Ongoing List of Topics:

- URL: http://www.ece.mtu.edu/faculty/bamork/EE5223/index.htm
- Labs - EE4224/5224 should be on track. TA: ssorvala@mtu.edu
- Term Project - teams: ~3, incl. 1 from 5223, begin in week 4 or 5.
- CT ratios, MR (multi-ratio) CTs
- CT saturation & accuracy issues: deration for less than full turns
- Print out MOCT & CCVT handout from web page
- MOCTs - Magneto-Optic Current Transformers
- CCVTs
- Voltage & Current relationships during faults
  - X/R ratio, dc offset, decay of dc offset
  - relative angles and magnitudes of all Vs & Is during fault

- $I_s \uparrow$
- $V_s \downarrow$ - phase angles change
Spec-ing CTs:

- C100 - Typical for dist switchgear (< 25kV)
  - Small Eb
  - Low S.C. Current
  - Typically Single Ratio.

- C400, C800 - HV Transmission Equipment
  - CBS
  - Transformers

More Costly
- Big Core
- More Copper
$ \text{Apply}$

- Spec a CTs so they can (hopefully) be used at full ratio, i.e. $X_1 - X_5$.
  
  - Can drive largest burden at higher currents w/o having large error.

- Always spec CT so that $I_{sec}$ at max primary current is just less than 5A. ($I_{sec} \leq 5A$).

- Iterative Method, RCF, calculate phasor $\bar{I}_2$.

- Add'l Concerns: 3-Ph $\Delta$ & $Y$ Connections.

EE 5210 - Power Systems Protection  Spring 2001

MichiganTech Instructor: Bruce Mork  Phone (906) 487-2857 Email: bamork@mtu.edu
3-Line Diagrams

"relay String"

- 3φ
- L-G
- L-L-G
- L-L

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a) No Saturation

b) Part Saturation

c) Severe Saturation

**Figure 5.15** Typical secondary voltages of a current transformer with symmetrical ac current input and increasing secondary burden.

### 5.11.2 Saturation by the Dc Offset of the Primary Ac Current

This is a function of the power system and it is not practical to avoid its effect by CT design. It will temporarily restrict the output of the CT, as illustrated in Fig. 5.16, in contrast to the
5.11 SUMMAF PERFOR

Two types of curr...

5.11.1 Satural Resulti and the

Figure 5.15 shows burden. There is a to operate relays. It be possible or prac

Saturation or decision. Thus, in transformer nears transformer is inten on the other side.

external fault is of formation. Ac satur

For overcur the current transfor in relay operation; in faults, these rela curve, for which p close-in heavy fau
CT Rating decreases for lower ratios.

Ex: 1200:5 - C800 only at full ratio, i.e. when all sec turns (X1-X5) are used.

at 500:5 (homework #5)

\[
\frac{800}{1200} \times \frac{500}{1200} = 330V
\]

\[\Rightarrow \text{Rating is reduced to C330.}\]

i.e. 10% accuracy assured only for 3.3Ω burden.

\[20 \times 5A = 100A, \ (100A)(3.3Ω) = 330V.\]
MOCT Optical Current Transducer System
69 kV to 765 kV Systems, 50/60 Hz

Application

The Magneto-Optic Current Transducer (MOCT) is a passive optical current transducer which uses light to accurately measure current on high-voltage systems. The MOCT system is suitable for outdoor application and has an accurate metering current range from less than 5 amps to 2000 amps using the same sensor. Higher current rated designs are available upon request. Metering accuracy exceeds class 0.2 per IEC 185 standards.

The MOCT system provides a 1.0 amp current output for metering. A low-voltage analog output can also be supplied to interface the MOCT system to certain protective relays. Contact the factory for application assistance.

Standard Bill of Material

- Three phases of MOCT sensors mounted on polymer insulator columns with preterminated fiber optic cable in the insulator.
- Electronic MOCT signal processing module suitable for installation in the substation control house.
- Fiber optic cables for transmission of the light signals between the optical sensors and the MOCT electronic module.

ABB Power Transmission
All dimensions are in inches unless specified otherwise.

<table>
<thead>
<tr>
<th>Maximum System Voltage kV</th>
<th>BIL kV</th>
<th>Dimension A (inches)</th>
<th>Minimum Creep Distance (inches)</th>
<th>Weight (lbs.)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>inches</td>
<td>mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>72.5</td>
<td>350</td>
<td>48.9</td>
<td>1242</td>
<td>70</td>
<td>1778</td>
</tr>
<tr>
<td>121</td>
<td>550</td>
<td>62.6</td>
<td>1590</td>
<td>113</td>
<td>2870</td>
</tr>
<tr>
<td>145</td>
<td>650</td>
<td>70.2</td>
<td>1783</td>
<td>137</td>
<td>3479</td>
</tr>
<tr>
<td>169</td>
<td>750</td>
<td>79.3</td>
<td>2014</td>
<td>165</td>
<td>4191</td>
</tr>
<tr>
<td>242</td>
<td>900</td>
<td>97.5</td>
<td>2477</td>
<td>222</td>
<td>5638</td>
</tr>
<tr>
<td>245</td>
<td>1050</td>
<td>109.6</td>
<td>2784</td>
<td>260</td>
<td>6604</td>
</tr>
<tr>
<td>362</td>
<td>1300</td>
<td>132.0</td>
<td>3355</td>
<td>272</td>
<td>6900</td>
</tr>
<tr>
<td>525</td>
<td>1800</td>
<td>191.2</td>
<td>4856</td>
<td>433</td>
<td>11000</td>
</tr>
<tr>
<td>800</td>
<td>2050</td>
<td></td>
<td>Contact Factory</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The table shows the dimensions and weight for different maximum system voltages and BIL voltages. The dimensions are given in both inches and millimeters. Weight is provided in both pounds and kilograms.
MOCT Magneto-Optic Current Transducer

Our passive optical current transducer uses light to accurately measure current on high voltage systems. It is suitable for outdoor application and has an accurate metering current range from less than 5 A to 2000 A using the same sensor. Metering accuracy exceeds class 0.2 per IEC 60044-1 over a wide metering range. For relaying applications, the system provides accurate waveform reproduction through 100 kA.

The MOCT system can satisfy current sensing needs for revenue metering or protective relaying in a wide variety of applications.

Technical data:
- System voltages: 72.5 - 800kV
- Insulation level: 350 - 2050kV
- Rated primary current: up to 2000 A (*)
- Rated secondary current: 1 A
- Accuracy: Exceeds class 0.2 (IEC)

(*) Higher ratings are available on request

MOCT Features and Benefits

- Wide primary metering current range from 4000 amperes to less than 5 amperes
- IEC metering accuracy class 0.2 over the full metering range
- Accurate waveform reproduction through 100 kA
- No requirement for oil or gas insulation system
- Improved safety with no mechanism for failure or open secondary
- Significantly smaller size and lighter weight than oil or SF6 insulated equipment
- Total isolation from surges for microprocessor based meters and relays
- Zero burden device that can support multiple meters and relays
- No magnetic core ferroresonance or saturation limits
- Over ten years of field proven experience

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Benefits of the MOCT Optical Current Transducer System

The MOCT system can satisfy current sensing needs for revenue metering or protective relaying in a wide variety of applications. Following is a list of key benefits:

- High Accuracy for metering over a wide range of primary currents.
- No requirement for oil or gas insulation system
- Improved safety with no mechanism for failure or open secondary
- Significantly smaller size and lighter weight than oil- or SF₆-insulated equipment
- Total isolation from surges for microprocessor-based meters and relays
- No magnetic core ferroresonance or saturation limits
- More than ten years of field proven experience
Wed -

MOCTs - Ampere's Circuit Law

\[ I_{enc} = \oint \mathbf{H} \cdot d\mathbf{l} \]

CCVTs -

\[ H \ell = MMF = N \ell \]

EE 5210 - Power Systems Protection   Spring 2001
1845 - Faraday Effect in Optical Materials

"...a rotation in the plane of polarization of linearly polarized light under the influence of a magnetic field parallel to the direction of light propagation."

\[
\Theta_{\text{rot}} = \mathbf{V} \cdot \mathbf{H} \cdot d\mathbf{l} \quad \text{radians}
\]

where

\( \mathbf{V} = \text{Verdet Constant, rad/A-turn} \)

\( l = \text{integration path} \)

\( \mathbf{V} \) depends on wavelength of light.

@ \( \lambda = 810 \text{ nm} \), \( 2.5 \times 10^{-6} < \mathbf{V} < 20 \times 10^{-6} \, \text{rad/A-turn} \)

"Faraday Rotators" - materials that exhibit this behavior. For example,

- Quartz: \( 3.1 \times 10^{-6} \, \text{rad/A-turn} \)
- SF-57: \( 16.1 \times 10^{-6} \)
- SF-6: \( 13.9 \times 10^{-6} \)
- BK-7: \( 2.7 \times 10^{-6} \)

\( \mathbf{V} \) also changes markedly for \( T < -20^\circ \text{C} \), decreasing about 5% at \(-40^\circ \text{C}\)
Since a closed path around the conductor is made, according to Ampere's Law:

$$\Theta_{rot} = \int \vec{H} \cdot d\vec{e} = Vi$$

The output light intensity $S_o$ occurs for $i=0$ (no rotation). In general,

$$S = S_o (1 + \sin 2\Theta_{rot}) = S_o (1 + 2\Theta_{rot})$$

For small rotations, $(2\Theta_{rot} < 0.1 \text{ rad})$, $S = S_o (1 + 2Vi)$
Linear Range

\[ S = S_0 (1 + 2Vi) \]

Faraday Rotation, Degrees

\( S = S_0 \) when \( i = 0 \), and increases or decreases depending on direction and magnitude of current flow. Since

\[ \Theta_{Rot} = Vi \]

and

\[ i = \frac{\Theta_{Rot}}{V} \]

and

\[ -45^\circ < \Theta_{Rot} < +45^\circ \Rightarrow i_{max} = \frac{\pi/4}{V} \]

<table>
<thead>
<tr>
<th>Material</th>
<th>( V )</th>
<th>( i_{max} )</th>
<th>( i_{max, \text{ linear}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF-57</td>
<td>16.1 \times 10^6</td>
<td>48.8 KA</td>
<td>3105 A</td>
</tr>
<tr>
<td>SF-6</td>
<td>13.9 \times 10^6</td>
<td>56.5 KA</td>
<td>3597 A</td>
</tr>
<tr>
<td>BK-7</td>
<td>2.7 \times 10^6</td>
<td>291 KA</td>
<td>18,520 A</td>
</tr>
</tbody>
</table>

\[ |\Theta_{Rot}| \leq 0.05 \text{ rad} \]
For measuring small currents, the MOCTs sensitivity may be increased by:
- Multiple loops of conductor
- Choose material with larger V
- Zig-zag light path
- Multiple loops of light beam

(Use small V and shortest optical path for large currents)

<table>
<thead>
<tr>
<th>345-KV MOCTs</th>
<th>Magnetic CTs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td>1 - 10,000 Hz</td>
</tr>
<tr>
<td>Saturation</td>
<td>No</td>
</tr>
<tr>
<td>Weight</td>
<td>350 lbs</td>
</tr>
<tr>
<td>Accuracy</td>
<td>±0.2%, 20-40,000 A</td>
</tr>
<tr>
<td>Cost (1995)</td>
<td>$70K</td>
</tr>
<tr>
<td>Interface</td>
<td>Must Convert</td>
</tr>
</tbody>
</table>

? ±5V

Good for mProc relays (A/D inputs)