

# Development of a new clamp-on ultrasonic flowmeter

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## Abstract

Feasibility study on a new type clamp-on ultrasonic flowmeter with a carbon fiber reinforced plastic (CFRP) tube as a meter body is presented in the report. Recently, CFRP is widely used in transportation industry because of its excellent characteristics. Also, non-destructive inspection of CFRP is increasingly important for safety reason and one of the important methods is to detect microscopic defects by use of ultrasound. Characteristics of ultrasonic propagation in CFRP have been well investigated. The paper reports a new type clamp-on ultrasonic flowmeter with CFRP by use of the characteristics. One of the main advantages of the flowmeter is very high S/N ratio.

## 1. Introduction

Carbon fiber reinforced plastic (CFRP) has extremely high strength per weight comparing carbon steel. Also, CFRP has an advantage as non-corrosive material. Because of these characteristics, CFRP is currently used in many transportation industries, such as an airplane, a car and a ship. Especially, Boeing 787 is famous for successful high fuel efficiency, which uses CFRP for airplane body up to about 50 % and achieves 20 % higher fuel efficiency comparing conventional airplanes. Also, CFRP pipe systems have increasingly become the superior choice for piping used in the oil and gas industry due to the higher performance of CFRP pipe. For example, CFRP pipe is more flexible than steel drill pipe. This flexibility is an especially important advantage in permitting producers to re-enter old wells and drill horizontally. CFRP pipe is also popular as non-corrosive material for underground piping.

On the other hand, CFRP has some weakness points. For example, surface of CFRP can be damaged by a sharp edge. Also, external impact can induce cracking of the inside layer of the material with no apparent damage to the surface of the material. Therefore, non-destructive inspection methods of CFRP are increasingly important for safety reason and various inspection techniques have been also developed. One of the important methods is to detect microscopic defects by use of ultrasound. Characteristics of ultrasonic pulse propagation in CFRP have been well investigated already [1].

Clamp-on ultrasonic flowmeters are widely used as a low cost non-invasive flowmeter and installed from the outside of a pipe. Although it is easy to operate, ultrasonic pulses from one of the emitting ultrasonic transducers propagate faster to the other receiving ultrasonic transducer through a pipe than through the fluid to be measured, and the transducer also receives reflecting ultrasonic pulses from various places. Therefore, the receiving transducer detects many ultrasonic signals of the same frequency besides the desired ultrasonic pulse and the signals cannot be removed by any filtering. These are reasons why clamp-on ultrasonic flowmeters are classified as not accurate flowmeter in the latest ISO Standard [2].

CFRP has numerous fine fibers in basic plastic which makes stronger attenuation of mechanical vibration comparing to other materials, such as aluminum and steel as shown in Fig.1 [3].

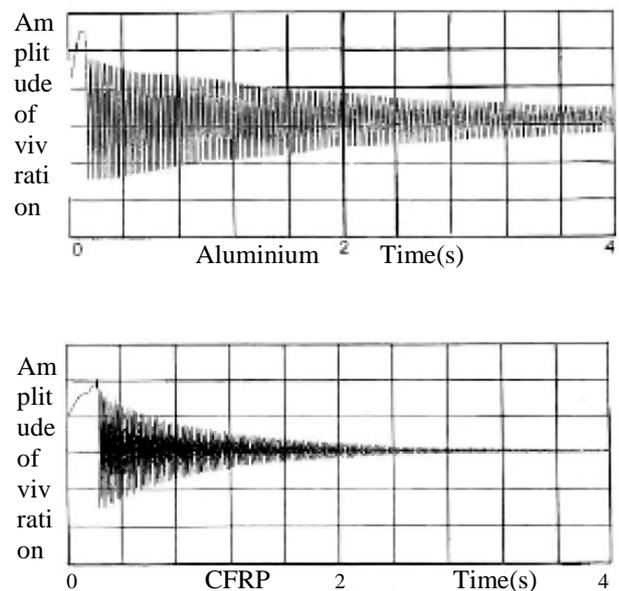


Fig.1 Attenuation of mechanical vibration [3]

Also, thermal expansion coefficient of CFRP can be controlled in very small values between  $-0.2 \sim 0.2 \times 10^{-6} / ^\circ\text{C}$ . These are very promising characteristics if CFRP were used for a meter body of a clamp-on ultrasonic flowmeter.

## 2. Experiment

Ultrasonic pulse propagation in a CFRP plate was measured and compared with a stainless steel plate. A pair of ultrasonic emitting and receiving transducers was mounted apart from 50 mm each other as shown in Fig.2.

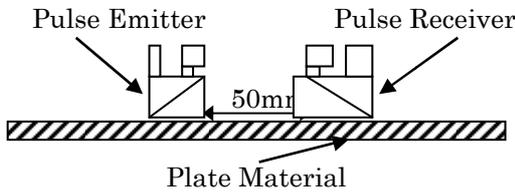


Fig.2 Propagation test in various plate materials

In the case of the stainless steel, an ultrasonic pulse was detected with almost no attenuation as shown in Fig.3.

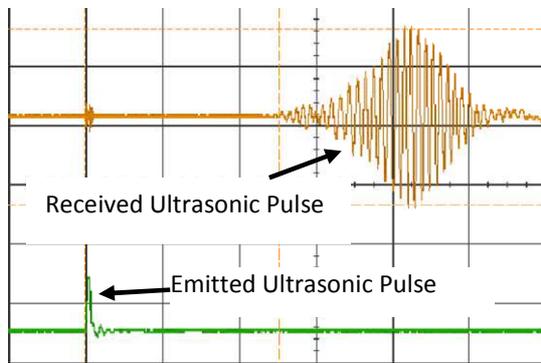


Fig. 3 Ultrasonic propagation in a stainless steel

However, an ultrasonic signal of the emitted pulse frequency was attenuated very much and hardly detected in the case of CFRP as shown in Fig.4.

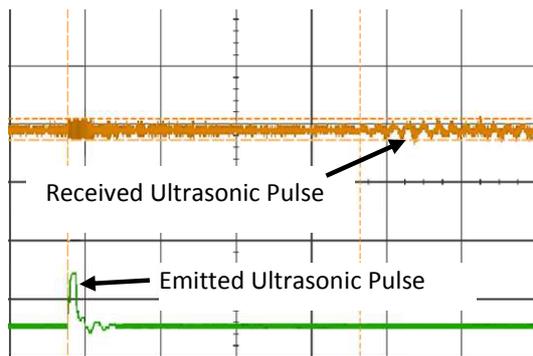


Fig. 4 Ultrasonic propagation in CFRP

As mentioned above, the reason of poor accuracy of a clamp-on ultrasonic flowmeter is that direct propagation of ultrasonic pulses through a clamping steel pipe or remaining ultrasonic pulses reflecting from various places of a steel pipe become main sources of the flowmeter noise and only poor S/N ratio can be achieved. S/N ratio is one of the essential parameters to determine the uncertainty of the flowmeter. Therefore, S/N ratios of ultrasonic pulses through CFRP filled with water were experimentally examined.

Fig.5 shows experimental arrangement to measure the S/N ratio of clamp-on type ultrasonic signal. At first, a pair of emitting and receiving transducer was installed to opposite side of CFRP pipe of 2 mm thickness at the angles of 35 and 45 degree. Ultrasonic pulse was generated by a function generator and amplified up to 50 V peak to peak. Measurement of S/N ratio is not stable because noise is dependent on environment condition and very small and weak signal. Therefore, measurement result gives very rough idea here. Also, the S/N ratio is dependent on the angle, thickness of pipes, density of fiber and pulse strength.

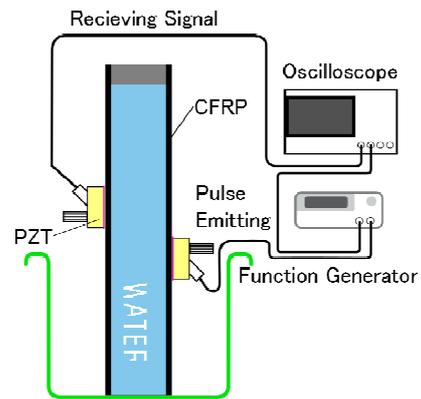


Fig.5 Experimental arrangement to measure S/N ratios of CFRP

Fig.6 shows examples of S/N ratio measurements of CFRP at different two beam angles. It was found that the S/N ratios of CFRP at two beam angles are both very high and are higher than a case of stainless steel, which may improve uncertainty of the CFRP clamp-on ultrasonic flowmeter. Also, there exists pulse frequency to maximize the S/N ratio around 1.4 MHz. It is thought that the best combination of the beam angle, thickness of pipes, density of fiber and pulse strength should be selected now on. Here, it should be also noted that the effect of the beam angle of ultrasound was very large and noise signal was maximum at the angle of 0 degree in the case of stainless steel.

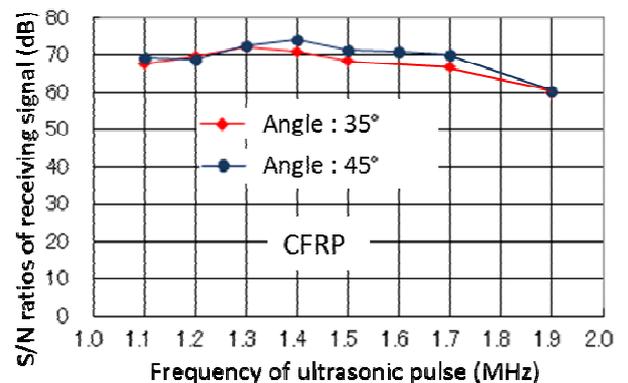


Fig.6 Measured examples of CFRP's S/N ratios at ultrasonic beam angle : 35° and 45°

A primitive converter for ultrasonic flowmeter was used to test characteristic of CFRP in actual liquid flow condition. A very simple experimental setup used for the test is shown in Fig.7. A tentative CFRP clamp-on

ultrasonic flowmeter was compared against a master meter of a coriolis flowmeter which has an excellent repeatability of 0.01 – 0.02 %. Water is just circulated by a pump, therefore flow velocity is not steady, but fluctuation is not very large.

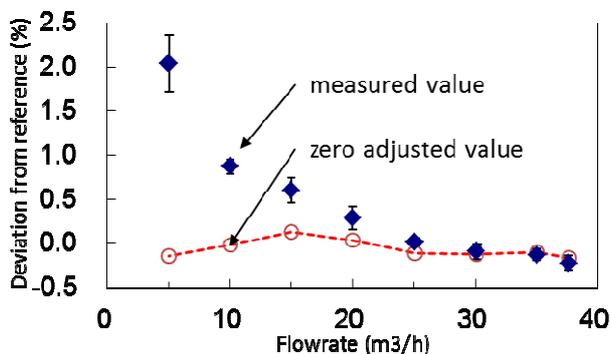


Fig.8 Tentatively calibrated CFRP flowmeter

Total pulse count of the coriolis flowmeter was collected 100,000 and the CFRP flowmeter was collected around 45,000 for one measurement in about 120 s. An example of the test results is shown in Fig.8. Each measurement was repeated 6 times at the same flow point. The variation of the measurements were within  $\sigma = 0.05$  except the minimum flow point. As the converter was not ready to adjust the zero flow point, numerically zero adjustment was made and was plotted in red mark in Fig8, which shows the all flow points were within  $\pm 0.2$  %. However, the scatter and linearity of the CFRP clamp-on flowmeter was not as good as a coriolis flowmeter and these performances are expected to be improved in certain level by a permanent convertor later.

Another important factor to determine the performance of a flowmeter is stability of the zero flow point when environmental temperature changes. The stability of the zero flow point of the CFRP flowmeter was tested in a steady temperature chamber during one day. Fluctuation of zero flow point was about  $\pm 2$  mm/s when temperature of the chamber was changed  $25 \pm 10$  °C as shown in Fig.9.

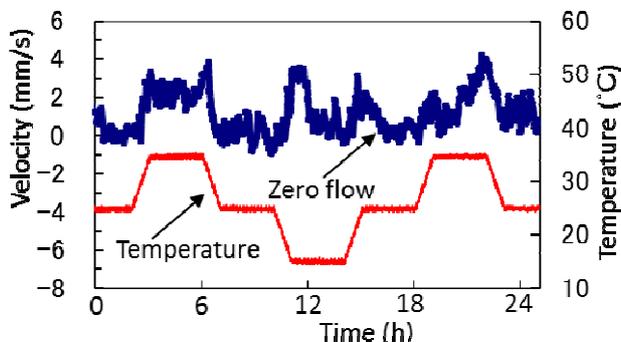


Fig.9 Zero flow stability during 24 hours

The result was not bad, but it is thought that the result can be further improved because the thermal expansion coefficient of CFRP is much smaller than carbon steel.

This is also one of advantages of the CFRP flowmeter. More detailed results will be reported at the conference.

## Conclusion

CFRP has very strong ultrasound attenuation characteristic and it was found that the characteristic can achieve very high S/N ratio when CFRP is used for the meter body of a clamp-on ultrasonic flowmeter. Therefore, development of accurate CFRP clamp-on flowmeter is thought to be highly feasible.

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