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APPLICATION OF ULTRASONIC FLOWMETERS FOR HIGH TEMPERATURES TO FLOW MEASURING FOR BOILER FEED WATER

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1 OUTLINE

1.1 Introduction

Research in regard to ultrasonic feed water flowmeters has been executed for the purpose of improving the thermal efficiency management for thermoelectric power plants, i.e. the performance control for thermoelectric plants.

Conventionally, flow nozzle flow meters have been used as boiler feed water flowmeters, but it can be said that a time change is caused by attachment of scale at the nozzle.

Detection of abnormal leakage in the boiler feed water system and the steam system requires feed water flow measuring with high accuracy and without time change. There are various types of flowmeters on the market, but there are none which satisfy the requirements of an aperture of about 500 mm, withstanding flow media of high temperatures (about 280°C) and high pressures (about 290 kg/cm^2), and having a good repeatability.

Here, the development of an ultrasonic flowmeter withstanding high temperatures, with good repeatability, and with a clamping mechanism permitting simple installation on existing piping is being reported.

1.2 Philosophy for the development process

(1) For development of a flowmeter for high temperatures with an aperture of 500 mm, it is desirable to execute flow measuring tests at high-temperature conditions, but execution with appropriate test costs is difficult.
(2) On the base of flow measuring tests at normal temperatures, the traceability to high temperatures is considered, and this is the largest problem for this development where especially high accuracy is required.
(3) Ultrasonic flowmeters principally use only the dimension and the angle of the sound wave transmission path as measuring factors, so that it is sufficient to obtain the piping conditions for the propagation path at the site.
(4) The change of the properties of the transmission path with the temperature (change of the speed of sound in the liquid) has been researched for pipes with a small aperture, and actual high-temperature flow measuring tests have shown that the compensation calculation method provides coincidence with differential pressure flowmeters for the temperature range from normal temperature to 300°C with an accuracy of ±2% FS for an aperture of 50 mm.[1]
(5) If it would be possible to confirm coincidence with flow nozzles by field testing at high temperatures in an actual plant with application of the above compensation calculation method to an aperture of 500 mm, this would indicate that this compensation calculation method also has the same performance for other apertures, and it can be expected that this will have large results for the realization of ultrasonic flowmeters for high temperatures which can be used generally.

1.3 Summary of the results

(1) The target accuracy of ±0.5% FS was reached with flow measuring tests at normal temperatures. The scale factor decided theoretically by dimension and angle showed coincidence with the actual measuring values.
(2) When the flow is not parallel to the piping (depending on the flowmeter installation conditions), a difference was caused between the theoretically obtained scale factor and the actual measuring values, but it was shown that this influence can be removed by the 4 measuring line method.
(3) The coincidence with flow nozzle flowmeters at high temperatures in power plants is within ±0.5% FS, and it has been shown that the principle of ultrasonic flowmeters is correct also at high temperatures.
(4) The plant flow measuring tests after completion of field testing for about 1 year fulfilled the target accuracy, thus proving long-time stability for the performance.
(5) It has been shown that the time change with attachment of scale is small in comparison with flow nozzle flowmeters.

This research has provided a prospect for ultrasonic flowmeters with good repeatability usable for thermal efficiency management.

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2 MEASURING PRINCIPLES AND CORRESPONDENCE TO HIGH TEMPERATURES AND HIGH ACCURACY

2.1 Measuring principles

As shown in *Fig. 1*, sensors are installed on the upstream and the downstream side, and ultrasonic pulses are transmitted and received alternately.

At this time, the difference between the propagation time T_1 from upstream to downstream and the propagation time T_2 from downstream to upstream is proportional to the flow V, and this is used as shown by the following formulas.

$$T_1 = \frac{D/\cos\theta}{C+V\sin\theta} + \tau \quad \cdots\cdots\cdots \quad (1)$$

$$T_2 = \frac{D/\cos\theta}{C-V\sin\theta} + \tau \quad \cdots\cdots\cdots \quad (2)$$

$$V = \frac{D\,(T_2 - T_1)}{\sin 2\theta\,(T_0 - \tau)^2} \quad \cdots\cdots \quad (3)$$

$$T_0 = \frac{T_1 + T_2}{2}$$

$$Q = \frac{1}{K} \cdot \frac{\pi D^2}{4} \cdot \frac{D}{\sin 2\theta} \cdot \frac{T_2 - T_1}{(T_0 - \tau)^2} \quad \cdots\cdots\cdots\cdots \quad (4)$$

K: Flow speed distribution compensation coefficient

In this way, the flow measuring factors for an ultrasonic flowmeter are decided only by the dimension, the angle, and the material.

2.2 Correspondence to high temperatures

The speed of sound for flow medium and pipe material changes according to flow medium temperature and pressure changes.

With this change of the speed of sound, θ and τ in the above formula (4) change, and an error is caused for the flow measuring.

Accordingly, compensation is executed with T_0 (average propagation time) and t (flow medium temperature) as shown in *Fig. 2*.

2.3 Correspondence to high accuracy

As can be understood from the measuring principles, it is a precondition that V is parallel to the pipe. When not parallel flow or spiral flow is caused because the straight pipe length is not sufficient, or because of a pump upstream, etc., this causes errors for the flow measuring. In such cases, the method of averaging the measuring values for two symmetric measuring values in the same plane (2 measuring line method) is effective. When this 2 measuring line method is applied to two planes at a right angle to each other, i.e. a 4 measuring line method, averaging of the four measuring values is effective.

Fig. 1 Ultrasonic flowmeter principle drawing

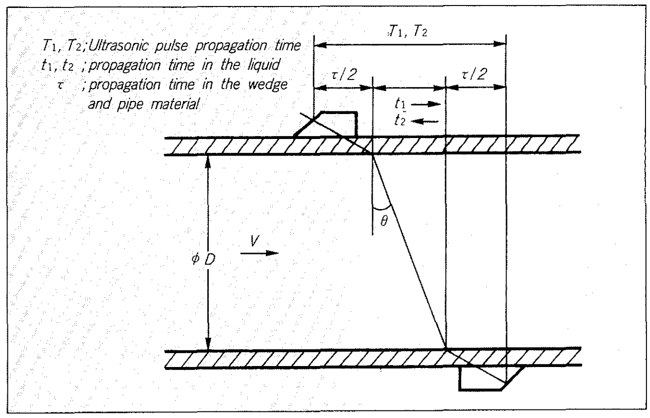


Fig. 2 Compensation calculation block diagram for speed of sound

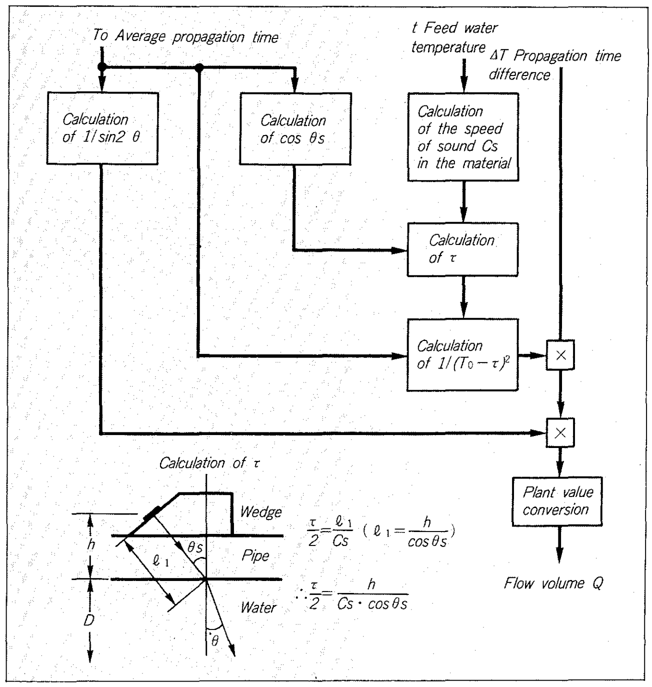
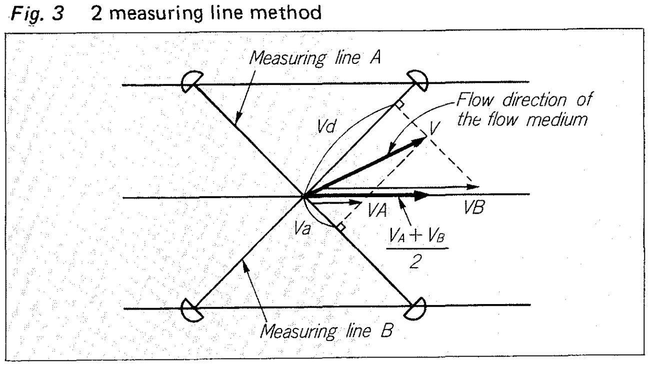


Fig. 3 2 measuring line method



3 CONSTRUCTION AND SPECIFICATIONS OF THE TEST UNIT

As shown in *Fig. 4*, the detectors are installed at the

Fig. 4 Detector construction

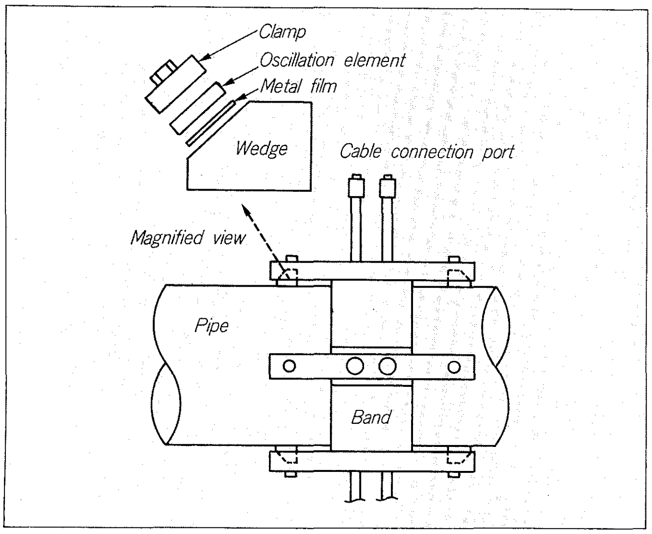


Table 1 Main specifications of test unit

Piping aperture	500 mm
Measuring method	4 measuring line ultrasound waves
Detector installation method	Installation on the outside of existing pipes
Detector temperature	Normal to 300°C
Measuring range	0 to 3000 m^3/h
Measuring accuracy	±0.5% FS

outer wall of the pipe (this is called the clamp method), and ultrasonic waves are transmitted diagonally. In order to withstand high temperatures, $LiNbO_3$ was used for the oscillation elements, while SUS was used for the wedge material, and ultrasonic wave propagation was made possible by a construction with insertion of a metal film.

A microcomputer was used for measuring of the propagation time with phase lock circuit application, and a total of four converters was used for average value processing, sound speed calculation execution, and output of flow measuring signals. The main specifications of the test unit are shown in *Table 1*.

4 TEST EQUIPMENT AND TEST ITEMS

4.1 Plant flow measuring equipment (refer to *Fig. 5*)

(1) Method

A pump is used for forced circulation, the flow volume is controlled by means of the pump speed and valves, and a constant flow volume is obtained. A commutator is used, the reference flow volume is calculated from the time and the weight obtained with a weighing tank, and this is compared with the results of the ultrasonic flowmeter.

(2) Specifications

Aperture: ID 312 mm (same as the site piping)
Max. flow volume: 5000 m^3/h
Measuring tank capacity: 20 m^3

Fig. 5 Plant flow measuring test equipment

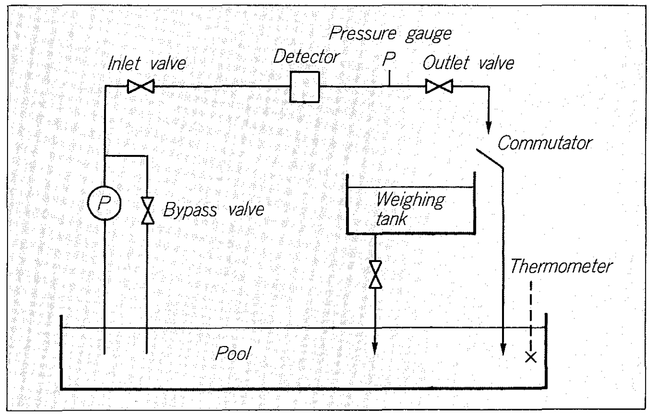
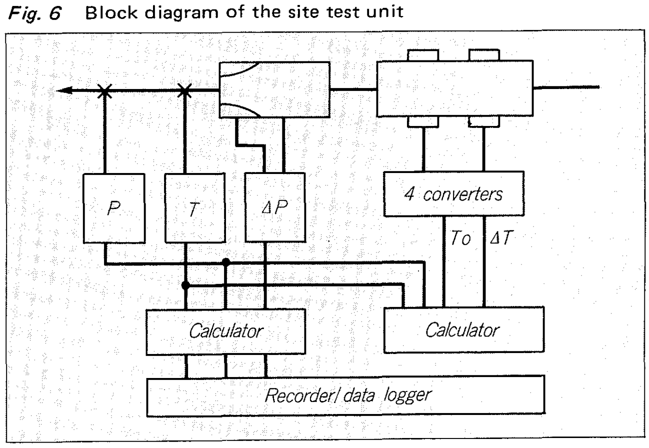


Fig. 6 Block diagram of the site test unit



Test equipment accuracy: ±0.081% or better

4.2 Site test equipment

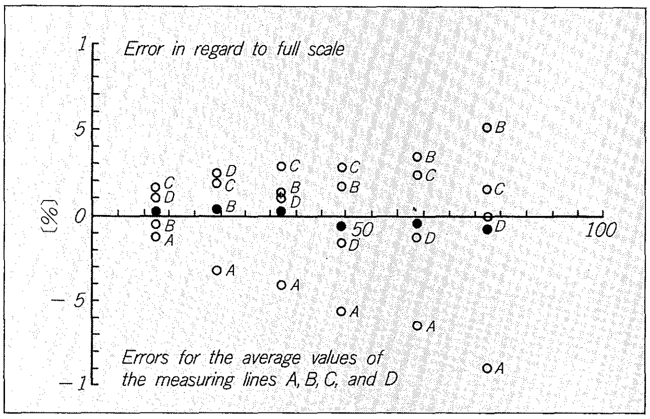
Field testing for about one year was executed with the equipment shown in *Fig. 6*, and the following measuring was executed.

(1) For comparison of flow measuring values
- Flow nozzle output (ΔP and flow volume calculation value)
- Ultrasonic flowmeter output ($T_2 - T_1$ and flow volume calculation value)
- Flow medium temperature (T) and pressure (P)

(2) For determination of the time change of the ultrasonic flow measuring diameter
- Average propagation time (T_0)
- Strength of the received ultrasonic waves

The above measuring values were recorded at all times with pen recorders, and digital voltmeters and data loggers were used for unit performance testing for measuring with high accuracy.

Fig. 7 Plant measuring test results



5 TEST RESULTS

5.1 Results of the plant flow volume measuring tests at normal temperature (*Fig. 7*)

(1) The test unit fulfilled an accuracy of ±0.5% FS.

(2) The theoretical values obtained from the pipe dimension and the speed of sound coincided with the average values for the measuring values of the 4 measuring lines.

(3) The plant flow testing after high-temperature field tests for about one year also showed an accuracy of ±0.5% FS or better.

5.2 Results of the high-temperature flow volume measuring tests at the site (*Fig. 8*)

(1) The detectors showed no performance deterioration independent of the heat cycles, clamp force and reception strength also showed no change, and stable measuring was possible.

(2) The results of the comparison with a nozzle flowmeter in high-temperature condition directly after pipe cleaning showed an accuracy within ±0.5% FS.

6 CONSIDERATIONS

While the difference between the nozzle flowmeters and the ultrasonic flowmeters at the start point was +0.4% FS, it changed to about +2% FS within several months. Return to +0.4% was obtained at the time of restart after unit stop. (Refer to *Fig. 9*.) It is believed that this is caused by attachment of scale at the nozzle throat and removal of the scale while the unit is stopped.

Fig. 8 Site test results

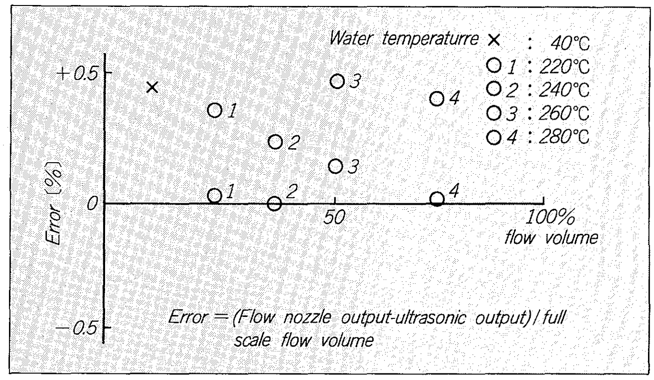
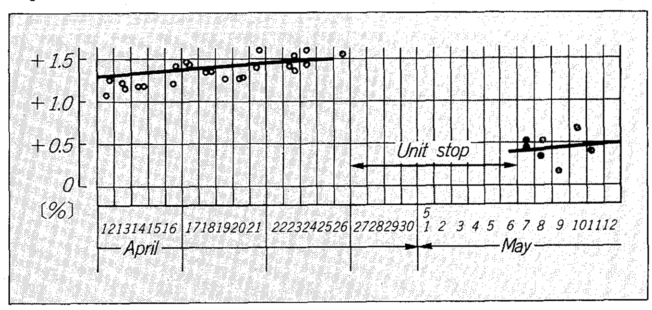


Fig. 9 Difference between flow nozzle and ultrasonic measuring



7 CONCLUSION

On the basis of this research, it can be assumed that ultrasonic flowmeters have the same performance as nozzle flowmeters, and that they can be applied sufficiently to boiler feed water measuring as flowmeters with little influence from scale attachment.

This research also has confirmed coincidence between the theoretical values determined by the pipe dimension and the angle at normal and high temperatures for the pipe aperture 500A. Accordingly, it has been shown that the compensation calculation formula in regard to the water temperature is correct from normal temperature to 300°C and pipe apertures of 50A and 500A.

Accordingly, it is believed that the same performance as with this research also can be obtained with this compensation calculation for other apertures.

Reference:

(1) "A Clamp-on Ultrasonic Flowmeter for High Temperature Fluid in Small Conduits" 'ISA FLOW-81 2. 549, 1981.