the camera using dashed lines. However the profile is observed through the glass tube. Actually, the light may be refracted by the cylindrical glass. In this case, the light proceeds as is shown by solid lines. In Fig.2, r1, r2 and r3 indicate the radiuses from the conical mirror to inner wall of glass, outer wall of that and inner wall of sample, respectively. Here, Δr means the error of the radius between RA' and the real radius RA. According to geometrical calculations, the error of the radius can be expressed as

$$\Delta r = \frac{r_2 \sin(\alpha + \phi)}{\cos\phi \cos\alpha} \qquad (2)$$

Here, α indicates the angle based on Snell's law. The α is given by the index of air n1, glass n2 and the angle α

$$\alpha = \sin^{-1}\left(\frac{n_1}{n_2}\cos\phi\right) \qquad (3).$$

This error Δr may not be negligible if we measure a small size tube, but usually we need not to be nervous about this.

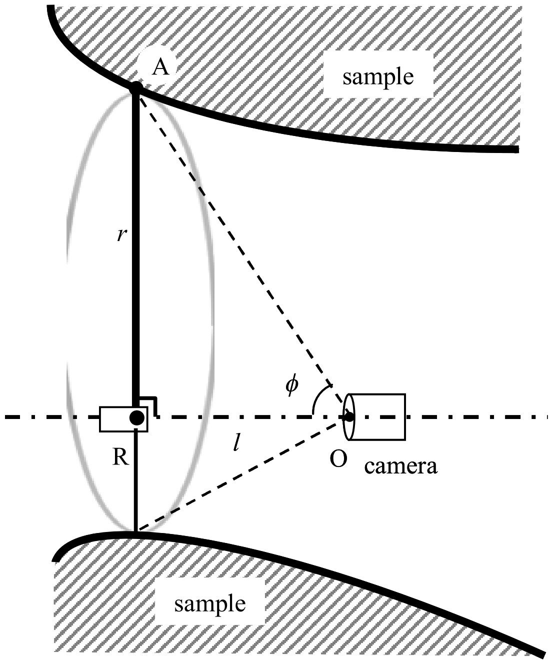


Fig.1 Fundamental principle of inner profile measurement

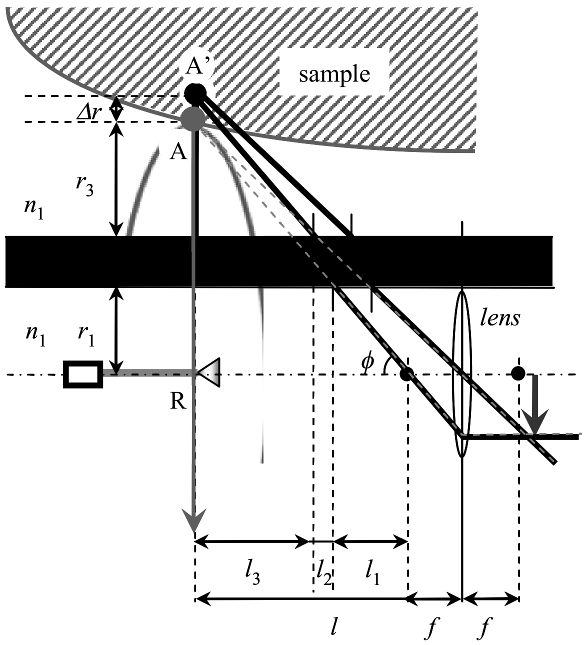


Fig. 2 Influence of glass pipe

At any rate we can observe an optically sectioned profile and this profile is captured by using a camera. According to the principle of triangulation, the radial length at the circular angle θ is given by the next expression

$$r(\theta) = AR = l\tan(\theta) \qquad (4).$$

Here the radius $r(\theta)$ can be determined from the intensity distribution which becomes Gaussian distribution along the radial direction $r(\theta)$. It should be noted that our method doesn't need to align the camera and the ring beam device at the center of the pipe.

2.2 Construction of the probe

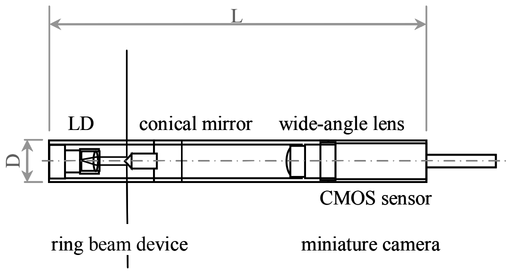


Fig.3 Inner structure of a probe

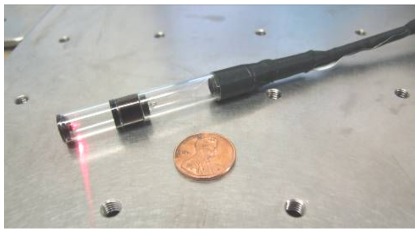


Fig.4 Appearance of a probe with 10mm diameter

We have developed a few sizes of compact inner profile measuring instruments. Figure 3 shows construction of one sample instrument and a picture of appearance. The ring beam device are built in together with a laser diode (with 650nm wave length), and a miniature camera. Each component should be adjusted precisely to be good in alignment. In this case, a miniature camera with a wide-angle lens and a 1/4 CMOS sensor is incorporated. The ring beam device and the miniature camera are jointed inside the cylindrical glass. The power of LD is supplied through a hairline enameled wire. In addition, we are developing another optical instrument using a transparent electrode instead of a metal wire.

Now we have various kinds of proto-type instruments with the diameter from 5mm to 120mm. additionally we have such an extremely small size probe as 3mm in diameter.

2.3 Experimental examples

We led the compact inner profile measuring instrument on a linear stage and moved along the guide rail inside the tube. Figure 5 shows a TV component (electron gun) which has too steep inner surface and grooves to check by a contact-type stylus. The optically sectioned profiles are shown in Fig.9 where optical sections are obtained by every 10mm. On the basis of these captured optical sections, inner profiles of this sample are analyzed as shown in Fig. 10. The 3D expression of the result from every 30 deg. angle are shown from (a) to (d) in Fig.10.

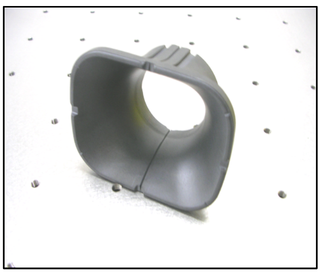
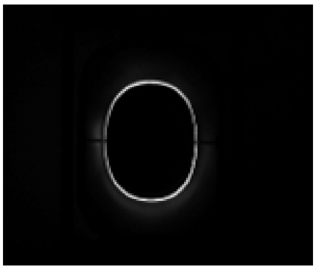


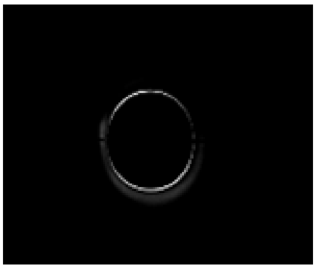
Fig. 5 Sample (TV gun)

(a) 0mm

(b) 10mm

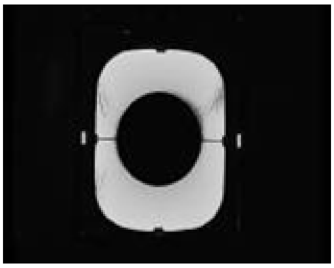


(c) 20mm

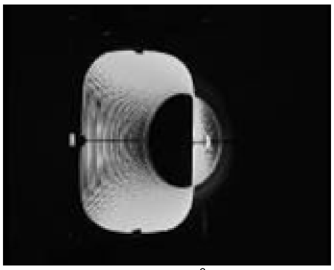


(d) 30mm

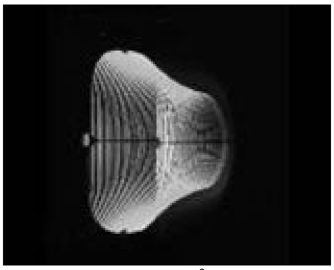
Fig. 7 Cross sections at every 10 mm



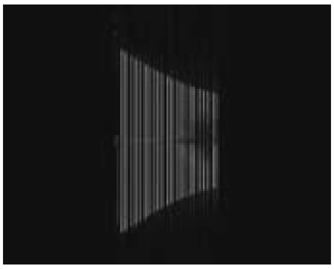
(a) 0°



(b) 30°



(c) 60°



(d) 90°

Fig.8 3D representation of inner profile

Currently we are trying to move this instrument to practical applications in industry. In fact, a few companies are checking availability of this prototype system for their own purposes. One example shown in Fig. 13 is under trial use for checking the inner diameter of a bore (80 mm in diameter) of an engine block. Now we are checking accuracy of this probe using a reference gage (Mitutoyo Corp.). One gage assured to be 25.000$\pm$ 0.002 mm is measured 25.05 $\pm$ 0.002 mm. At present, we are repeating experimental testing using three-size probes mainly

for car industry and heavy engineering industry. In our trial, defects or flaws on the inner surface are proved to be detected by our principle. Figure 9 shows one example that is commercially manufactured for practical use. Here let's show another example of measurement result on an irregular shape object in Fig.10 (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 is shown in truth. In addition to profile measurement, checking of defects and flaws on the inner wall of the pipe has been proved possible. In Fig. 14 an aluminum cylindrical sample.

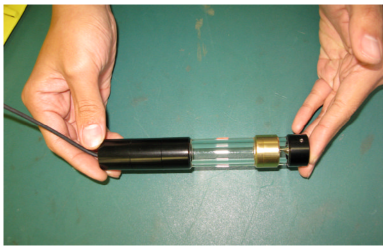


Fig. 9 Commercialized probe (with 25mm diameter)

In addition to profile measurement, checking of defects and flaws on the inner wall of the pipe has been proved possible. In Fig. 14 an aluminum cylindrical sample with original

(a) (b) (c)

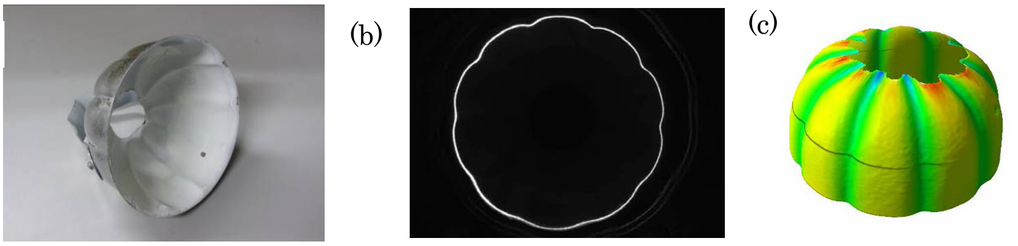


Fig.10 Measurement of an irregular object (a), inner profile (b), and total inner surface (c)

marks due to fabrication process and intentionally scratched flaw. The scratched mark is easily detected as is observed in Fig.15, and even the faint taint caused by drawing process is found at the bottom of the figure.

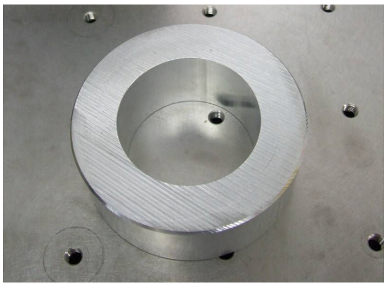


Fig. 11 Sample: (Aluminum cylinder)

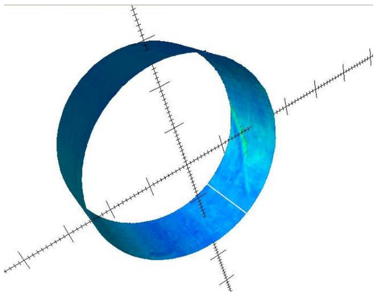


Fig. 12 Detection of flaws

3. Conclusions

We have developed a compact measuring instrument to know inner profiles of pipe-like objects. The instrument is so simple as consists of a ring beam device with a conical mirror and a miniature camera. The ring beam from this device brings optical section of the inner wall, and the section data captured by the miniature camera are used to calculate the inner profile. At the same time, we are trying to inspect defects and flaws on the inner surface of the sample. At this moment, various samples are inspected and measured. We are now trying to apply this principle to industrial measurement and, in the future, we expect to find applications in medical field.

References

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