District heating management in restricted situation

Cătălin Daniel Gălățanu
Technical University "Gh.Asachi" Iași
Department of Building Installation
Str. Lascăr Catargi 38
Iași, ROMANIA
expert-grup@xnet.ro

Keywords

district heating, domestic hot water quality, software modeling, automation system

Abstract

This research is a case study, and was focused on the District Heating (DH) System in Pascani town, powered with cogeneration engine. The main problem started because of the overload regime in domestic hot water (DHW) supply. In the case analysed, the level of the flow-metering in the interior installations is very low (about 10 to 15%). As a result, the level of consumption depends on the time period when DHW is available. In order to decrease the cost to the District Heating Company (DHC), the duration of DHW delivery is restricted. A direct solution to this problem is the submetering for DHW. Some questions remain. The issue was the differences registered between the general flow meter and the sum registered by the sub metering system.

The whole installation must be optimised, starting with heat exchanger, booster pumps, valves, actuators, and continuing with water accumulators. The aim is the client satisfaction, and the automatic control system must cover all the restricted situations. For simulating in MATLAB (high performance numeric computation and Vizualization Software) the thermal and hydraulically systems with pumps, we use the diagram of fluid circuit on which control valve and pumps are mounted.

Introduction

The overload problem in the production of DHW results from the intermittent load. This intermittent load is not technically imposed, but it is a social-economical phenomena. In order to decrease the cost to the District Heating Company (DHC), the duration of DHW is restricted. Huge load peaks are generated also by the working hours of the occupants of the apartments, with lower possibility of diversification.

In order to understand the reason for the multiple discussions about the sub-metering over registration in water installations for apartment houses, a bibliographical research was done. A large series of works was found, and some are very close to our topic (Cheesewright, 1994). Turbine flow meters are used extensively in fluid measurement and the ability of this flowmeter to respond rapidly to transient flow conditions is an important characteristic. According to (Cheesewright 1994), for sinusoidal pulsating flows, the meter accuracy deteriorates with increases in the amplitude and with increases in the frequency of pulsation. If the meter does not rapidly follow the flow rate, then erroneous mean flow measurements as well as erroneous time varying flow measurements can occur. A combination of these effects causes two common, known problems in turbine flow metering for gases. Firstly there is a difference between the pulsation amplitude indicated by the meter and the true pulsation amplitude; secondly the mean blade passing frequency is higher than that which would occur with the corresponding steady flow. These two effects are commonly termed "amplitude attenuation" and "over-registration" respectively.

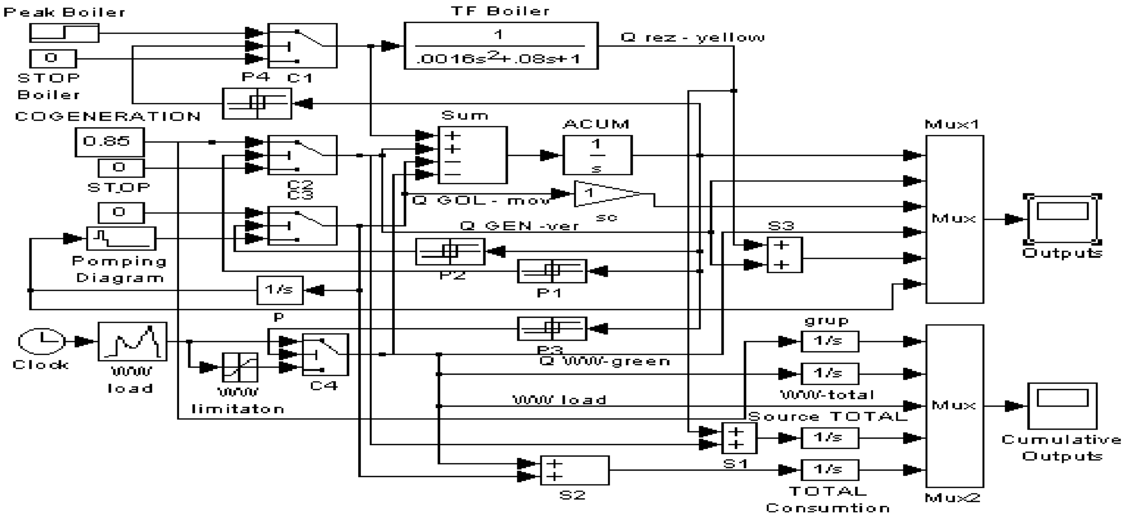

Figure 1. SIMULINK Block Diagram for DH simulations.

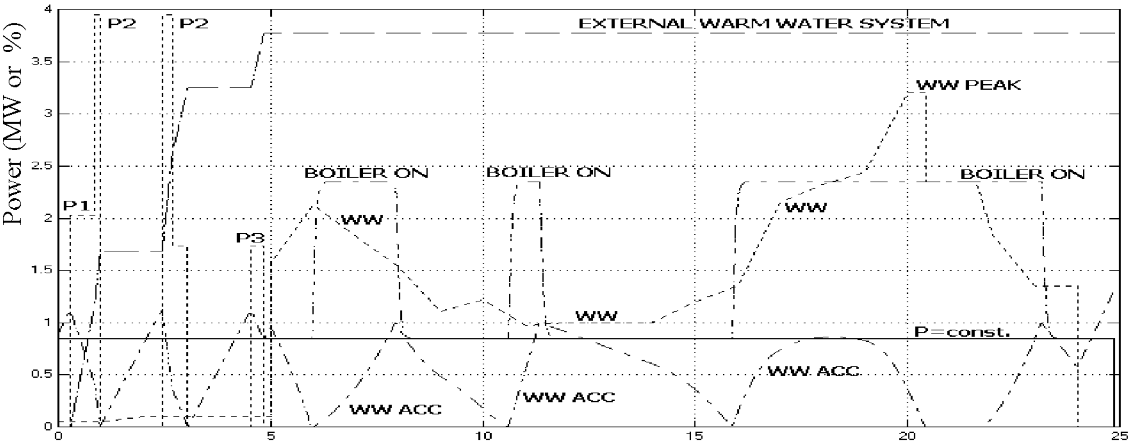

Figure 2. Results from SIMULINK Block Diagram for DH simulations.

MATLAB simulation for DH with Accumulation for DHW

Special problems occur in DHW water production if the power station imposes a constant load. This is a specific case for DHSC (District Heating Station with Cogeneration), named CT5, Pascani. Hardware components that have thermodynamic impact on the DH system are: a) Cogeneration unit (heat and power), with 0.87 MW heating power, using an internal combustion engine Otto using natural gas as the fuel; b) Boiler for DHW production on peaks in summer (1.7 MW); c) Boilers for heating (2 x 6 MW), in winter; d) Two dynamic accumulators 2 x 12.5 m^3, for heating agent; e) Pumps for winter/summer, with variable speed.

The specific problem for the DH system is night operation, when the warm water load is absent, but the cogeneration unit must produce electrical power. The local accumulators (25 m^3) cover only one hour of operation, and for this reason the DH is interconnected with three other DH systems, in which warm water in prepared and stored, using heat produced in CT5. Three heat exchangers with circulation pumps are involved, and the main task for the system is to maintain the cogeneration unit in function, with no stop period. This condition had to be met, and for this a dynamic simulation was used. An additional condition was to verify how the accumulators cover the warm water peak.

Hardware components that have thermodynamic impact on the DH were available in the form of numerical models. For the power plant, these components were (Figure 1): the peak boiler (1.7 MW), the cogeneration unit (0.85 MW), two boilers of 6 MW, for winter heating (are not included in the simulation, because in summer these are not necessary).

Computers models were created using SIMULINK software by the MathWorks. Simulink is a visually programmed mathematical modelling tool which offers direct simulations of graphically-constructed block diagrams (Figure 1). The block diagram interface makes the models easy to build and easy to understand, by direct reading.

In Figure 2 the simulation results are presented for a specific DHW load. It shows the influence of pumping periods **P1**, **P2**, **P3** and the DHW accumulators (**WW ACC**) filling on night operation. The period of operation can be evaluated for all the hardware, for all DHW load conditions.

A special situation occurs in the evening peak, when it was demonstrated that the overload can not be solved. An original solution was design for the DHW automation system. Figure 3 shows the diagram for the DHW system, where a supplementary valve with actuator A1 was introduced for flow limitation. Flow limitation is the solution to prevent the decreasing of the DHW temperature below the acceptable value (40 °C).

MATLAB simulation for heat exchanger used for DHW production

The heat exchanger models were based on general heat transfer theory and thermodynamic principles. The heat exchanger was divided into a number of elements in water flow direction. A general energy balance equation was developed for the cold fluid, hot fluid and the plate material for each of these elements respectively. A fast model was developed, with a reasonable level of accuracy (compared with some specialised data).

The purpose of the simulation was to verify the maximum rate at which heat that can be transferred to the DHW in the overload situation. The overload was imposed by the increasing the cold water flow **q2** (Figure 4).

An important conclusion was established after this simulation (Figure 5). Against the nominal power of the heat exchanger (Pn, for secondary temperature T22 = 60 ^{0}C, for the moment t = 2), an important overload capacity was proved for the DHW production, (q2 = 2.06 x Qn, for the moment t=8.8) if the temperature T22 = 40 ^{0}C is accepted by the customers.

Theoretical consideration for sub-metering over registration

The published theories of transient meter response in gas flow are all very similar and these treatments assume, either implicitly or explicitly, that the rotational inertia of the fluid

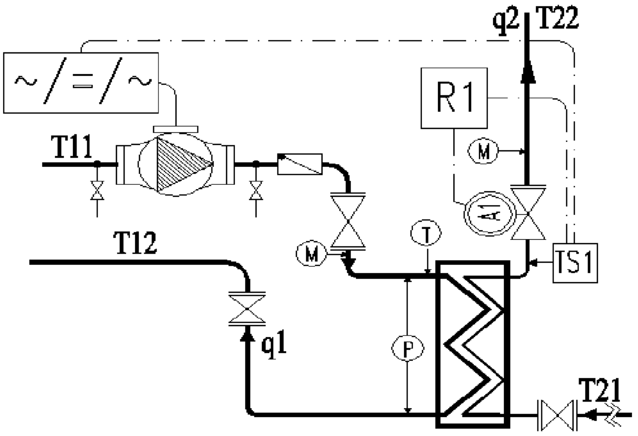

Figure 3. *Diagram for DHW System.*

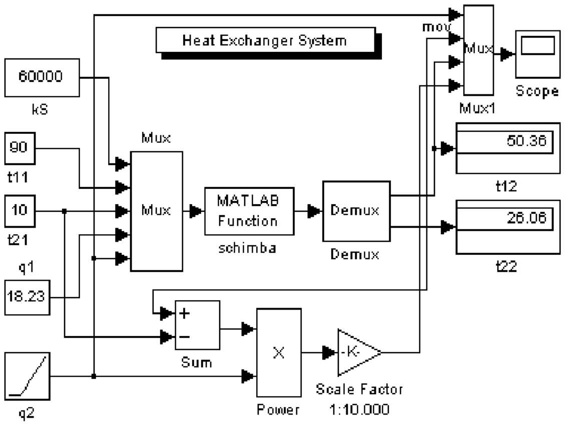

Figure 4. *Block Diagram for DHW System Simulation.*

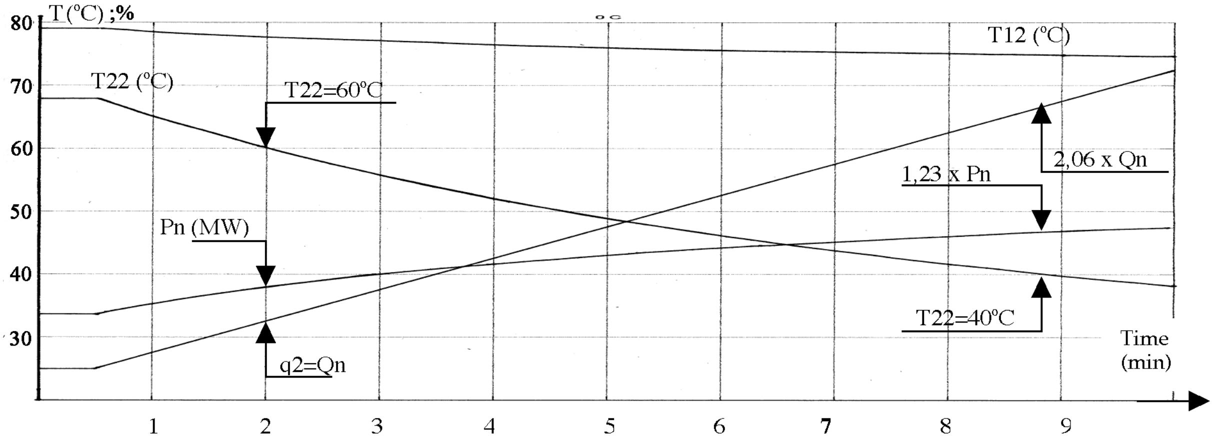

Figure 5. *Results from the Heat Exchanger Simulation in Overload Situation.*

contained within the turbine rotor is negligible compared to that of the rotor itself. In some cases, there are no friction effects, and the flow is assumed to follow the blades. This approach can be generalized in the form of the equation shown below (Lee 1975).

$$b\frac{dV_m}{dt} = V_a^2 - V_m V_a \tag{1}$$

where V_m is the volume flow rate indicated by the meter ($= kf_b$, where k is a meter constant and f_b is the blade passing frequency); V_a is the true volume flow rate and t is time. The response parameter, b, determines how quickly the meter responds to changes in the flow rate; it depends on: the inertia of the rotor IR , the hydrodynamic properties of the fluid and the aerodynamic characteristics of the blades. Different values of b have been observe but, for a generalised discussion, the value is not important.

The results (Lee 1997, Baker 1993, Ower 1973) for the studied meter were qualitatively very similar. At the largest pulsation amplitudes they all experienced significant over-registration for pulsation frequencies above 20 Hz and significant pulsation amplitude attenuation, for pulsation frequencies above 5 Hz. The maximum over-registration observed was 5%. The tests showed that both the over-registration error and the amplitude attenuation increased significantly with increasing pulsation frequency but they only increased slowly with increasing pulsation amplitude. In the following quantitative discussion of the meter behaviour, the 'relative pulsation amplitude' is defined by half of the peak to peak variation of the flow rate as a percentage of the mean flow rate; the 'over-registration' is defined by the indicated mean flow rate minus the true mean flow rate as a percentage of the true mean flow rate and the 'amplitude attenuation' is defined by the peak to peak variation of the true flow rate minus the peak to peak variation of the indicated flow rate as a percentage of the peak to peak variation of the true flow rate.

As an example of the effects, we can notice also from (Lee 1997), for one particular meter, at 20 Hz pulsation frequency, the imposed relative pulsation amplitude ranged from 17% to 40%, the observed over-registration errors were 0.27% to 1.58% with amplitude attenuation between 32% to 33%. For the same meter, at 40 Hz pulsation frequency and the same range of imposed pulsation, the over-registration errors were between 0.53% and 3.40% with amplitude attenuation between 43% and 44%. The true flow waveform was compared to the meter indicated flow waveform when 40% relative pulsation amplitude is applied at 20 Hz. The waveform of the true flow was obtained from an electromagnetic flowmeter, scaled to give a mean flow rate which agreed with that obtained from the weigh tank.

All these conclusions demonstrate the huge differences between continuous, constant flowmetering and random flow conditions. As we will demonstrate, these differences are incorrectly explained. For a superior level of generality, we propose to extend the Equation (1) to the second order differential equation. Because of some inconsistency and uncertainties in the values of the response parameter for the different meters, we had included an additional term in the meter response equation as suggested by (Dijstelbergen 1970).

Starting with Equation (1), which explains only the inertia of the process, we can study also the damping caused by the frictional effects.

$$\frac{d^2V_m}{dt_2} + 2\zeta\omega_a \frac{dV_m}{dt} + \omega_n^2 = V_a(t) \tag{2}$$

where V_m and V_a have the same nature, but two specific values are used, the undamped natural frequency ω_n and the damping factor ζ. The parameters ω_n and ζ are very important for characterizing a system's response. Note from Equation (2) that ω_n turns out to be radian frequency of oscillation when $\zeta=0$. As ζ increases in value from zero, the oscillation decays and becomes more damped. When $\zeta \geq 1$, an oscillation does not occur.

Starting from Eq. (2), on consider the second order quadratic, phase-lag transfer function given by:

$$Y(j\omega) = \frac{\omega_n^2}{(j\omega)^2 + 2\zeta\omega_n(j\omega) + \omega_n^2} =$$

$$= \left[\left(j\frac{\omega}{\omega_n}\right)^2 + 2\zeta\left(j\frac{\omega}{\omega_n}\right) + 1\right]^{-1} \tag{3}$$

Considering for this moment that the particulars values ω_n and ζ are less important (those values must be determinate using specific methods, like *System Identification*) we propose to study the dynamic response of the flowmeter not only for some frequency, but for all of them, starting to zero.

The dynamic response analysis

To study the flowmeter response in sinusoidal flow, we propose to use the Bode diagram approach (Shinners 1988), as one of the most commonly used methods for the analysis and *synthesis* of linear feedback control systems.

$$20\log_{10}\left[\left(j\frac{\omega}{\omega_n}\right)^2 + 2\zeta\left(j\frac{\omega}{\omega_n}\right) + 1\right]^{-1} =$$

$$= -20\log_{10}\left[\left(\frac{2\zeta\omega}{\omega_n}\right)^2 + \left(1 - \frac{\omega^2}{\omega_n^2}\right)^2\right]^{-1/2} - j\cdot 0,434\tan^{-10}\frac{2\zeta\omega_n\omega}{\omega_n^2 - \omega^2} \tag{4}$$

The Bode diagram for this transfer function can be obtained like in Figure 6.

To obtain practical information from this, on represent two diagrams which have ω as a common axis. These two diagrams, illustrated in Figure 6, are usually referred to as Bode diagrams. It is important to emphasize that the Bode diagrams represent the frequency response for the ampli-

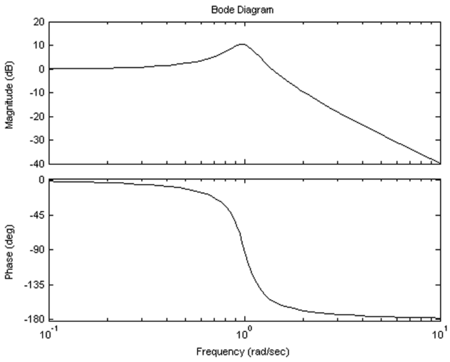

Figure 6. *Bode diagrams for a typical transfer function ($\omega_n = 1$ and $\zeta = 0,25$).*

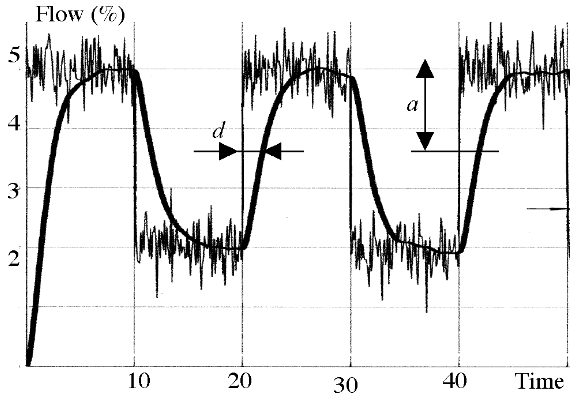

Figure 8. *Simulation results for random + square flow.*

tude and phase. Because this theory starts from open loop system, we can use it with success for our flowmeter analysis.

To obtain Bode diagrams, we can use MATLAB functions. Figure 7 illustrates a typical result of this. Without numerical examples, we notice that the aspect of the Bode diagrams will be the same, for any values given to ω_n and ζ, with small differences around the ω_n frequency. *For the highest frequencies, the same rate of amplitude attenuation will be obtained.*

It was easy to retrieve the attenuation presented above (Baker 1993), for 20 and 40 Hz.

As we intend to demonstrate, the **amplitude attenuation does not generate over registration**. The inertial behaviour introduce a delay, but the total flow will be correct. A fast model for this was realized (Figure 7), based on Eq. (3) witch can be retrieved in the block “Transfer Function”. The values obtained on *Display1* and *Display* are practical identical, because of the initial transitory time. Graphical results are obtained on block “Scope”, similar with (Baker 1993).

The sinusoidal wave study is useful only for the real random flow. The explanation is very easy, because any random signal can be decomposed as a sum of sinusoidal waves, using Fourier series. The next step in this study was to apply a random flow to the simulated meters. The graphical results are shown in Figure 8.

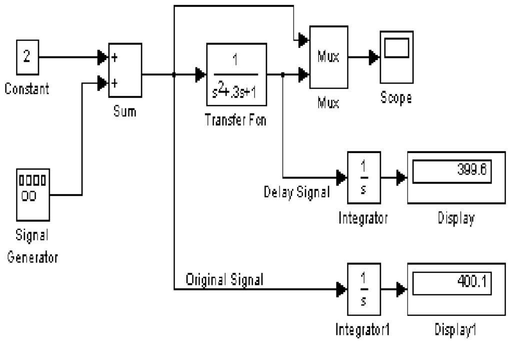

Figure 7. *MATLAB simulation for the flow meter dynamic response.*

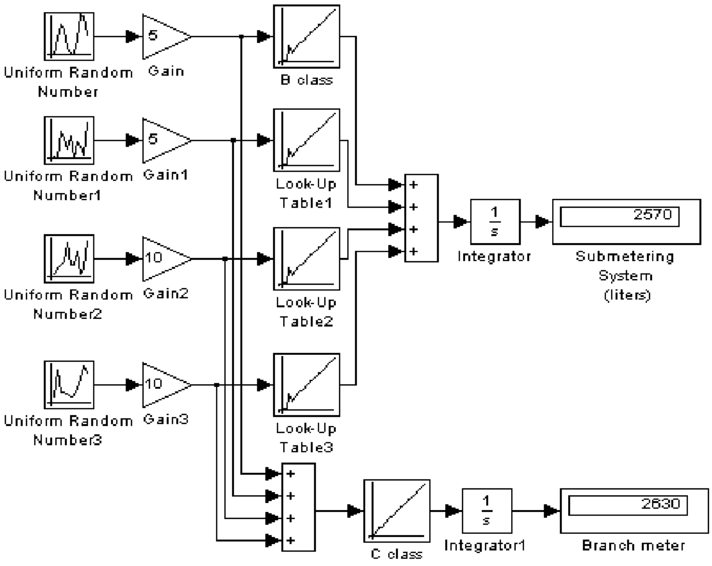

Figure 9. *Dynamic model for sub-metering system.*

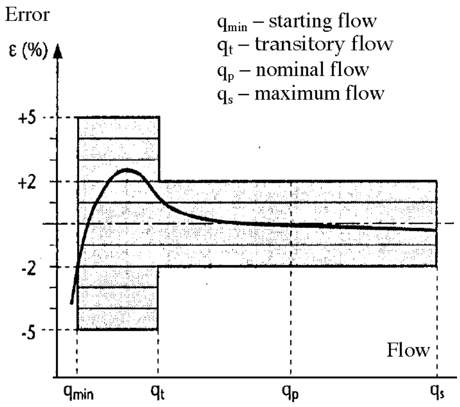

Figure 10. *Error distribution curve for a flow meter.*

It may be observed that there is a significant delay (d) and amplitude attenuation (a), but the final result has only small differences, explained by the numerical approximation of SIMULINK.

The most difficult aspect is to estimate the correlation between the errors generated by the general meter and the sub-meters, caused by the different precision class. In Figure 10 is presented a classical error curve for flowmeter, with the same aspect for the B class or C class, but with different caracteristical values q_{min}, q_t and q_p.

In order to evaluate the evolution of general metering process, we must consider the situation, which occurs frequently during the night, when the general flow meter works in transient region (close to q_t) and a number of sub meters work to the left of the starting flow (q_{min}). For some particular situations, the differences will be very important (Figure 9), and some difficulties in the payment procedure will occur.

Conclusion

The simulation and analysis of entire DH Systems are complicated by the great number of parameters involved. This paper, using a simple dynamic simulation, offers important answers for some critical aspects. The simulation results can be used to study the regime of DH with different configurations, control strategies and operating parameters. Furthermore, the simulation methodology can be used as a design tool by the consulting engineers to evaluate the performance of DH system not only under peak load, but also under partial loads (by night). Also, it can be a valuable diagnostic tool for examining the performance of existing DH system.

References

Baker, R. C. , Turbine flowmeters: II. Theoretical and experimental published information, Flow Meas. Instrum., 4(3), 1993, 123-144.

Bronner, J. W. and R. J. McKee, Cogen pulsation effects on turbine metering, American Gas Association,Operating Section, Proceedings, 1991, 625-638.

Cheesewright, R. , D. Edwards and C. Clark, Measurements with a turbine flow meter in the presence of large, non-sinusoidal pulsations, Proc. FLUCOME ’94, Toulouse, France, August, 1994.

Dijstelbergen, H. H. , Rotameters and turbine flowmeters in pulsation flow measurement, Measurement and Control, 3, December, 1970, 197-204.

Grey, J. Transient response of the turbine flowmeter, Jet Propulsion, February, 1956, 98-100.

Lee, B, R. Cheesewright C. Clark, The Dynamic Response Of Turbine Flowmeters In Liquid Flows, Systems Engineering Department, Brunel University, Uxbridge, Middlesex, UK, 1997.

Lee, W. F. Z. , M.J. Kirik, J.A. Bonner, Gas turbine flowmeter measurement of pulsating flow, J. Engineering for Power, Trans. ASME, October, 1975, 531-539.

Shinners, S. M. Modern Control System Theory and Application, Addison Wesley Publishing, 1988.