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Measurement of Water Stream Flowing to Steam Condenser in Condensing Power Plant

[1]S. AlSaqoor, [1]K. AlQdah, [2]A. Andruszkiewicz, [2]K. Kubas and [2]J. Gorecki
[1]Tafila Technical University, Jordan
[2]Wroclaw University of Technology, W. Wyspianskiego 27, 50-370 Wroclaw, Poland

Abstract: The study outlines technical solutions for measurement of water mass stream flowing from cooling towers to steam condensers. Such solution was applied in 200 MW power units of condensing power plants. Two methods were used for these measurements: probes averaging dynamic pressure and flowmeters using the forces of inertia in fluids resulting from a change in the flow direction or the so called elbow flow meters. The flow coefficient value found to be 7.01 for the flow meter under consideration. Also, the study presents the methods of measurements, metrological properties of flowmeters and measurement uncertainty analysis. At $\alpha = 0.95$, the uncertainty of volumetric stream measurement, at stable flow of water stream and for differential static pressure over 50 Pa, quickly approaches 2.30%.

Key words: Mass stream, turbine, measurement, transducer, elbow

INTRODUCTION

The energy demand world wide especially in the developing countries is growing significantly as a result of economic growth, industrial expansion, high population growth and urbanization. Thermal power plants play a major role in meeting this ever increasing demand. Selection of proper thermodynamic cycle plays a vital role in extraction of power from thermal power plants. The power cycles are investigated with an over all objective of providing high fuel conversion efficiency. The available research related to the power plant conducted by Azhdari *et al.* (2009), Naradasu *et al.* (2007), Barna and Baranyai (2009) and in addition to Wazed and Shamsuddin (2009).

Very little work has been done on measurement of condensation and flow measurements techniques, the available investigation in this regions done by Miskam *et al.* (2009), Mckeon and Smith (2002) and Gorecki and Kubas (2005, 2003).

The lack of available experimental work in this region is the motivation for this investigation.

Systems of continuous monitoring and measurements of cooling water mass streams for condensers of steam turbines are of extremely importance in power unit operation (Mahesh, 2006; Gorecki *et al.*, 2003, 2006; Behzadi and Golnabi, 2009). They allow for reasonable water management, thus considerable savings of water. The study describes the methods of water mass stream measurement using averaging dynamic pressure prop and using elbow-type flowmeter. As judged by the authors, such methods were the optimum solution as no classical measuring method (flow nozzle) was possible due to large diameter of pipelines exceeding one meter.

Measurement signal coming from the flowmeter is converted in pressure transducer to an analogue current signal and then sent to the power unit control room. Therefore, the signal is converted into digital form represents the cooling water mass stream for power unit condensers (Gorecki *et al.*, 2003, 2006).

MATERIALS AND METHODS

Flow meters averaging dynamic pressure: Water mass stream was measured by dynamic pressure averaging probes located downstream the power unit condensers. Pressure signal from probes is converted to analogue current signal (4-20 mA) in pressure transducer and sent to the power unit control room. Here, the measuring signal is converted into digital form and displayed as the mass stream of water cooling the power unit condensers. Figure 1 illustrates the model of a flowmeter which represents the averaging dynamic pressure while, Fig. 2 shows the mounting arrangement for the probes in a pipeline (Gorecki *et al.*, 2003).

The measuring principle is based on the proportional relation between mass stream and a square root of differential pressure:

$$q_m = C \cdot \sqrt{\Delta p_d} \qquad (1)$$

where, $C = k \cdot A \cdot \sqrt{2 \cdot \rho_w}$ when transducer characteristic is considered:

Corresponding Author: Sameh AlSaqoor, Tafila Technical University, Jordan

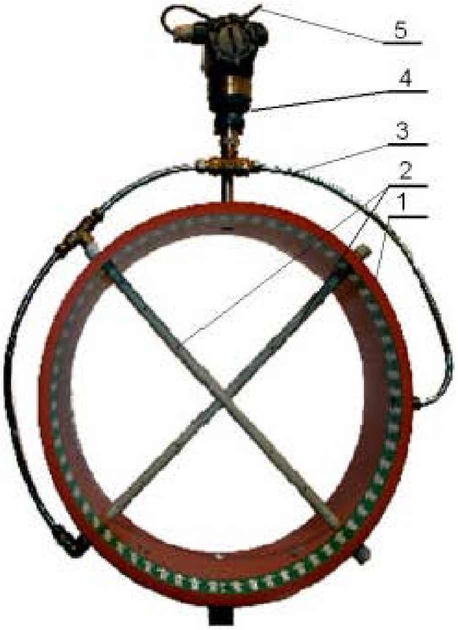


Fig. 1: Model of averaging flow meter. 1: Process pipeline, 2: Total pressure averaging pipes, 3: Averaging pressure lines to differential pressure transducer, 4: ΔP/I transducer and 5: Electrical signal sent to power unit control room

Fig. 2: Mounting arrangement of averaging probes in pipeline

$$\Delta p_d = f(I) = C_1 (I\text{-}4)$$

where, I is the output current of differential pressure transducer (4-20 mA):

$$q_m = C^* \cdot \sqrt{I-4} \qquad (2)$$

This equation forms a common application as an input signal to the measuring/control system of the power unit.

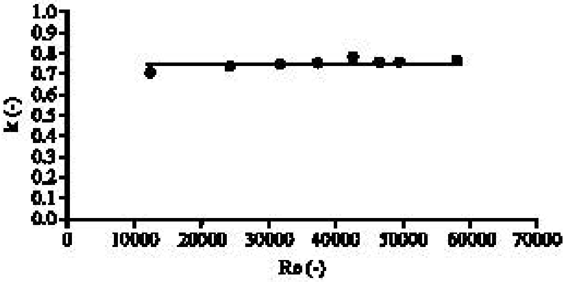


Fig. 3: Exemplary relation between sensitivity coefficient, k, of averaging flowmeter and Reynolds number

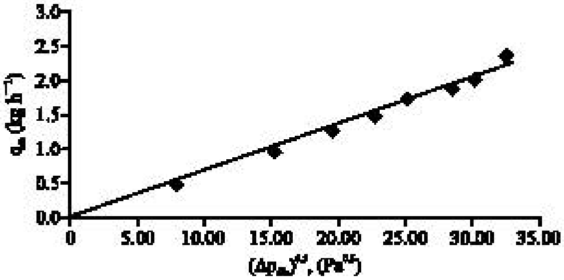


Fig. 4: An example of an averaging flow meter characteristics

Exemplary metrological characteristics of averaging flowmeters are shown in Fig. 3 and 4.

Elbow-type inertia flowmeters: An elbow-type inertia flowmeter is based on a curved section (elbow) of process pipeline and a transducer which measures a difference of static pressures, Δp, between external and internal wall of the elbow (Cengel *et al*., 2008).

The difference of pressures (differential pressure) results from inertia force. The measurement principle is based on the relationship between differential pressure and volumetric stream of flowing medium (Gorecki *et al*., 2003).

Signal transmission is similar to that outlined for the flowmeter with averaging tubes. Details of elbow-type flowmeter is shown in the schematic diagram Fig. 5.

The flow meter characteristic is given by two Eq. 3 and 4:

$$q_m = C \cdot \sqrt{\Delta p} \qquad (3)$$

Or

$$q_m = C^* \cdot \sqrt{I-4} \qquad (4)$$

The coefficients, C and C* are sometimes called the flow coefficients. They may be determined for specific type of flowmeter by means of calibration using measurements of volume/mass flow, or by other method, e.g., using a high-precision flowmeter.

Determination of measuring characteristic of elbow-type flowmeter: Measuring characteristics of the elbow-type flowmeter were determined on a laboratory stand used for flowmeter calibration at Institute of Heat Engineering and Fluid Mechanics, Wrocław University of Technology. Figure 6 illustrates the elbow-type flowmeter under testing together with differential pressure transducer.

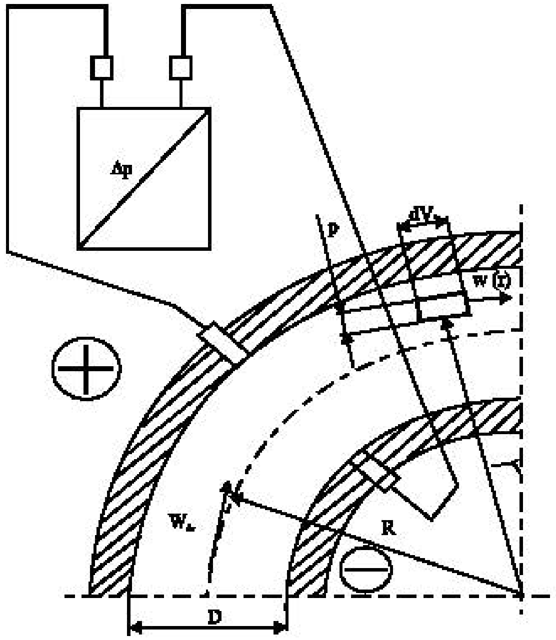
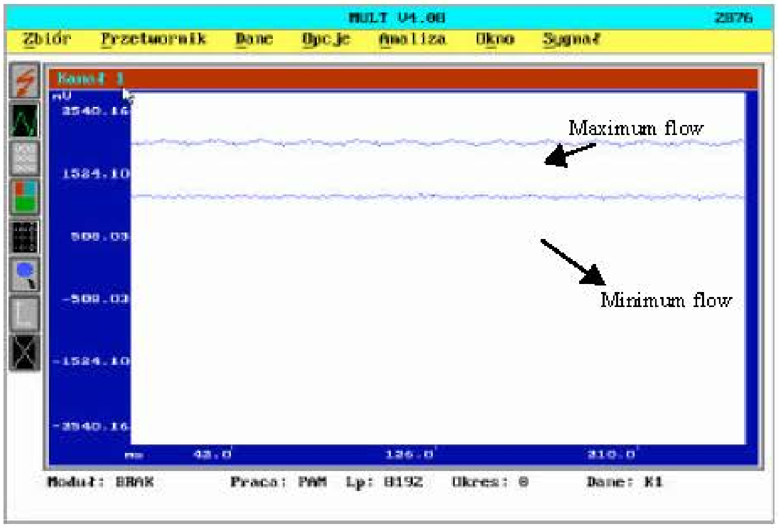


Fig. 5: Schematic diagram of elbow-type flow meter

The flow meter was installed in a pipeline 40 mm in diameter (ϕ). Differential pressure was measured by means of Rosemount type 3502 transducer with maximum measuring range Δp_{max} = 6.22 kPa and output current signal 4-20 mA. Testing instrumentation includes also IBM PC with LC-020 transducer card, LC-055-P10 digital control card and AMP-UNI-01 amplifier. The sampling period was Δt = 1 min and the number of samples was M = 8192. Ten measurements were taken for each measuring series (for volumetric stream of flowing water). In parallel, the volumetric stream was measured using turbine flowmeter (Sonntag *et al.*, 2003) with maximum range q_{Vmax} = 16 m^3 sec^{-1}. Figure 7 shows the range of

Fig. 6: Elbow-type flowmeter under testing



Moduł: BRAK Praca: PAM Lp: 8192 Okres: 0 Dane: K1

Fig. 7: Range of variations for measured signals

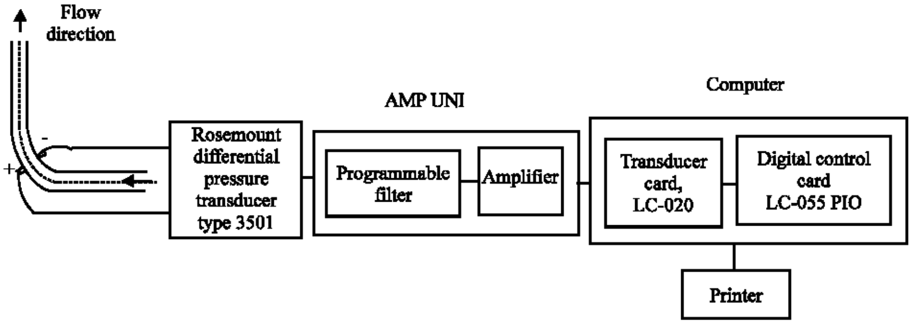


Fig. 8: Diagram of the measuring system

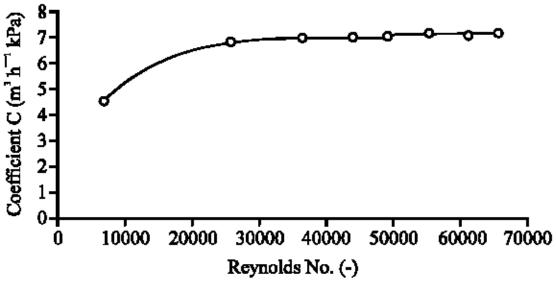


Fig. 9: Flow coefficient, C, versus Reynolds number for elbow-type flow meter

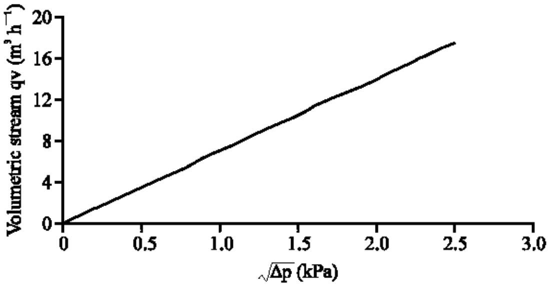


Fig. 10: Measuring characteristic of the elbow-type flowmeter under testing

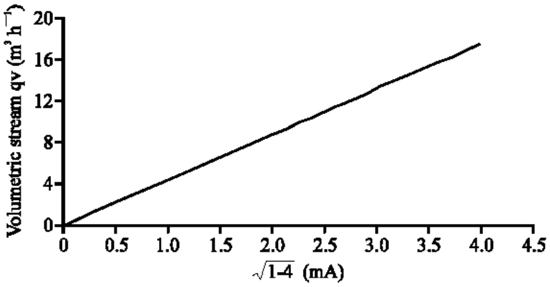


Fig. 11: Electric current characteristic of elbow-type flowmeter

variations of measured signals-from minimum to maximum volumetric stream of water flowing in the system.

Figure 8 shows the diagram of the system including measurement instrumentation.

The coefficient C was calculated from Eq. 5:

$$C = \frac{q_{v_T}}{\sqrt{\Delta p}} \qquad (5)$$

where, q_{vT} is the volumetric stream taken by reference turbine-type flowmeter.

Figure 9 shows the relation between the flow coefficient, C and Reynolds number as found from measurements for the flowmeter under testing.

As it clear from the measurements results taken, when Reynolds number is higher than 26,000, the coefficient C is constant and equals to 7.01, hence the flowmeter characteristic is given by the equation:

$$q_v = 7.01 \cdot \sqrt{\Delta p}$$

This is shown in Fig. 10.

Determination was also made for the electric current characteristic of elbow-type flowmeter to allow further signals processing. Since:

$$q_v = C \cdot \sqrt{\Delta p} \text{ and } \Delta p = -\frac{6.22}{4} + \frac{6.22}{16} \cdot I$$

Then:

$$q_v = C \cdot \sqrt{\frac{6,22}{16} \cdot I - \frac{6,22}{4}} = 4,37 \cdot \sqrt{I - 4}$$

This characteristic is shown in Fig. 11.

Analysis of measurement uncertainty: An exemplary uncertainty analysis for measurement of volumetric stream in case of elbow-type flowmeter is provided below (Central Office of Measures, 1999). It was assumed for the analysis that water flow in the system was stable and that the predominating is the type B standard uncertainty caused by inaccuracy of measuring instrumentation. Thus, the extended uncertainty is given by the equation:

$$u_{q_v} = k_B(\alpha) \cdot u_{B_{q_v}} \tag{6}$$

where:

$$u_{B_{q_v}} = \sqrt{\left(\frac{\partial q_v}{\partial C}\right)^2 \cdot u_{BC}^2 + \left(\frac{\partial q_v}{\partial \Delta p}\right)^2 \cdot u_{B\Delta p}^2} \tag{7}$$

Following transformations and using characteristic equation, we get:

$$u = k_B(\alpha) \cdot \sqrt{\left(\frac{q_v}{C}\right)^2 \cdot u_{B_C}^2 + \frac{1}{4} \cdot \left(\frac{q_v}{\Delta p}\right)^2 \cdot u_{B_{\Delta p}}^2} \tag{8}$$

and further on:

$$\frac{u_{q_v}}{q_v} = k_B(\alpha) \cdot \sqrt{\left(\frac{u_{B_C}}{C}\right)^2 + \frac{1}{4} \cdot \left(\frac{u_{B_{\Delta p}}}{\Delta p}\right)^2} \tag{9}$$

The standard uncertainty of type B for the flow coefficient, C, can be found from the flowmeter characteristic. Assuming that relative limiting error of Δ_{qc}/C for determination of the flow coefficient equals to 2%, the standard type B uncertainty is:

$$\frac{u_{B_C}}{C} = \frac{\Delta_{qc}}{\sqrt{3}} = \frac{2}{\sqrt{3}} \cong 1.15\%$$

The standard type B uncertainty for differential pressure on the elbow is assumed, according to Robert *et al*. (2007) and Gorecki *et al*. (2003) as:

$$u_{B_{\Delta p}} = 0{,}29 \cdot \delta x$$

Where:

δx = Is the resolution of differential pressure transducer, hence

$u_{B\Delta p}$ = 0.29·1 Pa = 0.29 Pa (the resolution of differential pressure transducer was 1 Pa)

Assuming, according to Central Office of Measures (1999), the expansion coefficient $k_B(\alpha) = 2$ for the level of confidence $\alpha = 0.95$, the relative extended uncertainty is given by the equation:

$$\frac{u_{q_v}}{q_v} = 2 \cdot \sqrt{(0.0115)^2 + \frac{1}{4} \cdot \left(\frac{0.29}{\Delta p}\right)^2}$$

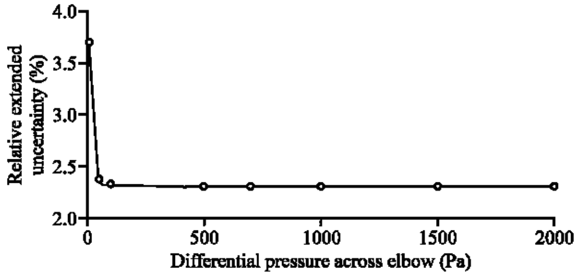


Fig. 12: Relative extended uncertainty, u_{q_v}/q_v, as a function of differential pressure across the elbow, Δp

which is shown in Fig. 12.

CONCLUSIONS

The study presented alternative continuous measurement of flow streams in pipelines exceeding 1 m in diameter using flowmeters which average dynamic pressure and inertia elbow-type flowmeters. Such flowmeters were successfully used to measure mass streams of cooling water for steam turbine condensers in one of Polish power plants. Operating principles for these flowmeters and their exemplary characteristics are also included. For the elbow-type flowmeter, the paper provides its characteristics-according to the equation $q_V = C \cdot \sqrt{\Delta p}$. An average value of flow coefficient, C, was 7.01 for the flowmeter under consideration, hence the characteristic is $q_V = 7.01 \cdot \sqrt{\Delta p}$, where q_V is expressed in $m^3\ h^{-1}$ and Δp in kPa.

The preliminary uncertainty analysis shows that, at the confidence level $\alpha = 0.95$, the uncertainty of volumetric stream measurement, at stable flow of water stream and for differential static pressure over 50 Pa, quickly approaches 2.30%. The measurements taken allowed also determining the measuring range of the flowmeter under testing. It may be used for Re >26,000, i.e., for water flow velocity over 0.7 m sec^{-1}. For this measuring range, the value of coefficient C is constant. For Reynolds number less than 26,000, an additional coefficient, C*, shall be introduced into the characteristic equation, so then $q_v = C^* \cdot C \cdot \sqrt{\Delta p}$.

NOMENCLATURE

A = Area (m^2)
C = Flow coefficient
I = Electric current (am)
K = Sensivity coefficient
K_{bx} = Coeffieint of expansion
M = Number of samples

P = Pressure, Pa.
q_m = Mass stream (kg sec^{-1})
q_V = Volumetric stream (m^3 sec^{-1})
Re = Reynolds No.
uqv = Uncertainty

Greek letters

ΔP = Pressure difference
α = Level of confidence
ρ = Density (kg m^{-3})
δ_x = Resolution of differential pressure transducer

Subscripts

d = Difference
m = Measured
w = Water

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