Introduction to Dynamic Flow Measurements

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Dynamic Flow Measurement

- Calibration laboratories try to establish **steady state** pressure, temperature, and flow conditions for customer calibrations
- But many important customer flow measurements are **not** stable
- **Both** steady state and dynamic calibration data are needed by some calibration customers
- Flow transients = pressure and temperature transients

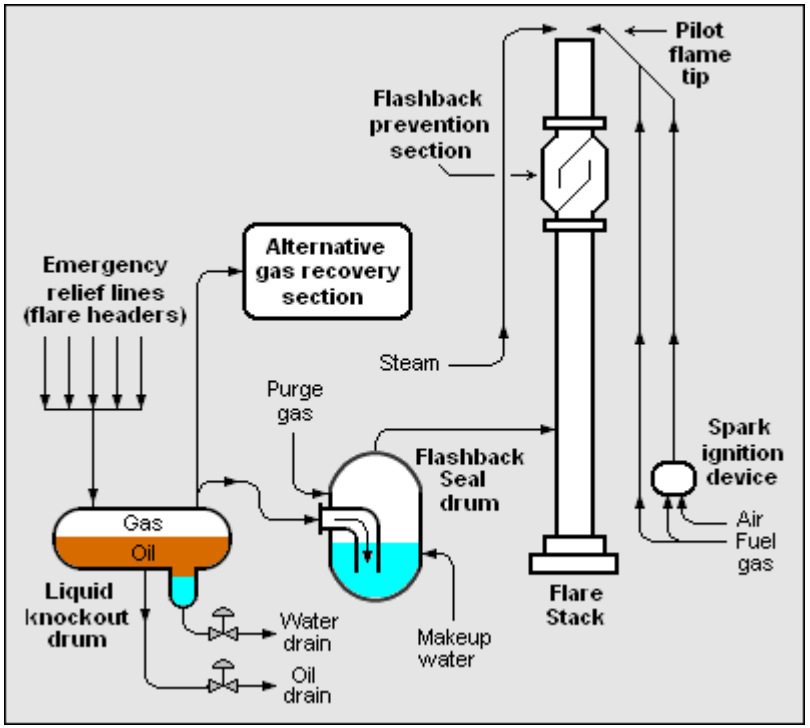
Dynamic Flow Measurement Applications

- Flare gas
- Evaluating / designing internal combustion and jet engines: fuel, air, exhaust
- Reciprocating compressors and pumps
- Blow-down calibrations of large gas flow meters
- Flow control for process industries
- Blood flow

- Batch filling
- Flow meter calibrations with field provers
- Vehicle refueling

Flare Gas

- Release of gaseous hydrocarbons from drilling and refining stations, burned to reduce greenhouse gas effects
- Measured for environmental regulations
- Sudden releases with wide dynamic range (>100)
- In 2011, 150 × 10^9 cubic meters per year worldwide (= 25% of US consumption)



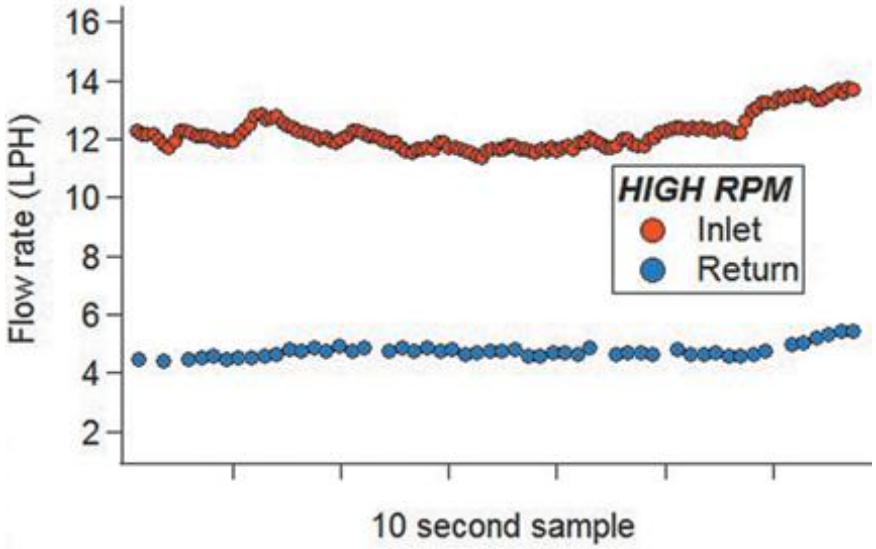
Vehicle Engine Test Stands

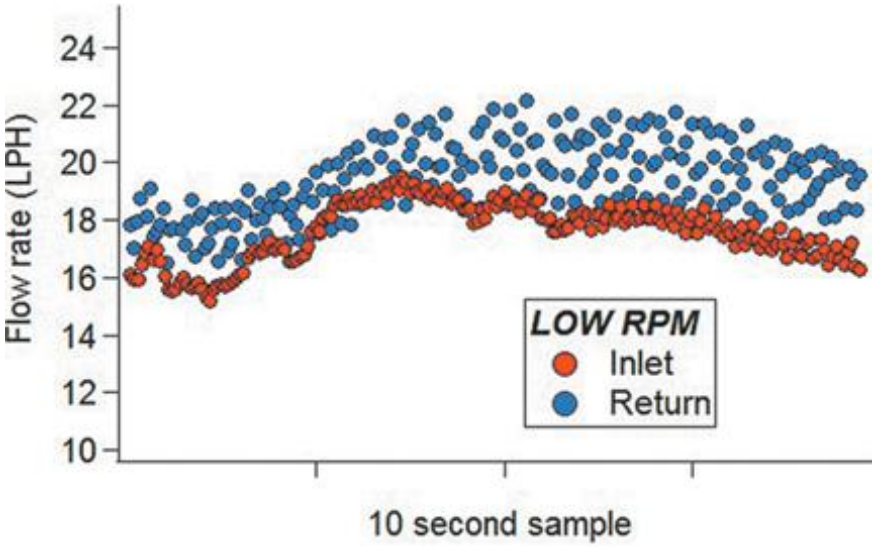
www.pdvconsult.com

www.audi-mediaservices.com

~10 kHz

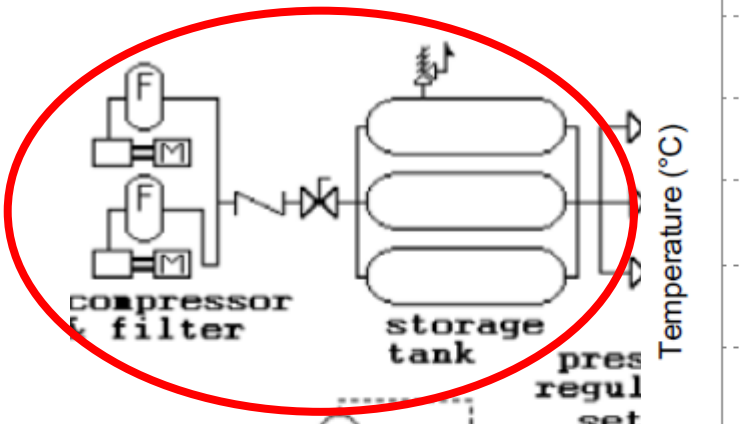
Vehicle Engine Fuel Flow

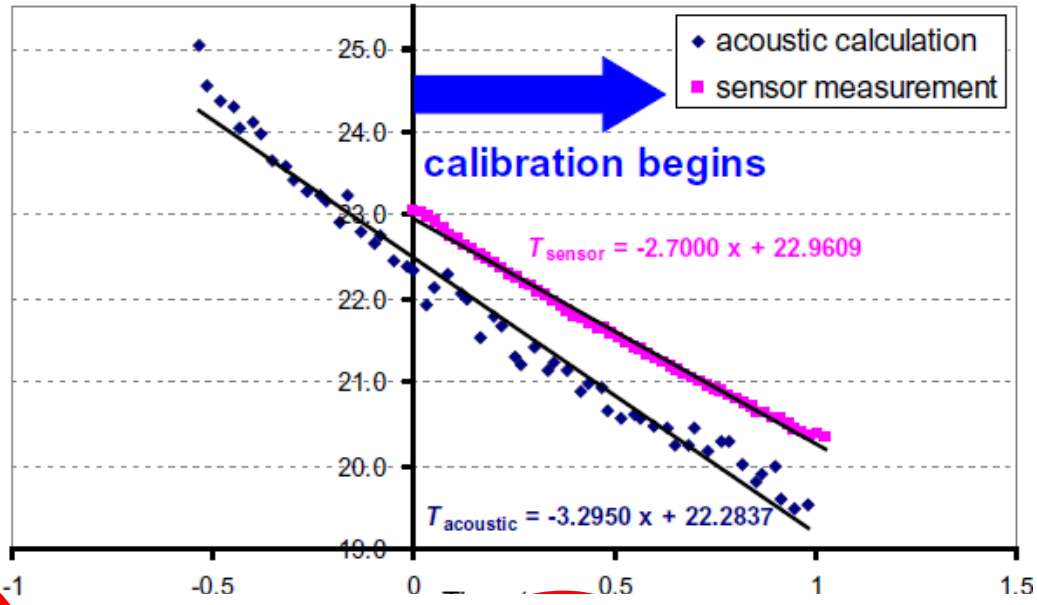


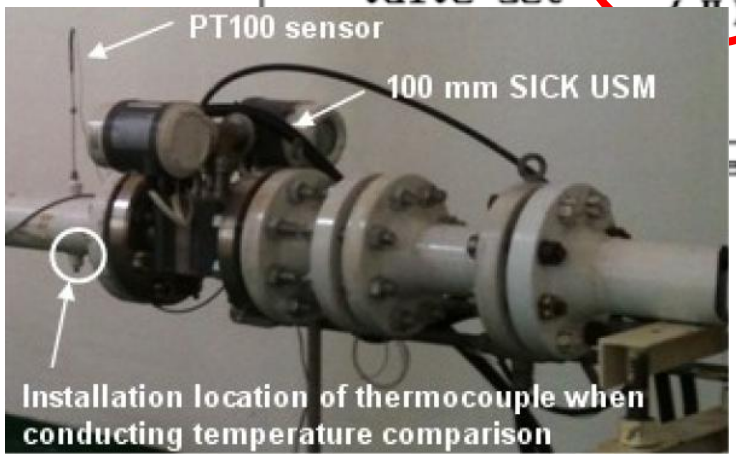


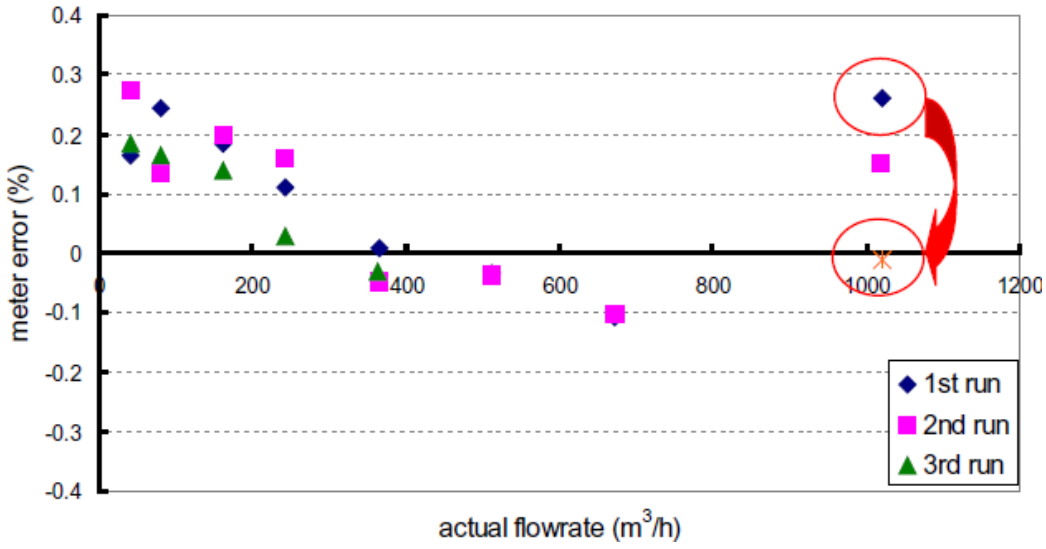
- For diesel engine, fuel pump runs continuously, keeping the fuel supply to the engine at a constant pressure. Any fuel that is not burned in the engine is fed back to the tank by a return pipe.
- To measure fuel consumed, calculate difference between the “inlet” sensor and the “return” sensor.

Blow-Down Gas Flow Calibrations





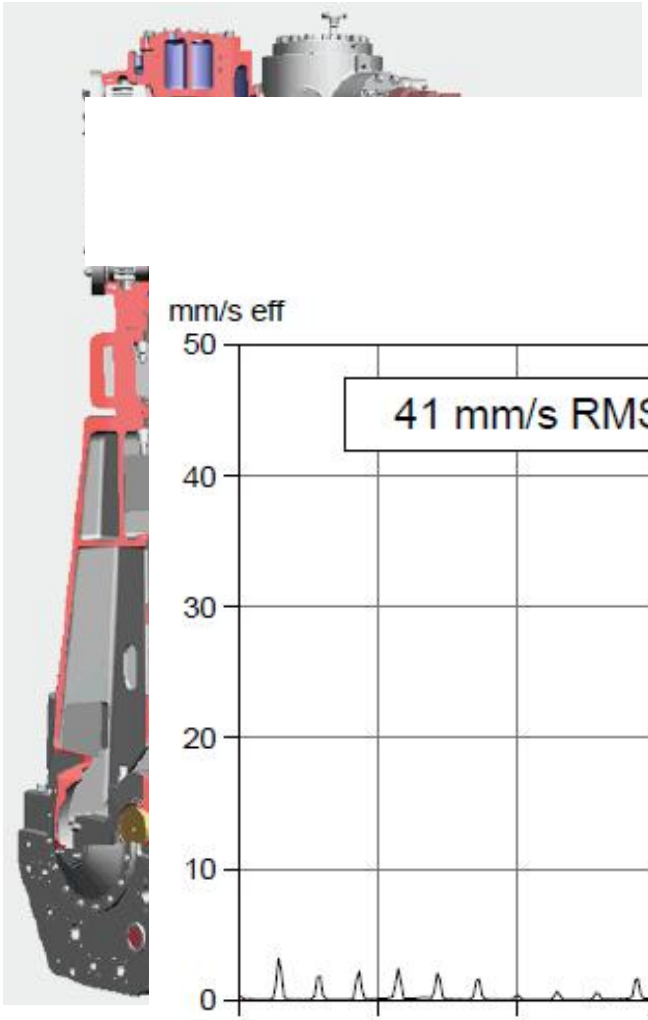




Kuo et al., International Symposium for Fluid Flow Measurements, 2012

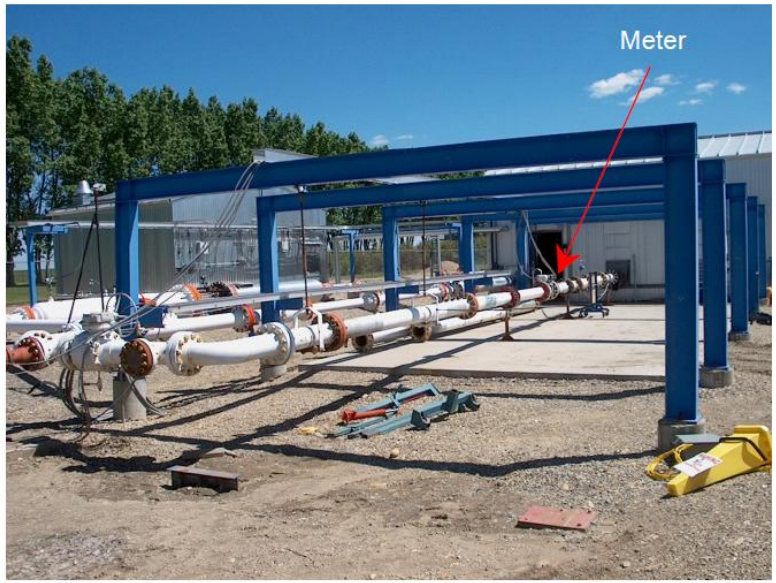
Calibration of Reference Flow Meter for the NIST Smoke Stack Simulator

Reciprocating Compressors, Vortex Shedding, …



Brümmer, Technical University of Dortmund

Natural Gas Flow Pulsations



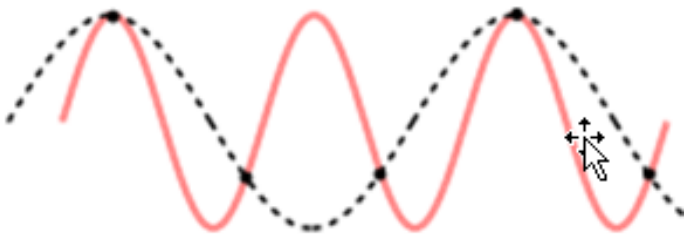
Lansing, International Symposium for Fluid Flow Measurement, 2012
Nova Didsbury Test Facility, Canada

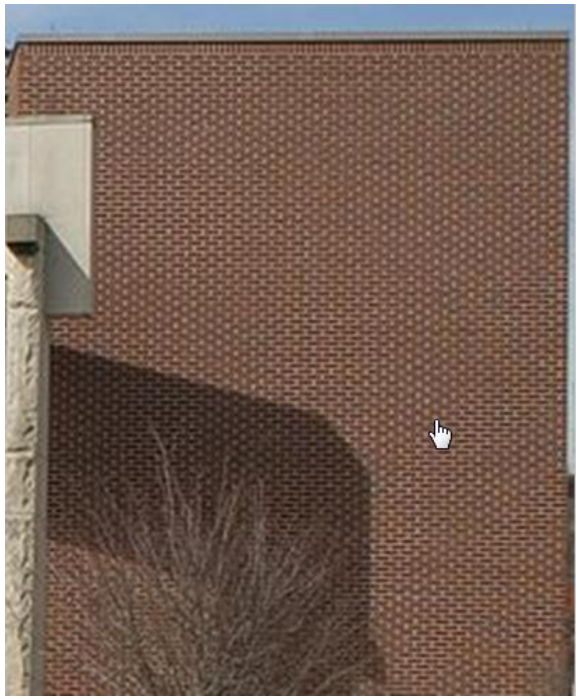
Control Theory

- Coughanowr and Koppel, *Process Systems Analysis and Control*, 1965
- Wiklund and Peluso, *Flowmeter Dynamic Response Characteristics*, International Symposium for Fluid Flow Measurement, 2002

Nyquist Limit

Sampling frequency must be 2 x signal frequency to avoid aliasing



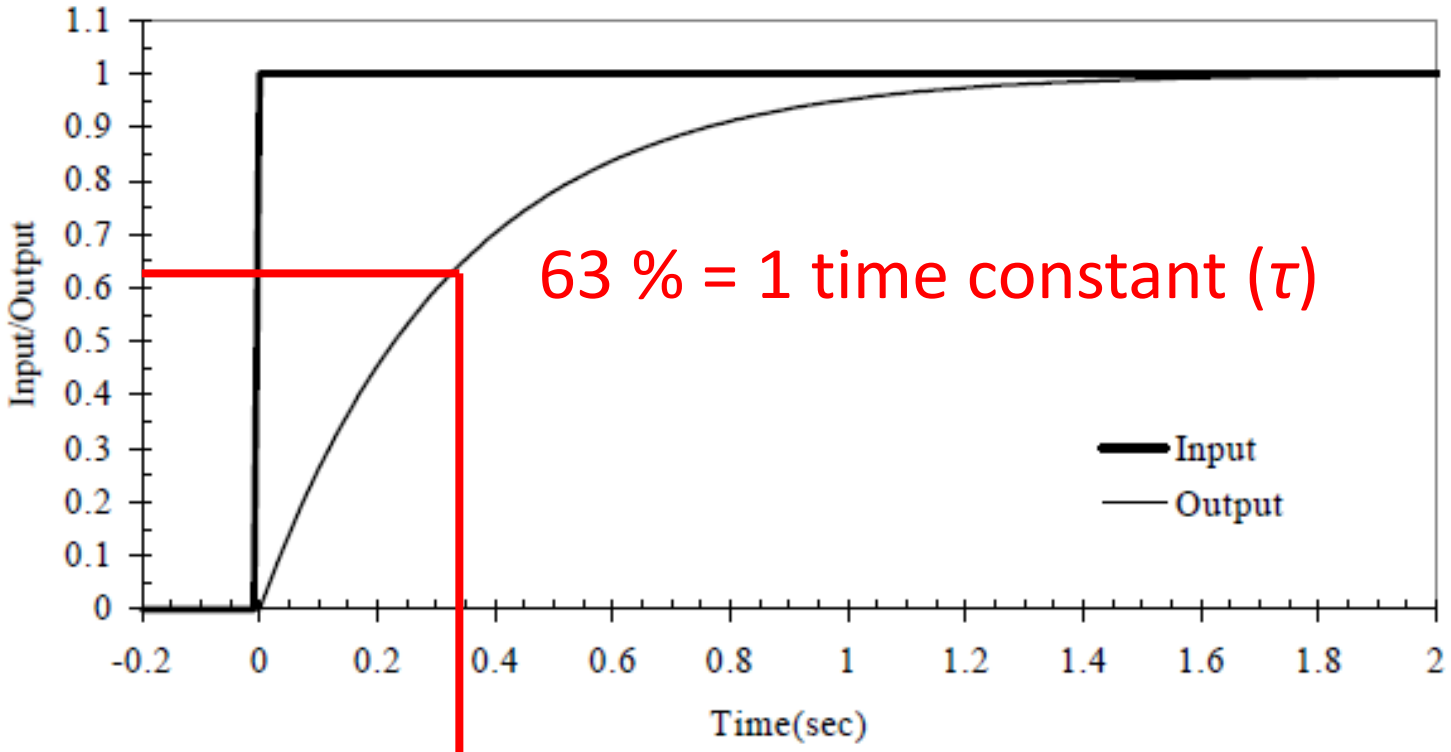


Moiré pattern caused by aliasing

www.wikipedia.org

1st Order Response

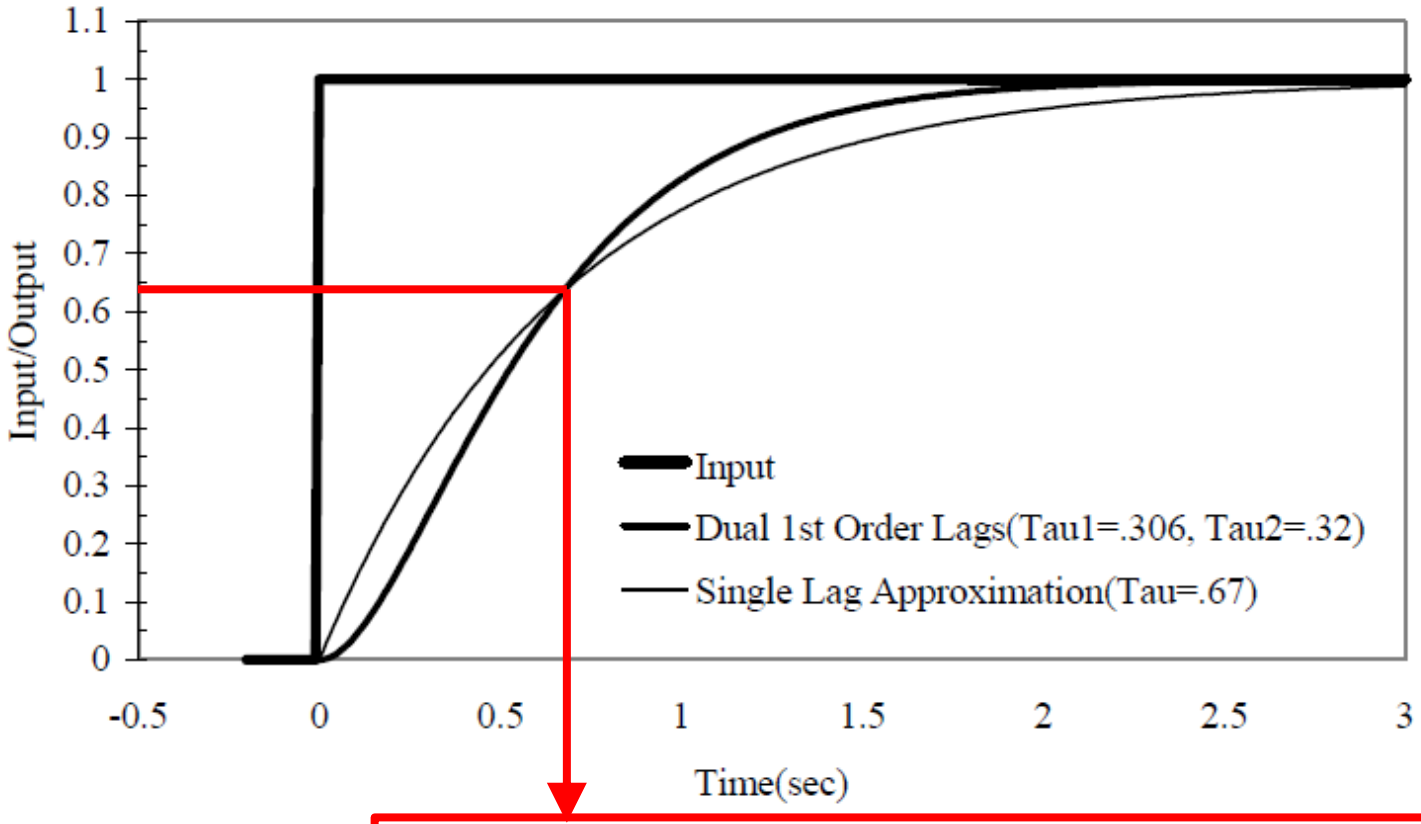
to a step input: ( )=–



τ completely describes transient response for a 1st order system

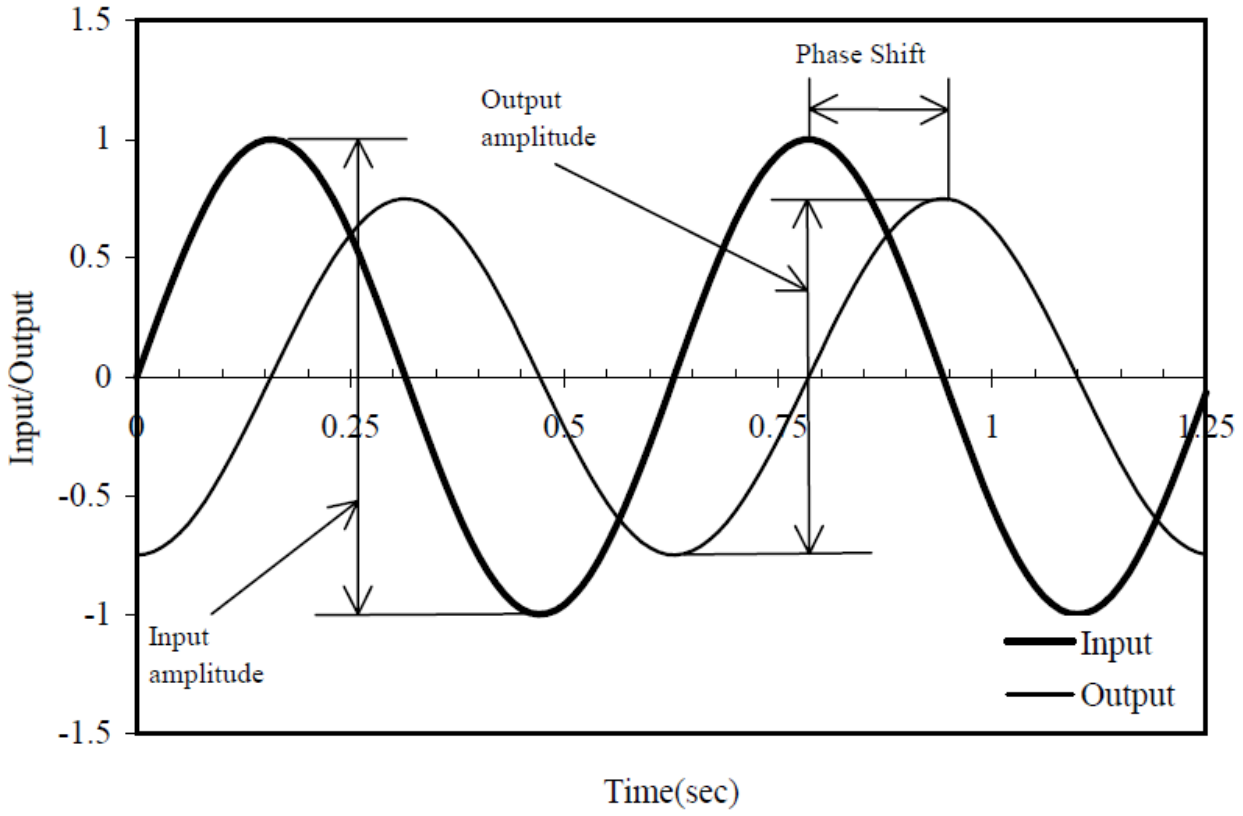
Dual 1st Order Lag

Flow meters often have dual 1st order response:
1) primary device, 2) signal processing



τ based on 63 % is a poor approximation

1st Order Response to Sinusoidal Input

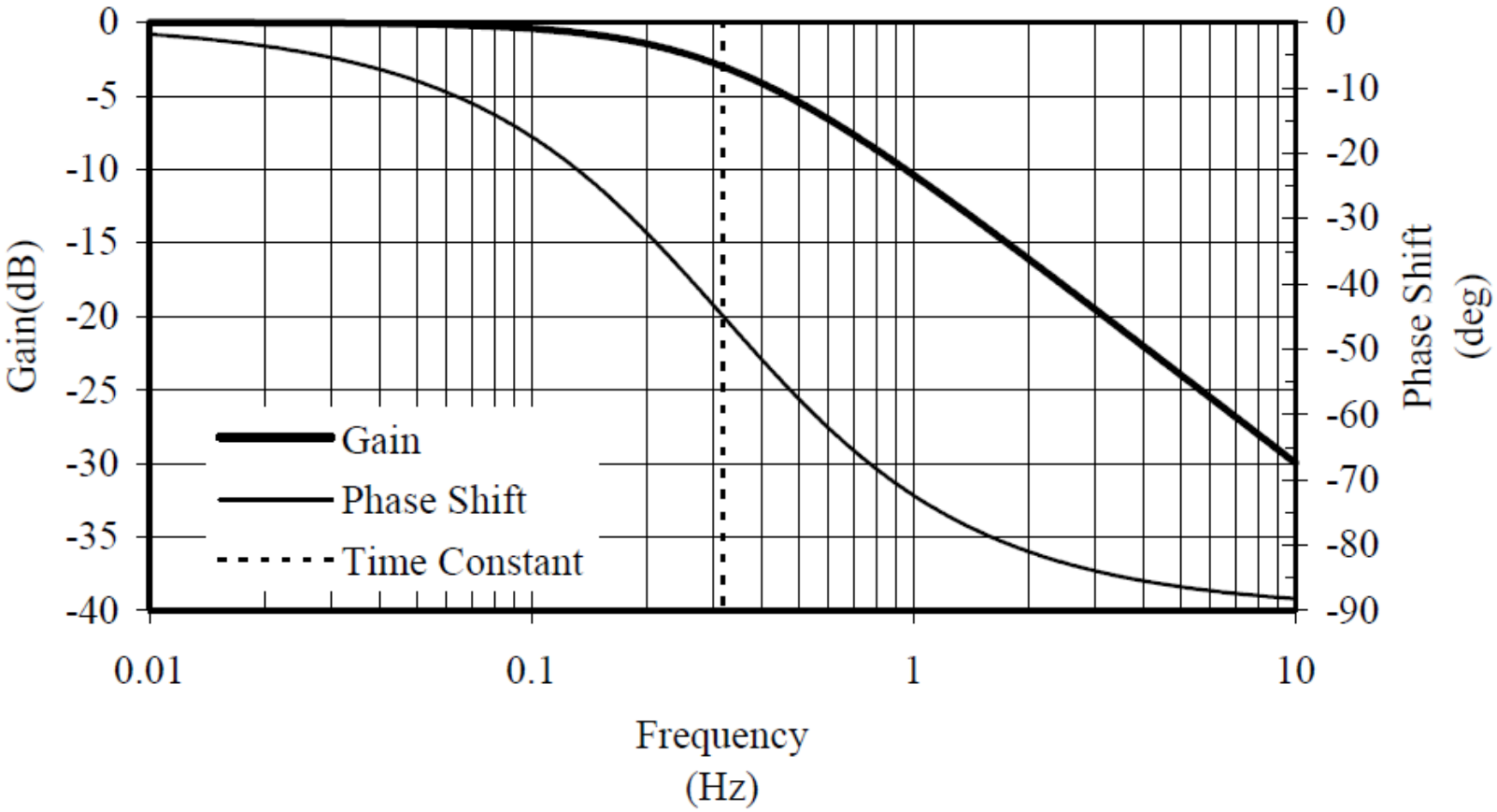


- Attenuated amplitude
- Phase shift

Both are a function of input frequency

Bode Plots

For a 1st order device with τ = 0.5 s…



Transfer functions

Use Laplace transform to move from time to frequency domain.
A Transfer Function (TF) describes sensor response:

- For a 1st order device: ——
- Two 1st order devices and dead time:

  $$\frac{\qquad\qquad}{(\qquad)(\qquad)}$$ (orifice, vortex, electromagnetic)

- 2nd order + 1st order + dead time:

  $$\frac{\qquad\qquad\qquad\qquad}{[(\qquad)\quad(\qquad)\quad](\qquad)}$$ (coriolis)

History

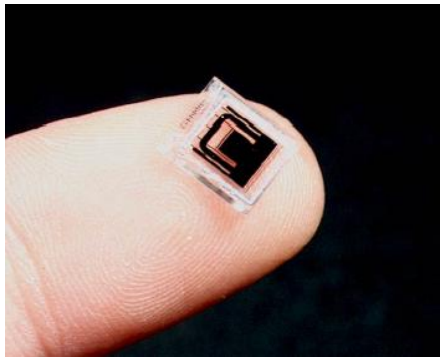
- Pulsation induced errors is a long studied problem
- Errors depend on meter type, frequency, and amplitude of pulsations

Solutions:

- Damping by settling volumes, baffles, mufflers (**R**esistance+**C**apacitance=throttling valve+chamber)
- Proper application: appropriate meter response for the pulsation frequency
- Fast response sensors, fast signal processing

Fast Sensors

- Small is good… MEMS
- Hot wire anemometer
- Coriolis?
- Critical Flow Venturi?



www.mems-issys.com