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# Evaluation of Orifice Flow Meter Accuracy under Pulsation Conditions

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**Abstract.**Orifice meter is a flow measuring device which is widely used in various industrial applications. Although the device gives accurate measurement during steady flow, measurement errors related to square root and sampling errors are unavoidable if pulsations exist. This research investigatesand improves the performance of an orifice plate flow meter under pulsation effects. A simple model for the pulsating flow through an orifice meter is presented. Square root error (SRE) is estimated. Sampling errors (SE) are reduced by proper selection of the averaging time.

## Introduction

Accurate fluid flow measurement is vital to reduce cost and energy loss[1]. Orifice meter is a pressure differential device thatiswidely usedfor its simplicity and low cost maintenance. Pulsation is defined as a steady time-mean flow with superimposed regular cyclic variations. It is triggered by a reciprocating compressor, pump, or engine [2]. When pulsation exists, orifice meter gives inaccurate flow measurement [3,4] because of the square root error (SRE) [5] and sampling error (SE) [6]. Hence, a proper analysis of these two measurement errors is needed to improve meter accuracy.

For digital flow meter, the differential pressure reading is averaged over sometime interval. During pulsating flow, the SRE occurred due to the square root lawthat relates the velocity and pressure difference [4].Since flow rateis proportional tovelocity, flow rate errors are inevitable if the differential pressure isaveraged before taking square root. For mean flow rate estimation, the pressure drop needs to be averagedover a time interval to avoid SE [5]. The length of the time interval affects the quality of flow measurement especially during pulsation. Thus, the averaging time needs to be selected carefully. Ideally, it should be equal to a multiple of the period of pulsation [6].

In this work, pulsating flow through an orifice meter is modeled to evaluate the meter accuracy.Both SRE and SEare analyzed. Fast Fourier Transform (FFT) is used to find the fundamental frequency of pulsation in noisy environment. This frequency is used to obtain the best integration time for averaging. The next section presents the methodology of this work followed by results and conclusion.

## Nomenclature

Variables usedin this study are instantaneous flow velocity ($v(t)$), mean flow velocity ($v_{mean}$), number of harmonics ($M$), relative amplitude of pulsation ($a_m$), fundamental pulsation frequency ($f_{pulse}$), noise ($w(t)$), instantaneous mass flow rate ($q(t)$),cross section area of meter tube ($A$), instantaneous pressure drop ($\Delta p(t)$), fluid density ($\rho$), orifice diameter ($d$), pipe diameter ($D$), ratio of d/D ($\beta$), discharged coefficient ($C_D$), effective length ($L_e$), contraction coefficient ($C_c$), time ($t$), expansion factor ($\varepsilon$), number of samples ($N$), sampling time ($T_s$), integration time ($T_i$), actual mean flow rate ($q_{mean}$) and measured flow rate ($q_{mean,m}$).

## Methodology

The instantaneous flow velocity (v(t))under pulsation conditions is modeled as [6]:

$$v(t)=v_{mean}[1+(\sum_{m=1}^{M} a_m \sin(2\pi\ m\ f_{pulse}t) +w(t) )] \quad (1)$$

This equation represents the velocity that reaches the measurement device. The instantaneous mass flow rate (q(t)) for compressible flow is calculated as:

$$q(t)=\rho\ v(t)A \quad (2)$$

The instantaneous pressure drop (Δp(t)), is obtained via temporal inertial equation [5]:

$$\Delta p(t)=\frac{8(1-\beta^4)}{C_D\pi^2 d^4\rho}q(t)^2 \text{sign}(q(t))+\frac{4L_e}{\pi d^2 C_c}\frac{dq}{dt} \quad (3)$$

The inclusion of sign function in Eq. 3 is to allow for flow reversal[5]. In orifice meter, themeasured mass flow rate($q_{mean,m}$) is calculated with standard ISO equation [5]:

$$q_{mean,\ m}=\frac{C_D}{\sqrt{1-\beta^4}}\varepsilon\frac{\pi}{4}d^2\sqrt{2\rho}\sqrt{\Delta p} \quad (4)$$

For measuring average flow in pulsation condition, Δp(t) needs to be averaged. SRE occurs, when the square root of the average differential pressure($\sqrt{\overline{\Delta p}}$) is used, instead of the average of the square root of the instantaneous differential pressure ($\overline{\sqrt{\Delta p}}$).Eq. 5 defines the percentage of SRE as:

$$\%\ SRE=\frac{\sqrt{\overline{\Delta p}} - \overline{\sqrt{\Delta p}}}{\sqrt{\overline{\Delta p}}}\times 100 \quad (5)$$

To further reduce the measurement error, proper integration time($T_i$) is selected to alleviate SE [6]. The meter averages the pressure drop as:

$$\overline{\sqrt{\Delta p}}=\frac{1}{N}\sum_{k=1}^{N}\sqrt{|\Delta p(t+kT_s)|}\times \text{sign}(\Delta p(t+kT_s)) \quad (6)$$

Similar to Eq.3, the inclusion of sign function is to allow for flow reversal. Proper selection of the integration time ensures correct evaluation of mean value. FFT of the measured pressure signal can be utilized to determine the principle frequency of pulsation ($f_{pulse}$). Optimum integration time is obtained as $1/f_{pulse}$. This frequency analysis can be done every suitable time interval to adjust the integration time of the averaging process. To calculate the deviation of measured flow rate ($q_{mean,m}$) from actual mean flow rate ($q_{mean}$), the percentage measurement error (% E) is defined as:

$$\%\ E=\frac{q_{mean,\ m}-q_{mean}}{q_{mean}}\times 100 \quad (7)$$

where $q_{mean} = \rho\ v_{mean}\ A$.

## Results

Table 1 presents simulation data [5].The mean velocity ($v_{mean}$) is 1 m/s. Pulsation is generated with 3 harmonics (M=3) with $f_{pulse}$=4 Hz. The additive noise (w(t)) is assumed as a normal distribution random variable with zero mean and variance of $10^{-2}$.

Table 1 Simulation data

| Variable | Value | Unit |
|---|---|---|
| Pipe diameter (D) | 0.07 | [m] |
| Orifice diameter (d) | 0.035 | [m] |
| Fluid density for air (ρ) | 1.205 | [kg/m$^3$] |
| Effective length ($L_e$) | Equal to d | [m] |
| Discharged coefficient ($C_D$) | 0.6 | - |
| Expansion factor (ε) | 1 | - |
| Contraction coefficient ($C_c$) | 1 | - |
| Sampling time ($T_s$) | 0.02 | [s] |

Fig.1 shows SRE of the orificefor $T_i$ = 0.35 s with 3 different sets of amplitudes {$a_1$,$a_2$,$a_3$}. Set 1 is {1,0.5,0.25}, set 2 is {0.5,0.25,0.125}, and set 3 is {0.25,0.125,0.0625}.The percentage error is around 40% for set 1, around 13% set 2 and around 4% for set 3. This shows that SRE increases to unacceptable values whenthe ratio of pulsation amplitude to mean is beyond 50 percent.This error is eliminated if the average of the square root of the instantaneous differential pressure ($\overline{\sqrt{\Delta p}}$) is used.

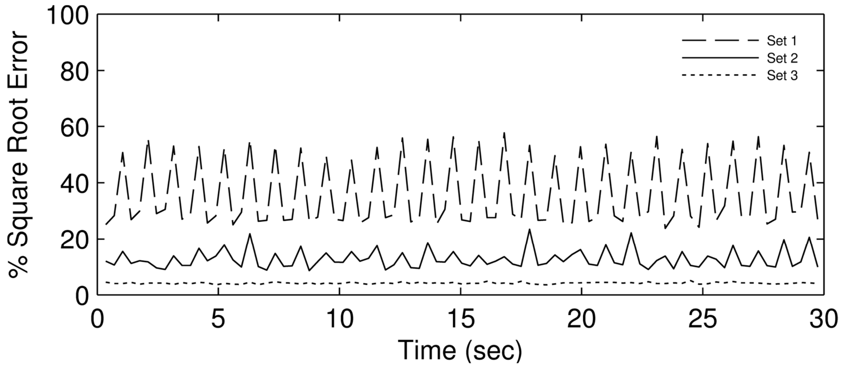

Fig.1 Orifice square root error

To further reduce the measurement error, FFT is implanted to the pressure drop measurement to identify the principle frequency for as shown in Fig. 2. The pulsation frequency is identified clearly as 4 Hz even with the presence of noise. Thus, the ideal integration time is $T_i$ = 1/4 Hz = 0.25 s.

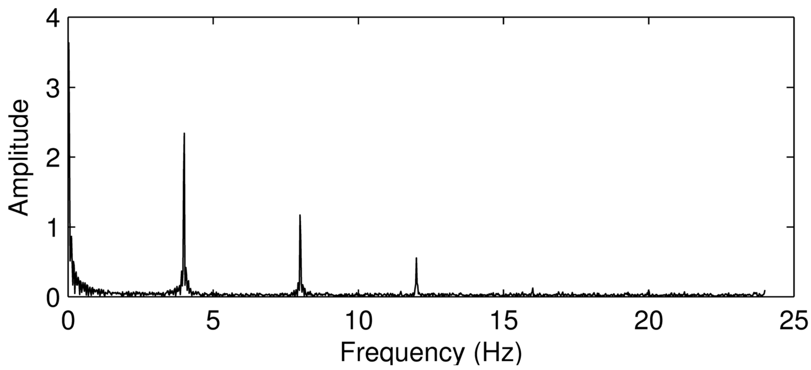

Fig.2 FFT for pressure drop

Fig. 3demonstrates the measurement flow rate error subjected to various integration time to study the effect of sampling error.Set 2 are selected as the pulsation amplitudes. When Ti = 0.1 s, the measurement error is approximated around 40% which is the highest error. Selecting Ti = 1/$f_{pulse}$ = 0.25s, the measurement error reduced dramatically to 8%. As the integration time is increased to Ti =

0.35 s, the error increase to 12%. However, when the Ti is increased to a multiple $f_{pulse}$ ($T_i$ = 2s), the percentage error become very small around 3%. This shows that a good integration time is dependent on the pulsation frequency.

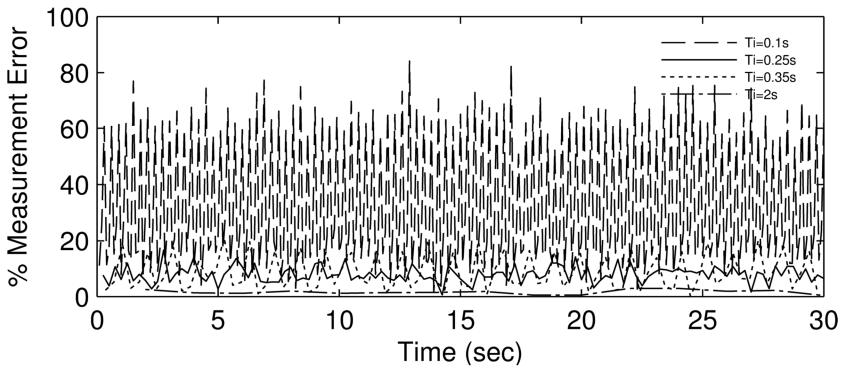


Fig 3. Measurement error for different $T_i$

## Conclusion

A simple modelling of flow pulsation is presented in this work. The pulsating flowis modelled as mean flow with added pulsation components and noise. The effect of square root error and sampling error are investigated. It is proved that a proper way of averaging is vital for measuringmean flow when pulsation exist. The mean SRE for this study is approximately around 80%. By averaging the square root of the instantaneous differential pressure ($\overline{\sqrt{\Delta p}}$), this error can be avoided.In addition, the integration time also affects the quality of the measurement. If pulsationsexists, the integration time should be selected equal to a multiple of the period of the pulsation frequency which can be determined through FFT. This selection willeffectively reduce the measurement error related to sampling error.

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