IEEE Standards

Transformers Committee

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Inrush Current Tutorial Session

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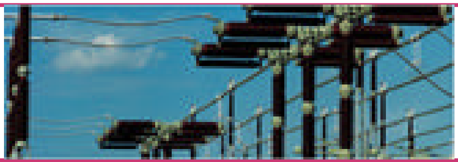


Inrush Current in Power Transformers

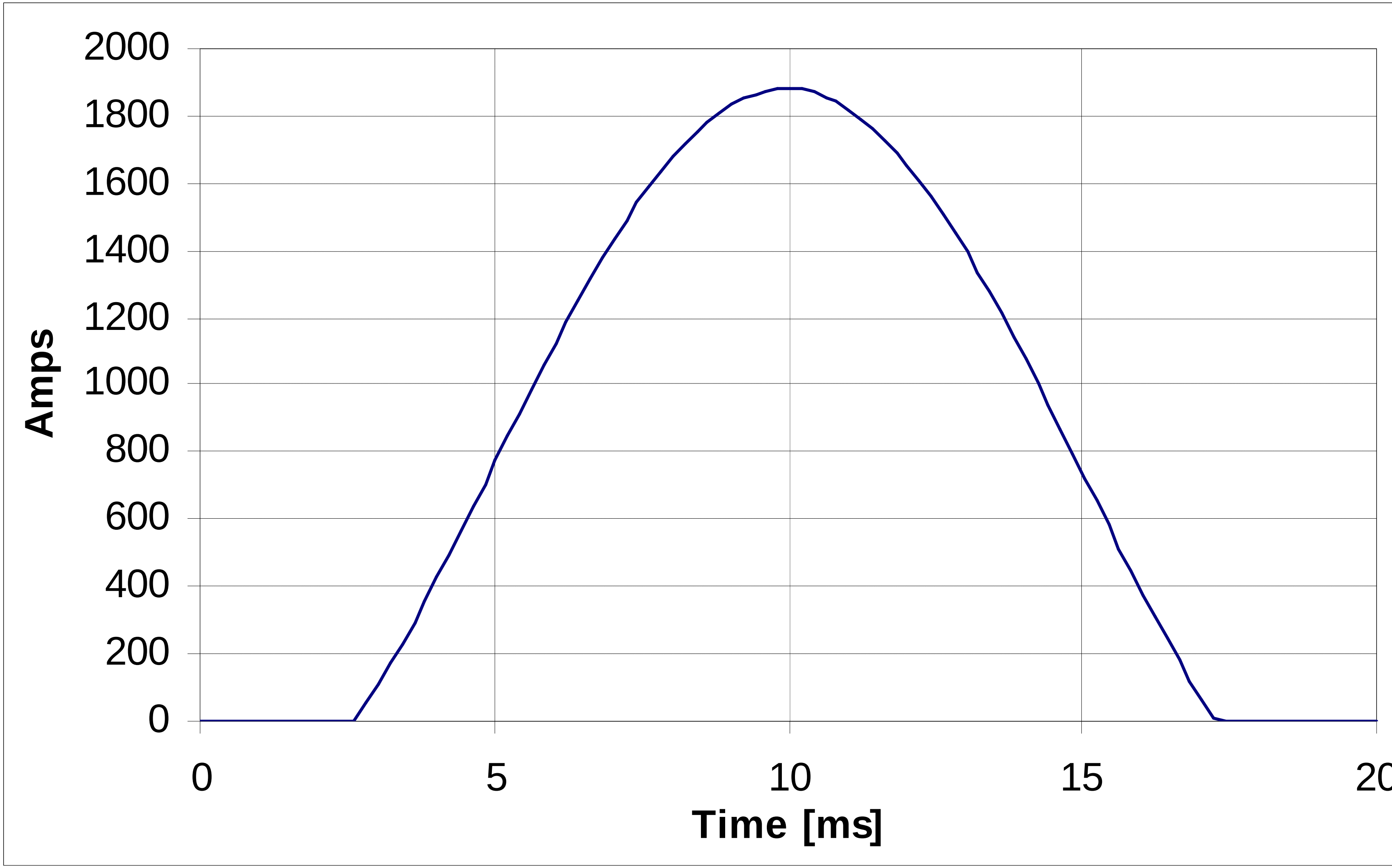
- **Calculation & typical values of inrush current parameters requested by customers**
  - **Peak value**
  - **Wave-shape**
  - **integral of i^2dt (Energy parameter)**
  - **Maximum di/dt**
  - **Minimum % ratio of 2^{nd} harmonic / peak**
- **Effect of transformer design parameters**
  - **Number of phases and Winding connection**
  - **Size of transformer**
  - **Core material, geometry, design induction, and type of joint**

General Inrush Current Equation

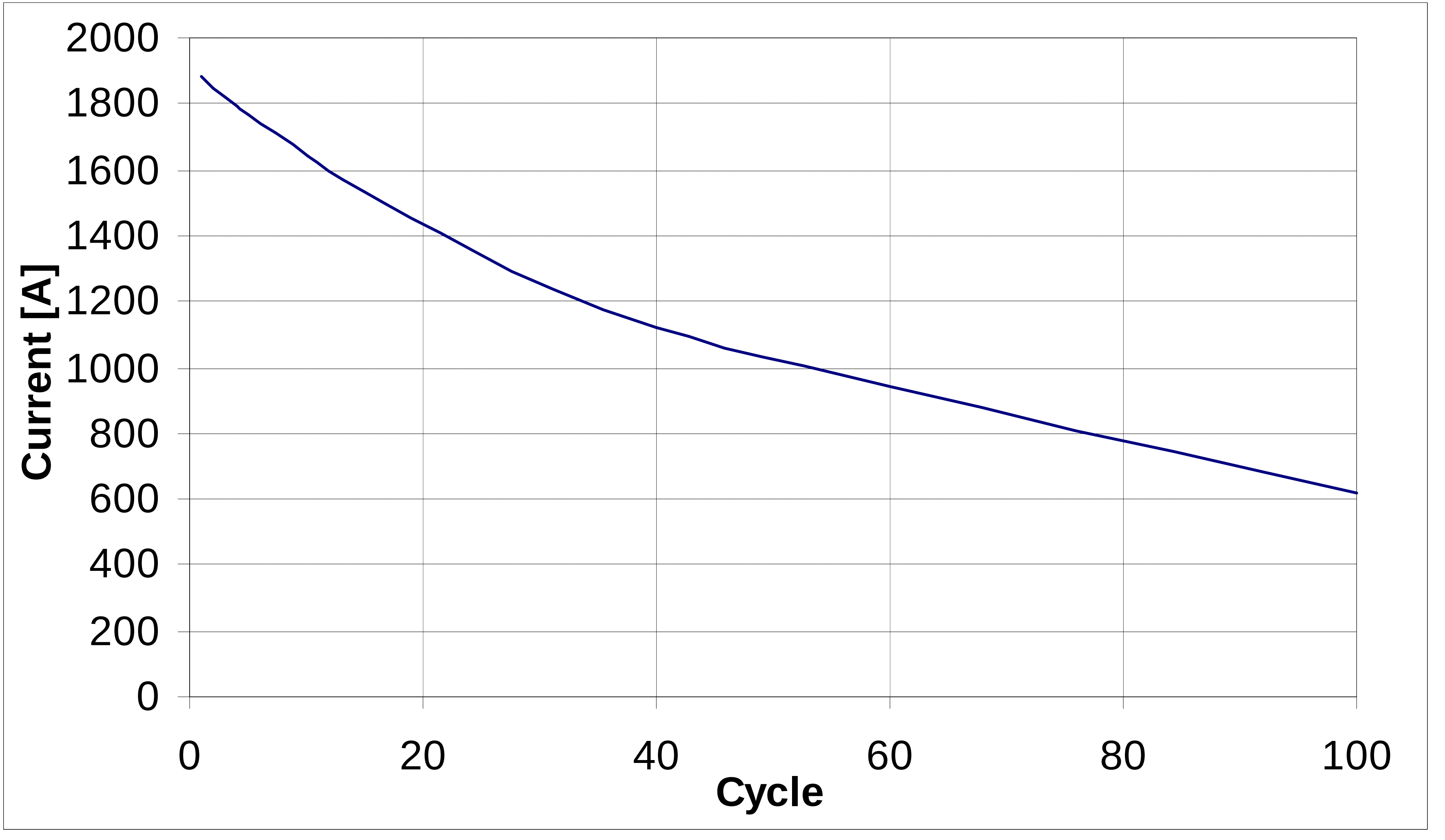
$$\frac{\sqrt{2}U}{z_t}\left(\sin(wt - j\,) - e^{\frac{-(t - t_o)}{t}} \cdot \sin a\right) \cdot K_w \cdot K_S$$

- **U = applied voltage**
- **z_t = total impedance under inrush, including system**
- **j = energization angle**
- **t_0 = point at which core saturates (function of B_R, B_S, B_N, j)**
- **B_R = remenant flux density**
- **B_S = saturation flux density**
- **B_N = normal rated flux density**
- **t = time constant of transformer winding under inrush conditions**
- **a = function of t_0**
- **K_W = accounts for 3 phase winding connection**
- **K_S = accounts for short-circuit power of network**

Calculated Inrush Current Waveshape



Calculated Peak inrush current



Inrush Current Energy Parameter

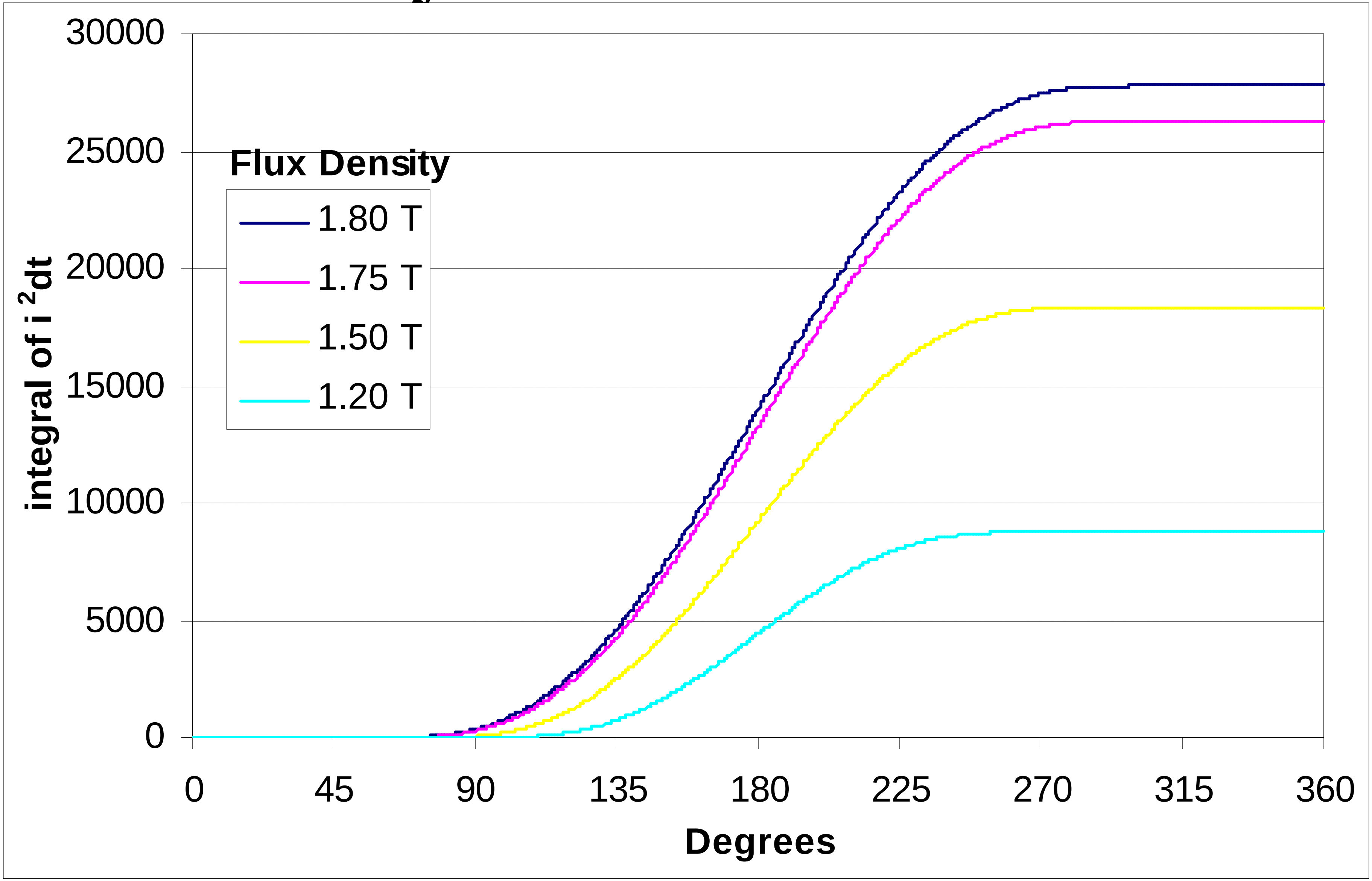
- **General Equation**

$$= \int v(t) \cdot i(t) dt$$

$$\propto \int i^2(t) dt$$

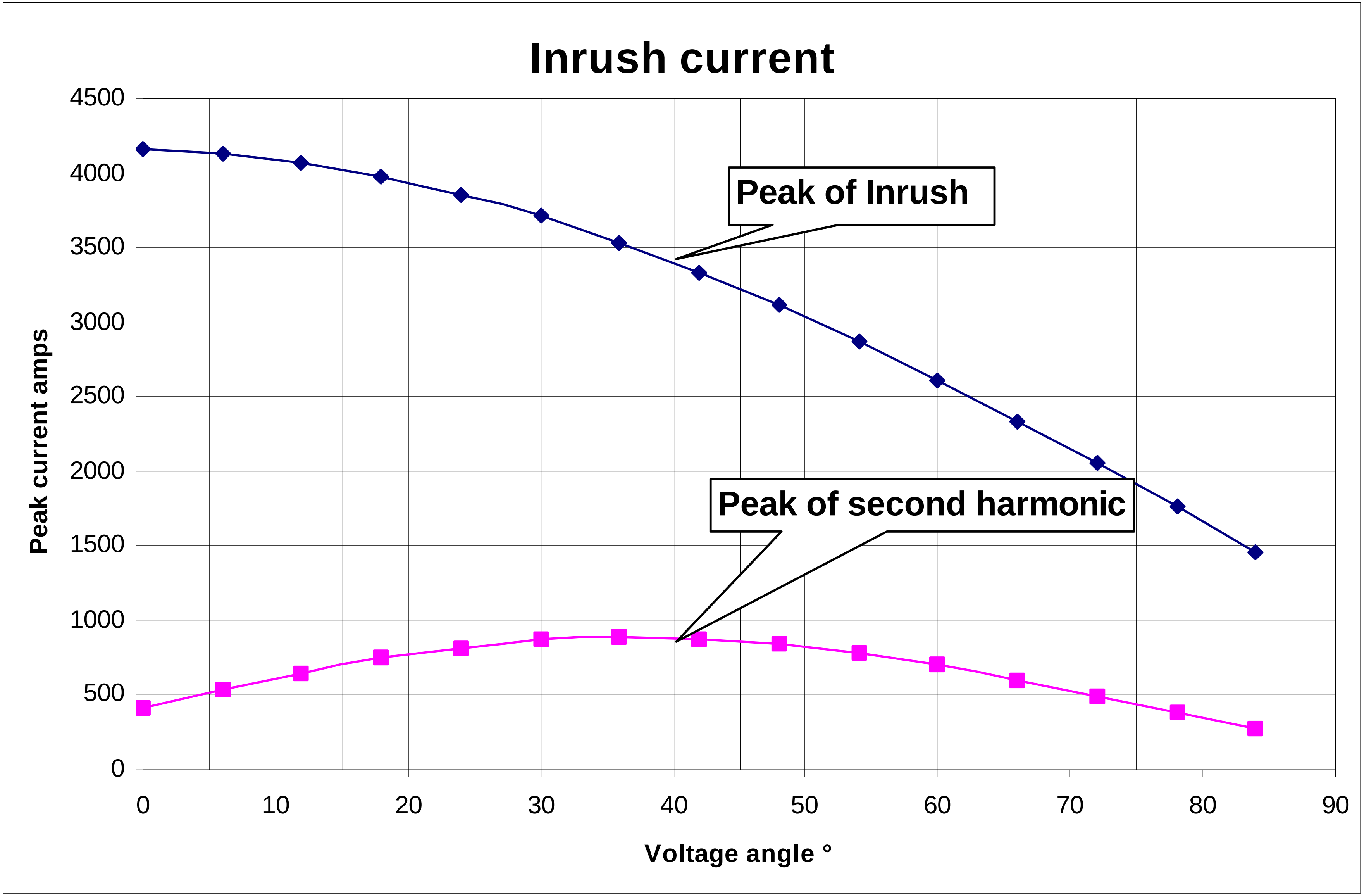
Users ask for this value over the first cycle

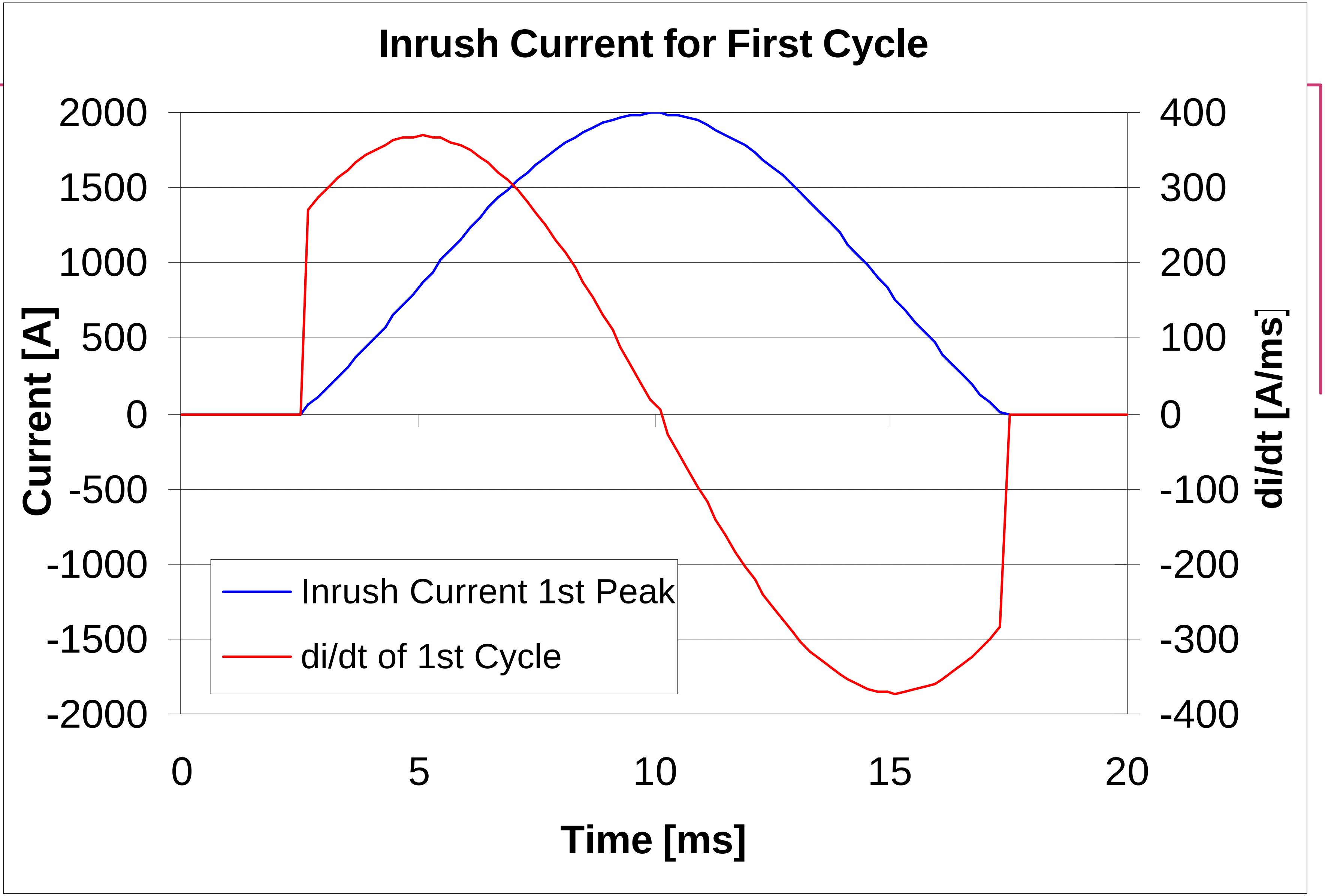
Calculated $\int i^2 dt$ for RGO Grade



Minimum % Ratio of 2nd Harmonic / Peak

- **Customers use this value to distinguish between Inrush current and short circuit current**
- **This minimum % ratio occurs when the transformer is energized at voltage-angle = 0º ; which is also the condition that results in the maximum peak inrush current value**


Inrush current
Peak of Inrush
Peak of second harmonic
Peak current amps
Voltage angle °
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
10
20
30
40
50
60
70
80
90



- **Value used in setting size of vacuum switch**

Effect of Design Parameters

- **Number of Phases and Winding connection**
  - **Inrush current in 3 phase transformers is equal to, or less (by 30-40%), than 1 phase, depending on winding connection**
    - **delta, wye, grounded wye, auto, etc**
    - **winding connection combination of energized and secondary windings**
- **Transformer Size (MVA)**
  - **Generally inrush/rated current ratio is lower for larger MVA**
  - **Time constant for inrush current is larger for larger MVA**
- **Core Steel Material**
  - **HiB materials have lower remenance, but slightly higher saturation level compared to RGO materials**
  - **Thus, HiB materials are associated with lower peak inrush currents & higher min % 2nd harmonic / peak ratio**

Effect of Design Parameters

- Core Geometry
  - affects core remenance
  - affects the magnetic field distribution in the core (which hence affects core air inductance)
- Design induction
  - peak inrush increases with induction
  - min % 2nd harmonic / peak decreases with induction
- Joint type
  - transformer core has lower remenance than material of the core because of the high reluctance of the joints
  - non step lap core has slightly lower peak inrush current than the step lap core
    - lower core remenance