Detection of dynamic installations effects by an ultrasonic flow meter in non-stationary flow

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Abstract Installation effects represent a major cause of the metering errors in a flow meter. Ultrasonic flow meters are especially sensitive to installation effects. Installation effects can be static, like those due to pipe bends or diameter reduction at the inlet of the meter, or dynamic like pulsating flows generated by pumps. Recently presented, the detection of pulsating flows has been achieved in stationary flow conditions. In that case, the distribution of the flow rate is not supposed to vary with time. By applying Hinich's harmogram, the detection of pulsating flows is correctly done. However, in real cases, flow rates vary with time. The endless openings, closings, and adjustments of valves and faucets make the flow rate to vary with time. The aim of this article is to answer whether, or not, the method using the harmogram is suitable for detecting pulsating flows when the average flow rate over a pulsation period is time varying. The simulations provide good results for the detection of pulsations in such flows by the harmogram.

Keywords: Ultrasonic flowmeter, pulsating flow, harmogram, non-stationary

1-Introduction

The problems caused by flow pulsations on flow measurements have been known for more than a century [1]. Pulsating flows are dynamic installation effects generated by pumps, compressors, and reciprocating valves. Such pulsations generate different types of errors on different types of meters. Transit-time ultrasonic flowmeters are mostly affected by the prediction error [2], the presence of turbulent structures in the sound path, and by velocity profile errors. In figure 1 the relative error of a D-Flow transit-time ultrasonic flowmeter is compared to the European standard EN-1434 (class 2). The experimental points, obtained in the calibration facility at Luleå University of Technology, show errors that are much larger that the maximum permissible error (M.P.E.) [3] described by the standard. The detection of flow pulsations is then a necessary step before improving the flow rate estimation. The detection of flow pulsation has been treated recently [4] in the case of stationary flows. By "stationary" is meant flows that are stationary in the wide-sense [5], but that can include a sum of components with constant amplitudes and instantaneous frequencies [6]. Hence, a simple periodic pulsation [7] $\bar{v}(t)$ written as:

$$\bar{v}(t) = \bar{v}_0 + \bar{v}_1 \sin(2\pi f t),$$

where $\bar{v}_0$ is the constant part of the flow rate, and $\bar{v}_1$ is a constant amplitude associated to the constant frequency f. The object of the present paper is to study if the harmogram [8] used in [4] to detect flow pulsations is suitable for detecting flow pulsations when $\bar{v}_0$ is a function of time. As the non-stationarity is more a non-property than a property, the study has to be bounded to a special class of non-stationary flows. Hence, the simulations include a term $\bar{v}_0$ behaving as a ramp against time. This behaviour of the flow rate can be a model for tap opening.

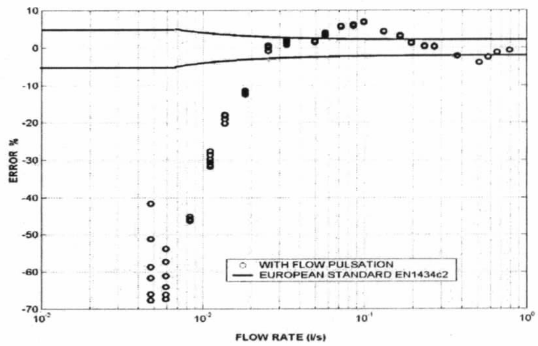

Figure 1: The relative error of the D-Flow transit-time ultrasonic flowmeter when flow pulsations are involved. The error (points) is compared to the black curves delimiting the M.P.E. according to the European standard EN-1434 (class 2).

As a first step, we will briefly look at the principle of the detection of flow pulsations in the stationary case. Then, we will apply the principle to a simulated flow rate whose time-average velocity $\bar{v}_0$ increases linearly.

2-Detection of pulsations in a stationary flow

The principle of the detection of pulsations in stationary flow conditions is the following. Pulsations in a flow generate periodicities in the velocity signal measured by a flow meter. A periodicity is transformed in the frequency plane by a series of harmonics in the Power Spectral Density (P.S.D.). If the power of the pulsations is strong enough, these harmonics emerge from the P.S.D. estimation of the background Gaussian noise present in the measured flow velocity. Hinich [8] has successfully found a method to automatically detect such harmonics in a Gaussian background noise. Defining by "signal" the periodic signal in the measured flow rate and by "noise" the Gaussian background, the harmogram developed by Hinich is an estimator of the signal-to-noise ratio (S.N.R.). If there is no pulsation in the flow, there are no harmonic in the P.S.D., and consequently, the distribution of the ordinates of the P.S.D. follows a χ^2 with two degrees of freedom.

3-Detection of pulsations in a Non-stationary flow

It is possible to simulate a measured flow rate from an ultrasonic flow meter even when the flow is non-stationary. Assuming that the flow is linearly increasing from 0,0014 l/s to 0,75 l/s and neglecting the bias error of the flow meter, the measured flow rate can be modelled by an increasing Gaussian noise added to a ramp starting from 0,0014 l/s to 0,75 l/s (figure 2). The Gaussian noise is centred and its standard deviation increases non-linearly with the flow rate. That simulated velocity is a discrete signal whose sampling frequency is 111,11Hz and that has a total duration of 9 seconds (1000 points). A 5Hz sinusoid representing the pulsation is then added. The amplitude of the pulsations is equal to the half of the mean standard deviation. It means that the S.N.R. is high at low flow rates and low for high flow rates. As the flow rate and its standard deviation increase reasonably on a 256 points interval, it is possible to detrend the measured velocity and then to compute the harmogram on an interval of 256 points or every 1,15 seconds. As we can see in figure 3, the harmogram provides good results for the detection of flow pulsations when $\bar{v}_0$ varies with time, since the component of the harmogram at frequency 5Hz is beyond the threshold modelled by the dashed line.

4-Conclusion

The method using Hinich's harmogram for detecting pulsating flows has been applied to non-stationary flows. As long as the signal does not vary excessively on the interval where the harmogram is computed, it is possible to detrend the velocity signal and then to correctly detect the pulsations in the flow. This extends the results found in [4] to more real situations like for example tap opening.

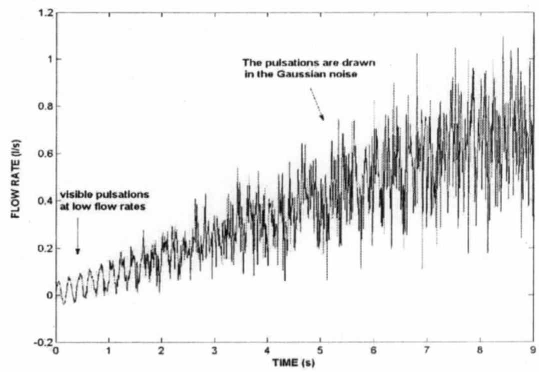

Figure 2: Simulation of the flow velocity measured by an ultrasonic flow meter. The flow rate increases linearly from 0,0014 l/s to 0,75 l/s in 9 seconds.

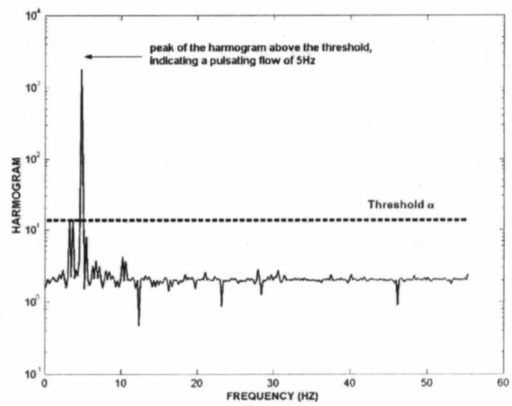

Figure 3: Harmogram of the mesured velocity signal for flow rates linearly increasing from 0,29l/s to 0,48l/s.

5-Referenses

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