BENG 186B: Principles of Bioinstrumentation Design

Lecture 13

Blood Pressure Measurement

References

Webster, Ch. 7 (Sec. 7.1-7.4, Sec. 7.13-7.14).

BLOOD PRESSURE

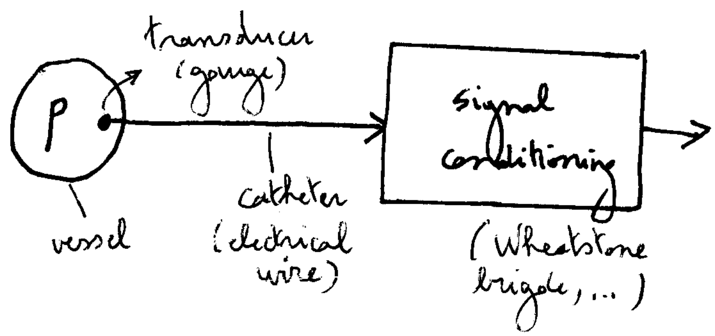
Webster Ch. 7

— Direct measures of blood pressure:

Invasive, requiring contact to vessels, and sometimes the heart, using a CATHETER inserted in the blood stream.

- INTERNAL: micro-tipped manometer (pressure transducer)

  Pressure strain gauge on the tip of a catheter, inserted into the circulatory system (intravascular):



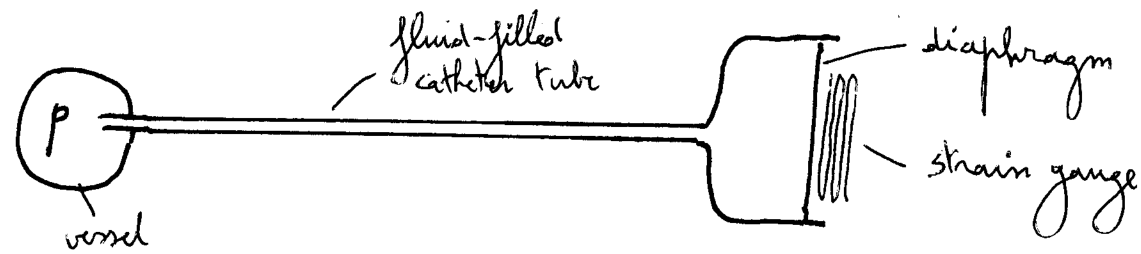
Example transducers:

- fiber optic (expensive!)
- micro-electro-mechanical system (MEMS) (disposable)

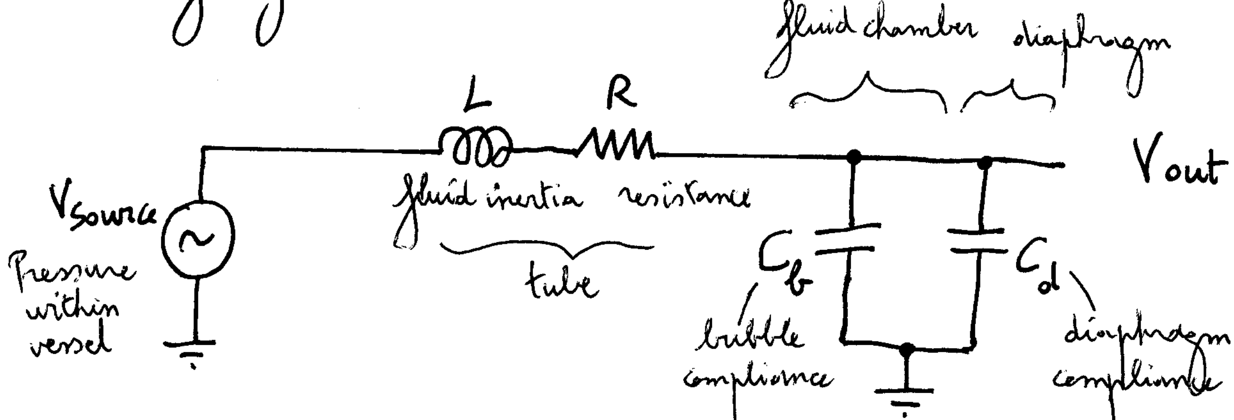
Micro-tipped manometers offer the smallest form factor and the highest frequency response for direct measurement, at a higher cost.

- EXTERNAL : fluid-filled catheter tube (Sec. 7.3)

External pressure transducer on a diaphragm with fluid-filled catheter to the source :



Inexpensive and reusable (easy to sterilize), but the frequency response is affected by the dynamics of the fluid and diaphragm mechanics, which need to be carefully modeled :



Electrical EQUIVALENT of the pressure-fluid-diaphragm system:

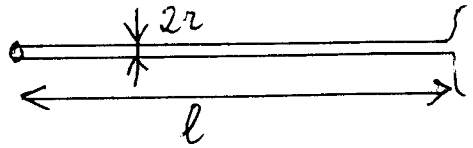
V_{source} : pressure (mechanical potential) within vessel

V_{out} : pressure on the diaphragm transduced by strain gauge

$\dfrac{V_{out}(j\omega)}{V_{source}(j\omega)}$: frequency response of the external transducer due to catheter-diaphragm dynamics

L : inertia of the fluid in the catheter tube

$$L = \rho \frac{l}{\pi r^2} \quad \text{with} \quad \begin{cases} \rho : \text{mass density} \quad (kg/m^3) \\ l : \text{tube length} \\ r : \text{tube radius} \end{cases}$$



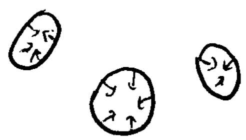
R : resistance of fluid flow in the catheter tube

$$R = \frac{8 \eta l}{\pi r^4} \quad \text{with} \quad \eta : \text{viscosity of fluid} \quad (\text{Poiseuille flow})$$
$(Pa \cdot s = kg/ms)$

C_d : compliance of the diaphragm

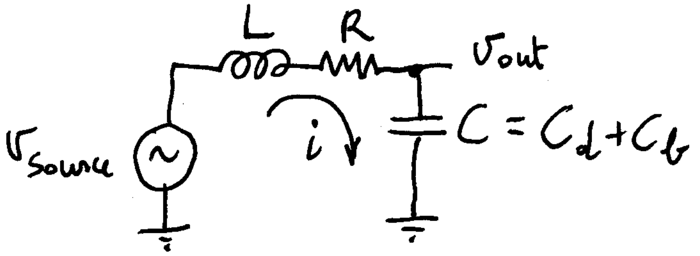
$$C_d = \frac{\Delta V}{\Delta p} = \frac{\text{volume change}}{\text{pressure change}} = \frac{1}{E_d}$$
with E_d : Young's modulus of volume elasticity of the diaphragm $\left(\frac{Pa}{m^3}\right)$

C_b : compliance of air bubbles suspended in the liquid

$$C_b = \frac{\Delta V}{\Delta p} :$$  $$\frac{\text{volume change}}{\text{pressure change}}$$

The more air bubbles in the liquid, the larger C_b, sometimes much greater than C_d
→ avoid air bubbles entering the catheter tube

Second-order dynamics:



KVL: $$v_{source} = L\frac{di}{dt} + Ri + v_{out}$$

and $$C\frac{dv_{out}}{dt} = i$$

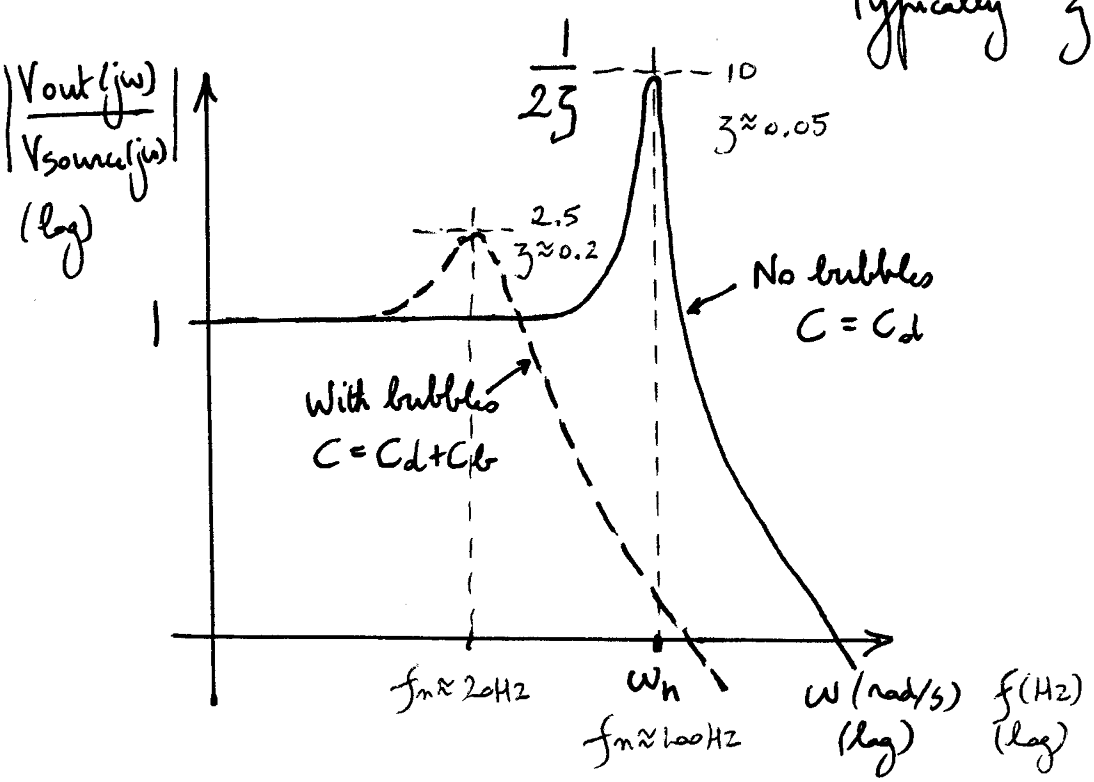
$$\Rightarrow v_{source} = LC\frac{d^2 v_{out}}{dt^2} + RC\frac{dv_{out}}{dt} + v_{out}$$

$$\Rightarrow \frac{V_{out}(j\omega)}{V_{source}(j\omega)} = \frac{1}{1 + RCj\omega - LC\omega^2} = \frac{1}{1 + \frac{2\zeta j\omega}{\omega_n} - \frac{\omega^2}{\omega_n^2}}$$

with $\omega_n = \frac{1}{\sqrt{LC}}$: natural frequency (radial)

$\zeta = \frac{R}{2}\sqrt{\frac{C}{L}} = \frac{RC\omega_n}{2}$: damping ratio

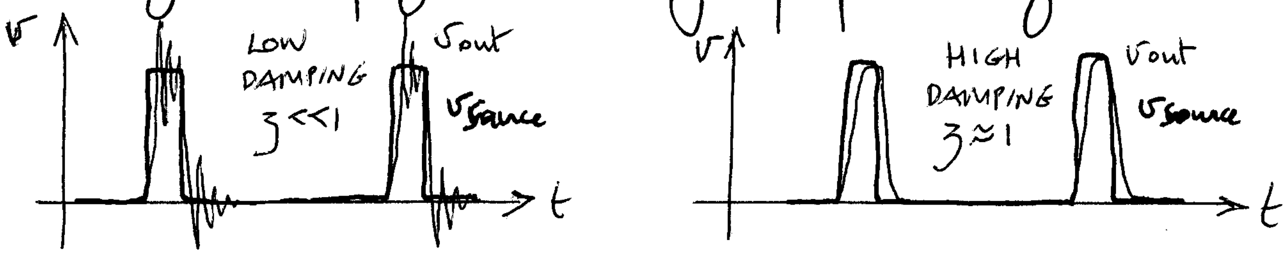
Typically $\zeta < 1$ UNDERDAMPED



$$f_n = \frac{1}{2\pi}\omega_n$$

Frequency bandwidth requirement: the system frequency bandwidth f_n should be at least a factor $\times 10$ greater than the base frequency of the signal: $f_n \geq 10\ \underset{\substack{\text{heart rate} \\ < 2\,Hz}}{HR} \geq 20\ Hz$

Also, higher damping is better for proper settling:

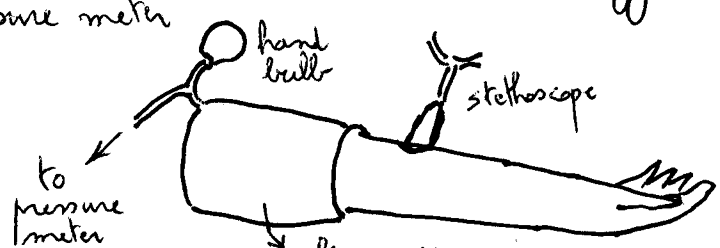


— Indirect measures of blood pressure:

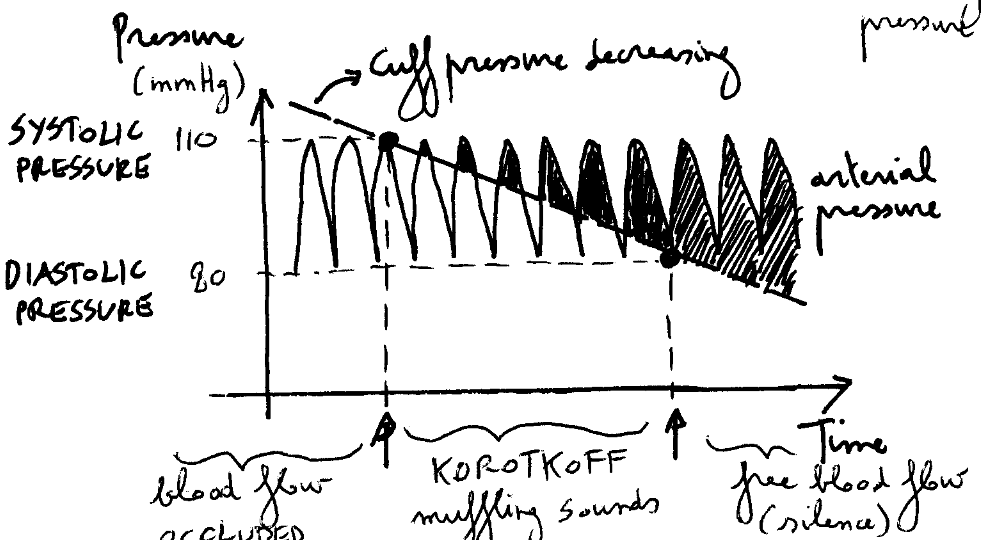
Non-invasive, but less accurate, and lower frequency response

- $\underbrace{\text{SPHYGMO}}_{\text{pulse}}\ \underbrace{\text{MANOMETER}}_{\text{pressure meter}}$: external cuff, over the arm

(Sec. 7.13)



cuff applies pressure occluding blood flow, next slowly releasing pressure to measure systolic/diastolic pressure

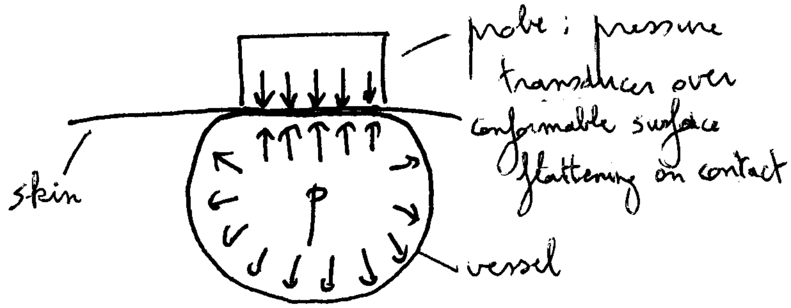


Onset and offset of KOROTKOFF sounds indicate the timings of SYSTOLIC and DIASTOLIC pressure readings.

More modern instruments use ultrasonic transducers to detect opening and closing of blood vessels for automated measurement of systolic pressure, diastolic pressure, and heart rate.

- TONOMETRY : indirect measure of blood pressure by applying pressure as needed to flatten the curvature of the vessel:

(Sec. 7.14)



Probe flattens vessel, making the pressure difference across the wall (and surrounding tissue and skin) zero.

$\Rightarrow$ Measured pressure on the probe is the same as in the vessel.

Limitations:

- Only measures specific peripheral pressures, such as brachial artery
- Highly sensitive to position and angle
- Requires calibration for precise measurement