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Introduction to Microsystem design. Date 17/03/2015

Flow Sensors:

The measurement of volume flow or flow velocity has a lot of applications in modern life. For e.g. for the control of the engine of a car with low exhaust emission, it is important to know the fuel and air flow to the engine.

There is a variety of measurement principles in use and several ways are known how micro sensors for flow meters can be built. ~~For the~~ The two most important principles that can be employed in microsensors are.

(1) Thermal flow sensors and

(2) the measurement of the pressure difference over a capillary.

Thermal flow sensor: Simplest flow sensor is a thin wire heated by an electric current. When a fluid is passing the wire, it takes away a part of the heat and lowers the temperature of the wire. Thus the temperature of the wire is a measure of the flow Velocity.

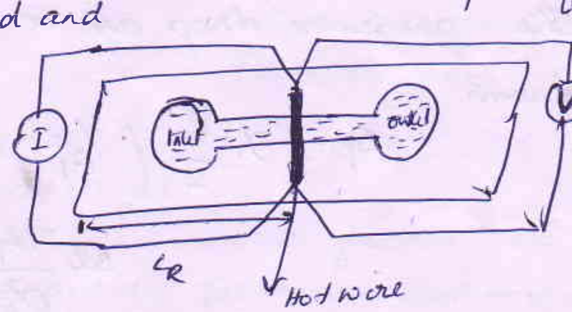
- The temperature of the wire can be determined from its electrical resistance

$$R_{wire} = R_{ref}\left[1+\alpha\left(T_w - T_{ref}\right)\right]$$

α - thermal coefficient of resistance

R_{ref} - resistance at the ref. temp. T_{ref}

Here a constant ~~too~~ current is going through the wire. If the temperature of the wire is lowered by the flow, its resistance is decreased and the voltage measured over the wire becomes smaller.



When the wire, heated by the electric current input is in thermal equilibrium with its environment, the electrical power input is equal the power lost by heat transfer

$$I^2 R_\omega = h \cdot A_\omega \, (T_\omega - T_f)$$

T_ω: temp. of wire

T_f: temp of fluid

h: heat transfer coefficient of wire

A_w: projected wire surface area.

~~Now the heat transfer coefficient is a function of the fluid velocity by King's law~~

The heat transported away by the flow is a function of the thermal conductivity λ_F, the viscosity η and density ρ_f of the fluid, the temperature difference ΔT between the hot wire and fluid, the area A_w of the heater wire and the mean flow velocity v. The heat transported Q_k can be estimated as

$$Q_k = a \cdot \lambda_F \, A_\omega \, \Delta T \sqrt{\frac{\rho_F v}{{}^{4}R \, \eta}}$$

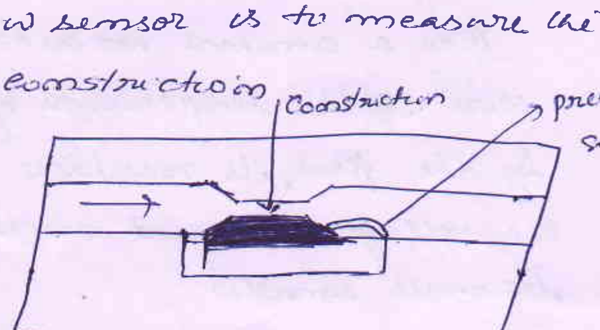
There are two ways to drive an anemometer

(1) Constant current and the temp. diff is calculated

(2) Constant temp. by adapting the input current (power)

A common disadvantage of the principle discussed is that the characteristic curves are a functions of the properties of the fluid such as viscosity, density, heat capacity and heat conductivity. Hence, a calibration is required for each kind of fluid, and it is not possible to obtain a reliable flow measurement of an <u>unknown</u> <u>fluid</u>.

(2) Another important principle of flow sensor is to measure the pressure drop over a capillary or construction.



The pressure drop can be calculated from

$$\Delta p = -\chi \frac{\rho_F}{2} \left(\frac{1}{A_1^2} - \frac{1}{A_2^2} \right) \phi_F^2 - 32 \frac{\eta L_F}{D_h^2} \frac{\phi_F}{A_2}$$

→ A certain pressure difference Δp is necessary to move fluid inside of a capillary, because friction needs to be overcome.

→ The pressure difference to move a fluid with length L_F and viscosity η in a capillary with velocity v is given by Poiseuille equation

$$\Delta p = -32 \frac{\eta L_F}{D_h^2} v .$$

where D_h denotes the hydraulic diameter of the capillary. It expresses the influence of the geometrical shape of the cross-section of the capillary on the flow and is given by

$$D_h = \frac{4 A_F}{U_w}$$, A_F - area of cross-section
U_w = wetted circumference

Also velocity $v = \frac{\phi}{A}$, From the mean flow velocity v, the volume flow ϕ_F is calculated by multiplying with the crosssection A of the channel.

→ When there is a construction in a flow channel, the mean flow velocity needs to become larger. (Because by Bernoulli theorem flow volume should be a constant).

→ Static pressure reduced in the construction.

→ If the flow is slow

Mean v behind constriction = Infront of constriction

Static pressure behind constriction = Static pressure infront of construction — Poiseuille term.

→ If the flow is quick

- flow comes out as jet
- jet may loose K.E. due to friction. The energy which is absorbed by friction is lost and results in an additional pressure drop over the construction
- function of flow velocity, geometry at the entrance and the exit of the channel

- a quantity x is defined to describe the amount of the effect

The additional pressure drop is

$$\Delta p = -x \frac{\rho_F}{2} (v_1^2 - v_2^2).$$

Now $V = \dfrac{\phi}{A}$

$$= -x \frac{\rho_F}{2} \left(\frac{\phi^2}{A_1^2} - \frac{\phi^2}{A_2^2} \right)$$

$$= -x \frac{\rho_F}{2} \left(1/A_1^2 - 1/A_2^2 \right) \phi^2$$

So adding both the pressure term we get

$$\Delta p = -x \cdot \frac{\rho_F}{2} \left(1/A_1^2 - 1/A_2^2 \right) \phi^2 - 32 \frac{\eta L_F}{D_h^2} \frac{\phi}{A_2}.$$

$\Delta p =$ pressure drop to overcome friction + pressure drop to accelerate the liquid

$$dF = a\,dm$$

$$= \frac{dv\,dm}{dt}$$

$$\rho_F \cdot x\, A_F^x\, dx$$

$$= \frac{dv \cdot \rho_F A_F\, dx}{dt}$$

$$= \rho_F A_F\, v\, dv$$

$$F = \rho_F A_F v_F^2/2.$$

$$\frac{F}{A_F} = \frac{\rho_F v_F^2}{2}$$