Problem #1

- The natural frequency of oscillation of the balance wheel in a watch depends on the moment of inertia of the wheel and the spring constant of the torsional hairspring. A temperature rise results in a reduced spring constant, which lowers the oscillation frequency. Propose a compensating means for this effect. Non-temperature-sensitive hairspring material is not an acceptable solution.
Device for the Measurement of the Mass Flow Rate of Gases
• A device for measurement of the mass flow rate of gases is shown. The mass flow rate of gas through an orifice may be found by measuring the pressure drop across the orifice, perhaps by means of a U-tube manometer. Unfortunately, the mass flow rate also depends on the density of the gas, which varies with pressure and temperature. Thus the pressure-drop measuring device cannot be calibrated to give the mass flow rate, since variations in gas temperature and pressure yield different mass flow rates for the same orifice pressure drop.

• The instrument overcomes this problem in an ingenious fashion. Explain this application of the method of opposing inputs.
Problem # 3

- The tachometer (schematic shown) is a velocity-measuring device (passive) that uses the principle of electromagnetic generation. The field windings are powered by DC voltage $v_f$. The across variable at the input port is the measured angular speed $\omega_i$. The corresponding torque $T_i$ is the through variable at the input port. The output voltage $v_o$ of the armature circuit is the across variable at the output port. The corresponding current $i_o$ is the through variable at the output port. Obtain a transfer-model for this device.

\[
\begin{bmatrix}
  v_o \\
  i_o
\end{bmatrix} = \begin{bmatrix}
  \omega_i \\
  T_i
\end{bmatrix}
\]
DC Tachometer

(a) Equivalent Circuit

(b) Armature FBD
• **Problem # 4**
  
  A mechanical device for measuring angular velocity is shown. The main element of the tachometer is a rotary viscous damper (damping constant b) consisting of two cylinders. The outer cylinder carries a viscous fluid within which the inner cylinder rotates. The inner cylinder is connected to the shaft whose speed $\omega_i$ is to be measured. The outer cylinder is resisted by a linear torsion spring of stiffness k. The rotation $\theta_o$ of the outer cylinder is indicated by a pointer on a suitably calibrated scale. Neglecting the inertia of moving parts, perform a bandwidth analysis on this device. What are the conflicting design requirements?
Mechanical Tachometer

- Shaft Speed $\omega_i$
- Viscous Fluid $(b)$
- Torsional spring $(k)$
- Pointer
- Dial Reading $\theta_o$
### Problem # 5

In the study of sensors, there are many terms typically used by manufacturers to describe performance that are most important to understand the meaning of.

Define the following:

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linearity</td>
<td>Resolution</td>
</tr>
<tr>
<td>Saturation</td>
<td>Drift</td>
</tr>
<tr>
<td>Hysteresis</td>
<td>Useful Frequency Range</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>Bandwidth</td>
</tr>
<tr>
<td>Dynamic Range</td>
<td>Accuracy</td>
</tr>
<tr>
<td>Error</td>
<td>Precision</td>
</tr>
<tr>
<td>Signal-to-Noise Ratio</td>
<td>Input/Output Impedance</td>
</tr>
</tbody>
</table>

What are the characteristics of a perfect measuring device?