Current Sensors

What is it?

A transformer like device designed to detect Alternating Current (AC), Direct Current (DC), or Leakage Current through the induced magnetic field.
CT Sensor Construction and Material

Filled with epoxy or no epoxy

Housing

Wire

Core case

Core

Core case cover
## Core Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Output voltage</th>
<th>Temp. characteristics</th>
<th>Linearity (Bs)</th>
<th>Phase angle</th>
<th>Ratio error</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permalloy</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Good</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Good</td>
</tr>
<tr>
<td>Ferrite</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
<td>Excellent</td>
</tr>
<tr>
<td>Silicon steel</td>
<td>Poor</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Poor</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Nano crystal</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Poor → Good</td>
</tr>
</tbody>
</table>

### MR series, CT series
- MR/C series

### CCT series, LA series

### Magnetic field $H$ (A/m) @ DC

![Graph showing magnetic field $H$ (A/m) @ DC](image_url)

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Operation Principle
Method of Sensing Current - 1

1. Resistance (Shunt resistance)
   - Ohm’s Law
   - Easy and simple to measure
   - Increase loss, heat

2. Current Transformer (CT, CCT, MR series)
   - Current trans method
   - Measure wide frequency
   - Measure wide current
   - Difficult to measure DC (Magnetic saturation)

3. Hall element (LA series)
   - Use hall effect (E $\propto$ H)
   - Measure DC to AC
   - Need drive circuit for Hole element

$$I = \frac{V}{R}$$

$$I_1 = \frac{N_2}{N_1} \times I_2$$

$$V_{out} \propto \text{Magnetic field} \propto \text{Primary current}$$
Method of Sensing Current - 2

4. Fluxgate current sensor (FG series under development)
   - Use nature of hysteresis symmetry of magnetic material
   - Detect magnetic field
   - Very low offset (error at zero current)

![ Fluxgate current sensor diagram ]

- Magnetic flux in magnetic material
- Applied magnetic field
- Current = 0
- Current > 0

Excitation coil
Detection coil

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Operation Principle of AC CT Sensor

- Magnetic field ($\phi$) is generated around a primary conductor ($I_O$)
- Magnetics flux ($\phi_f$) is generated in the core in opposite direction of $\phi$
- Current flows through the secondary winding
- Output voltage ($E_O$) is obtained across a sensing resistor ($R_L$)

$$E_O = k \times I_O \times \frac{R_L}{n}$$

- $E_O$: Output voltage (Vrms)
- $k$: Coupling factor
- $I_O$: Through current (Amps)
- $R_L$: Load resistance (Ohms)
- $n$: Number of windings
Operation Principle of Zero-Phase Current Transformer (ZCT)
Ground Fault Current Detection Sensor, Detecting mA Range Current

- $I_1$ is the AC forward current traveling to the load and $I_2$ is the AC return current traveling from the load.

- Opposite magnetic fields ($\Phi_r$ and $\Phi_f$) are created.

- When $I_1 = I_2$, magnetic fields $\Phi_r$ and $\Phi_f$ are equal and cancel each other out ($\Phi_f - \Phi_r = 0$). No magnetic flux in the core.

- When a ground fault occurs on the load side, $I_2$ will be smaller than $I_1$. There will be a proportional difference between $\Phi_f$ and $\Phi_r$. This will induce a proportional voltage across $R_L$. 

![Diagram of ZCT sensor with magnetic fields and voltage generation](image)

**Level of leakage current and the impact**
- mA (~10mA - 100mA)
- A

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Operation Principle of Direct Current Sensor (DC & AC)

- Detecting magnetics field generated by primary conductor by a hall element
- Hall element converts magnetic field to voltage
- Output from the hall element is small, so the output voltage is amplified by an amplifier
- Can measure AC and DC current

Can measure AC and DC

Alternating Current

Direct Current

Can measure AC and DC

Sensor Output Voltage

Current to be measured

Time

Sensor Output Voltage

Current to be measured

Time

Magnetic Core

Current

Power Supply

Hall Element

AMP

Output Voltage

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Output Voltage $ (E_O) $ vs. Through Current $ (I_O) $

Output Voltage Linearity

Magnetic flux density of the core increases proportional to output voltage.

Large load resistance $\rightarrow$ Large output voltage $ (E_O) $
Large measurement current $\rightarrow$ Large output voltage $ (E_O) $

Output voltage saturation
Output voltage loses linearity as core enters into magnetic saturation.

Output voltage loses linearity at small current region
Due to permeability of the core material
Higher the permeability, better linearity at small current region
Parameter to determine accuracy of current sensor

Amplitude Difference = Ratio error
Phase difference = Phase angle

Total error is compensated at Secondary circuit when used

Primary current

Secondary side

Sensor

I₀(A)

R_L

E₀(mV)

Design parameters
1) Core material (Temperature characteristics, Permeability)
2) Winding structure
Balancing Current Characteristics

Characteristics not causing ZCT output voltage by excessive inrush current (Example: 10 times of Rated current)

When electric motor is connected to the earth leakage circuit breaker, a voltage is generated on the secondary side of the ZCT in excessive inrush current, and the same phenomenon as when a ground fault occurs. The performance does not generate voltage on the secondary side of the ZCT due to excessive inrush current which is called balancing current characteristics. The ZCT is required to keep this balancing characteristics at least 1- times the rated current and accurately detect a minute ground fault.

This characteristic can be improved by shielding technique (Manufacture’s know-how)
Over Input / Leakage (Current) Characteristics

When an excessive current (over current) such as a grounding ground fault passes, the sensitivity to the zero-phase current becomes worse as compared with that before the passage. That means the output voltage becomes lower. The degree of this reduction in sensitivity is called Over input/leakage Characteristics. This is important factor for ZCT.

Over input characteristics (%)  
= (Output voltage after over current - output voltage before overcurrent)/(Output voltage before over current)x100

KEMET specification = 10% (maximum) after DC5A passed

Primary Current

Output voltage measurement condition  
F = 60Hz, RL = 300Ω, I0 = 22.5mA
Temperature Characteristic

Temperature vs. Output Voltage ($E_O$)

-30 - -20 - -10 0 10 20 30
-30 - -20 - -10 0 10 20 30 40 50 60 70 80

Output Voltage (mV)

Temperature (°C)

- New Product (Nanocrystal)
- Conventional product (Permalloy)
# KEMET Current Sensor Capability

## Rated Current

<table>
<thead>
<tr>
<th>Series</th>
<th>Type</th>
<th>Current Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LA12 Series</strong></td>
<td>DC/AC Measurement</td>
<td>1A, 10A, 60A</td>
</tr>
<tr>
<td></td>
<td>MDCS®</td>
<td></td>
</tr>
<tr>
<td><strong>CT Series</strong></td>
<td>AC Current Transformer</td>
<td>3A, 50A, 250A</td>
</tr>
<tr>
<td></td>
<td>(Through type)</td>
<td></td>
</tr>
<tr>
<td><strong>C/CT Series</strong></td>
<td>AC Current Transformer</td>
<td>40A, 100A, 250A, 600A</td>
</tr>
<tr>
<td></td>
<td>(Clamp type)</td>
<td></td>
</tr>
<tr>
<td><strong>MR Series</strong></td>
<td>Zero-Phase Current</td>
<td>30A, 125A, 250A</td>
</tr>
<tr>
<td></td>
<td>Transformer (Through type)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Blue</strong>: Existing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Gray</strong>: Can develop</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Red</strong>: Under developing</td>
<td></td>
</tr>
</tbody>
</table>

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Applications
Target Applications

**ZCT (Existing Market) AC Fine Current**
- 1mA
- 10mA
- 100mA
- 1A
- Target: Ground Fault Circuit Interrupter
- New Platform (No Potting, Auto assembly.)
- Expanding Line Up: 30A, 60A, 120A

**DCCT (New Marker) DC Fine Current**
- Target: EV/PHV Charging Cable
- Feature: Excellent Temperature Stability (Material & Design)

**CT (Existing Market) AC Large Current**
- 10A
- 100A
- 1000A
- Target: Energy Monitoring System, Power Conditioner
- Expanding Line Up: 120A, 30A, 250A

**DCCT (Industrial Market)**
- Target: Solar Panel (Power Conditioner), Inverter, EV/PHV Charging Cable
- Expanding New DCCT Design Technology

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Where are AC Current Sensors Utilized

Example: Inverter Driven AC Load

- Power factor improvement (DC Sensors)
- Excess power detection (DC Sensors)
- Vector control (our product)

Examples:
- Air Conditioner
- High efficiency Refrigerator
- Industrial Drive
- HEV/EV
- Inductive Cooking/Heating
Example: Distribution Board

Snap on type CT = (C/CT-1216)
Current Sensor for EV / PHV Charger Cable

Regulation by Region

<table>
<thead>
<tr>
<th>Current Sensor Type</th>
<th>Function</th>
<th>Japan</th>
<th>America</th>
<th>Europe</th>
<th>China</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCCT</td>
<td>DC Leakage</td>
<td>N/A</td>
<td>N/A</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>ZCT</td>
<td>AC Leakage</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>CT</td>
<td>Over Current</td>
<td>N/A</td>
<td>✓</td>
<td>N/A</td>
<td>✓</td>
</tr>
</tbody>
</table>

AC/DC Leakage, Current Measurement

Current Sensor Requirement: Excellent Temperature Stability

1. DCCT: Driving Circuit & Off-set Stability
2. ZCT: Standard Product Development
3. CT: Under Development for EV Charger application

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Thank You!