# Fast and reliable temperature measurement at end of melting cycle in EAF

## FiT-Temp product description

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# In modern mini-mill setups, accurate end temperature control is key to achieve efficient operational performance of the EAF

**Modern mini-mill philosophy**:

- EAF is primarily a melting unit
- Final temperature control and alloying is done during secondary metallurgy

- Key to successful operational performance is **accurate determination of end point of melting cycle**

Problem-free tapping is guaranteed by:

- Sufficiently high temperature of liquid steel (superheat)
- Low fraction of residual solid scrap at time of tap hole opening

**Accurate and reliable temperature measurement is needed to determine appropriate end point**

**Large variations** in the progress of individual heats are **inherent to the EAF process**:

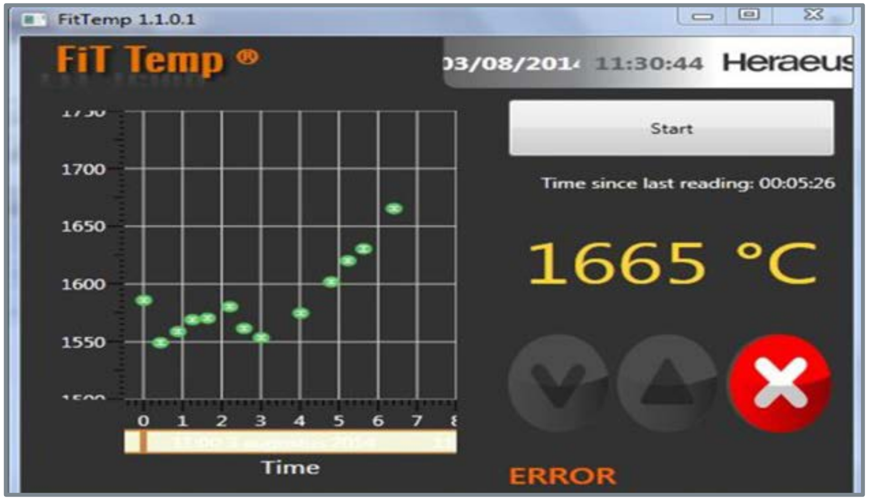
- **Uncertainties on raw material quality** (especially for scrap based furnaces) leading to inaccurate mass and energy balances

- **Process scatter on thermal efficiency** of furnace caused by varying:
    - Scrap quality
    - Slag foaming conditions
    - Hot heel conditions
    - State of the furnace (skulls)
    - Residual solid scrap
    - Loading of the furnace

# Current automatic lances use disposable probes for temperature measurement of liquid steel bath at end of heat cycle

- **Equipment description**:
  - Mechanical automated lancing system fitted with disposable thermocouple on probe holder at tip of lance
  - Temperature measurement is done by dipping the probe in liquid steel
- **Points of concern** of current automatic lancing systems:
  - Low measurement frequency (60 seconds between dips)
  - High risk of failure (disposable probe can hit piece of scrap during dip)
  - Lance operator is present at dangerous area in EAF plant near slag door (fits probe to lance system)

# Erratic temperature profiles and significant amounts of residual solid scrap are observed at end of melting in spite of safety margins



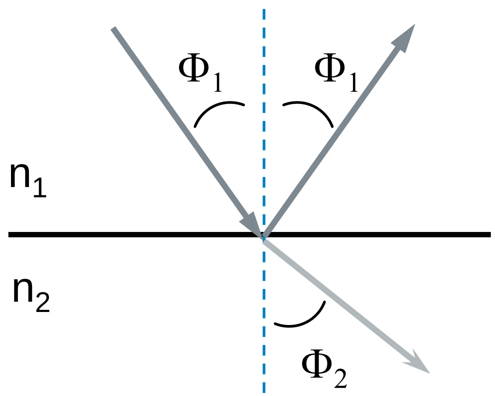


- **Standard operating procedure**:
  - Target end point of production cycle is fixed at 20 °C above ideal conditions to avoid freezing in the EBT area during tapping of liquid steel
- **Frequently observed issues**:
  - Large fraction of superheated cycles due to sharp increase of liquid steel temperature right before tapping
  - Significant amounts of residual solid scrap present in the EBT area after tapping, especially when tap to tap times are shorter than 40 mins
  - First dip measurement 4 mins before tapping of liquid steel breaks deep foamy slag conditions (lowers furnace efficiency)

Low frequency of current measuring systems is unable to fully capture erratic temperature profile at end of production cycle in EAF

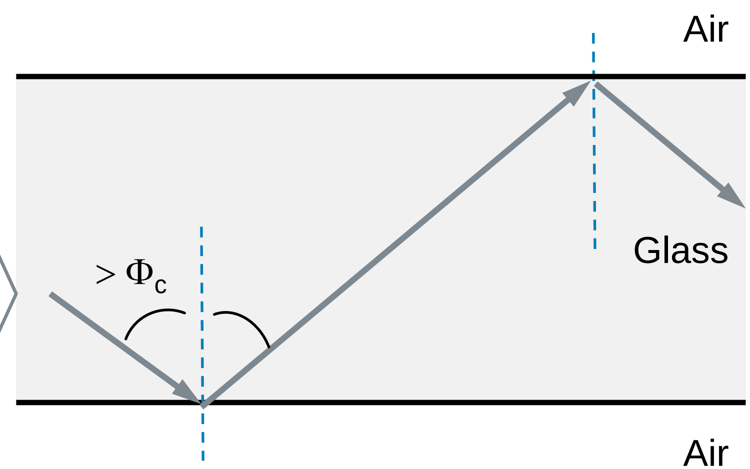
# Black body radiation inside liquid steel can be transmitted to a light emission detector through internal refraction in an optical fiber

## Law of refraction (Snell's law)




- Mathematical formulation of Snell's law : $n_1 \sin \Phi_1 = n_2 \sin \Phi_2$
- Internal refraction when $n_1 < n_2$ or $\Phi_2 > \Phi_1$
- Total internal reflection when $\Phi_2 = 90°$ or $\Phi_1 > \Phi_C = \arcsin (n_2 / n_1)$

## Transport of light through fiber




- $\Phi_C = \arcsin (n_{Air} / n_{Glass}) \cong 42°$

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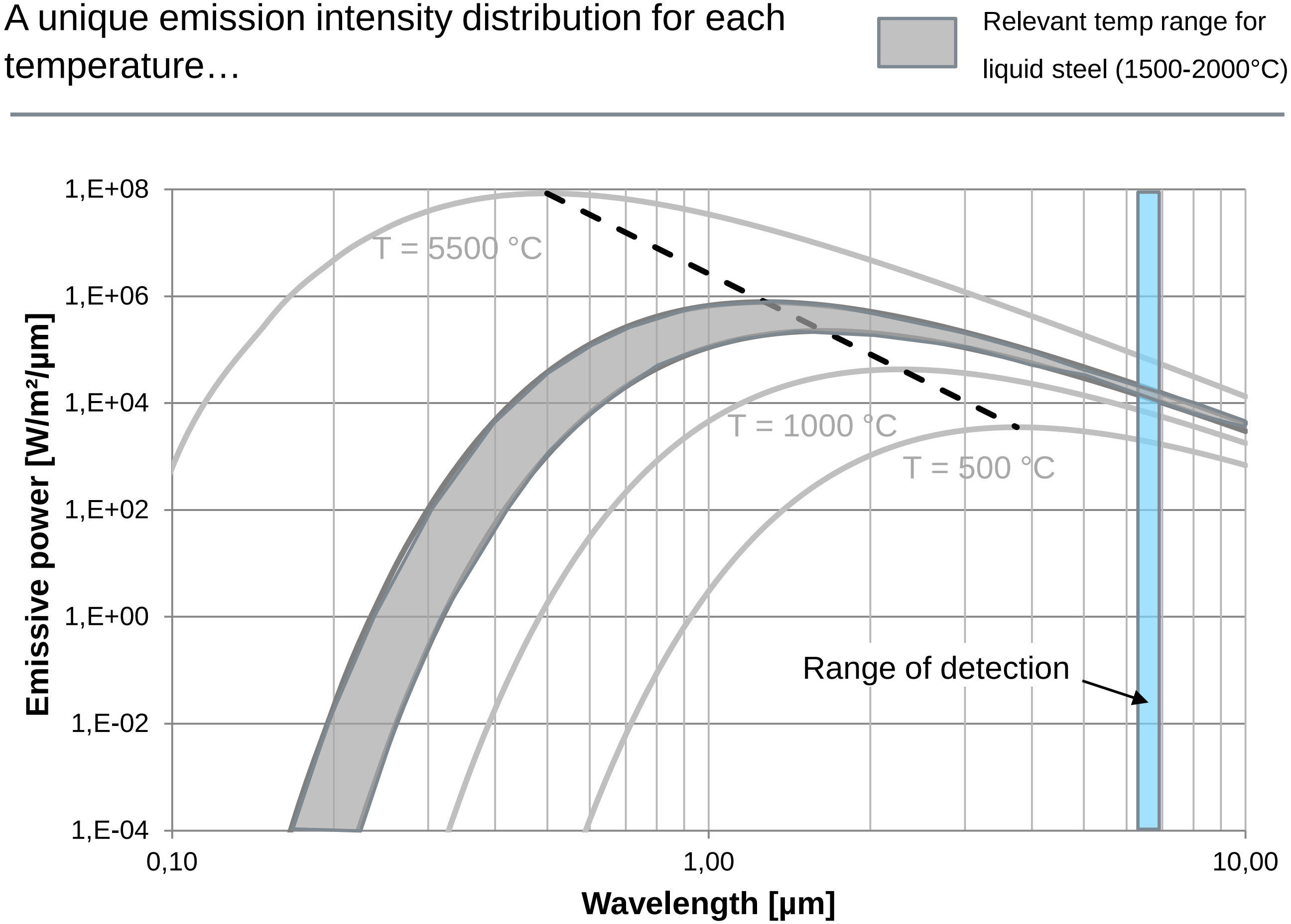
# Temperature is determined by applying Planck's law of radiation to the measured emitted light intensity

A unique emission intensity distribution for each temperature…

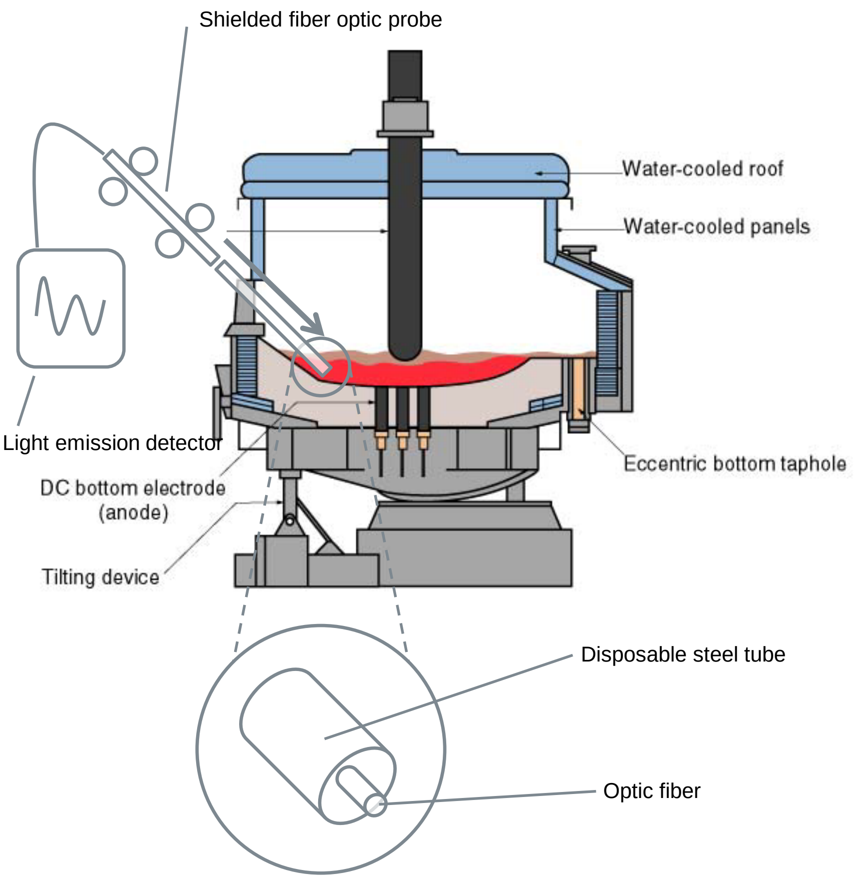



… makes an accurate measurement possible

- Emission intensity is determined at 1,550 nm (chosen for minimal signal attenuation in fiber)
- Planck's law states that for a given fiber cross section and exposure time a unique temperature corresponds to the measured emitted light intensity

# A shielded optical fiber probe is inserted into the liquid steel bath where emitted light intensity is measured

## Equipment setup




## Sampling sequence FiT-Temp

1. Load shielded fiber optic probe for insertion in furnace shell
2. Insert disposable steel tube together with optic fiber at high speed in liquid steel bath
3. Measure emitted light intensity in fiber with standard light detecting sensor
4. Retract fiber before significant high temperature deterioration occurs
5. Release disposable tube in furnace for further melting

Total target sampling time : 15-20 seconds

Critical parameters for good quality measurement:

- End position of disposable tube in liquid steel bath
- Position of optical fiber relative to steel tube

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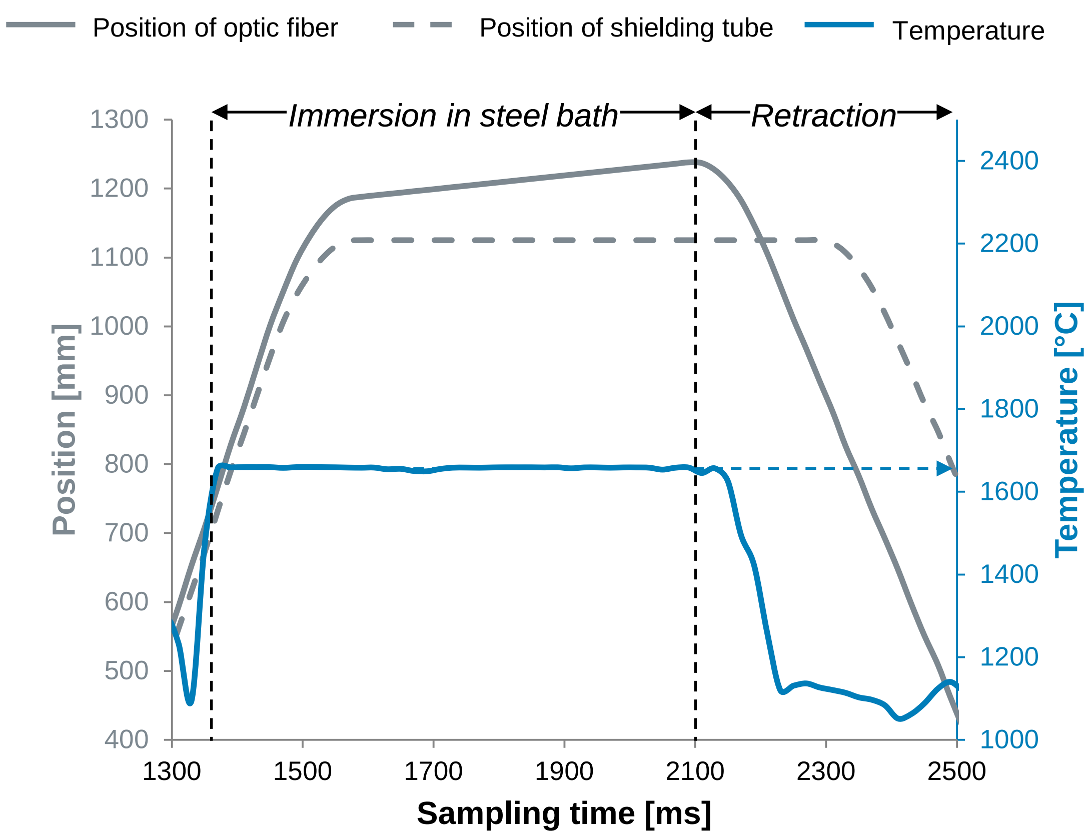
# During each optical temperature measurement a set of 3 main parameters is tracked

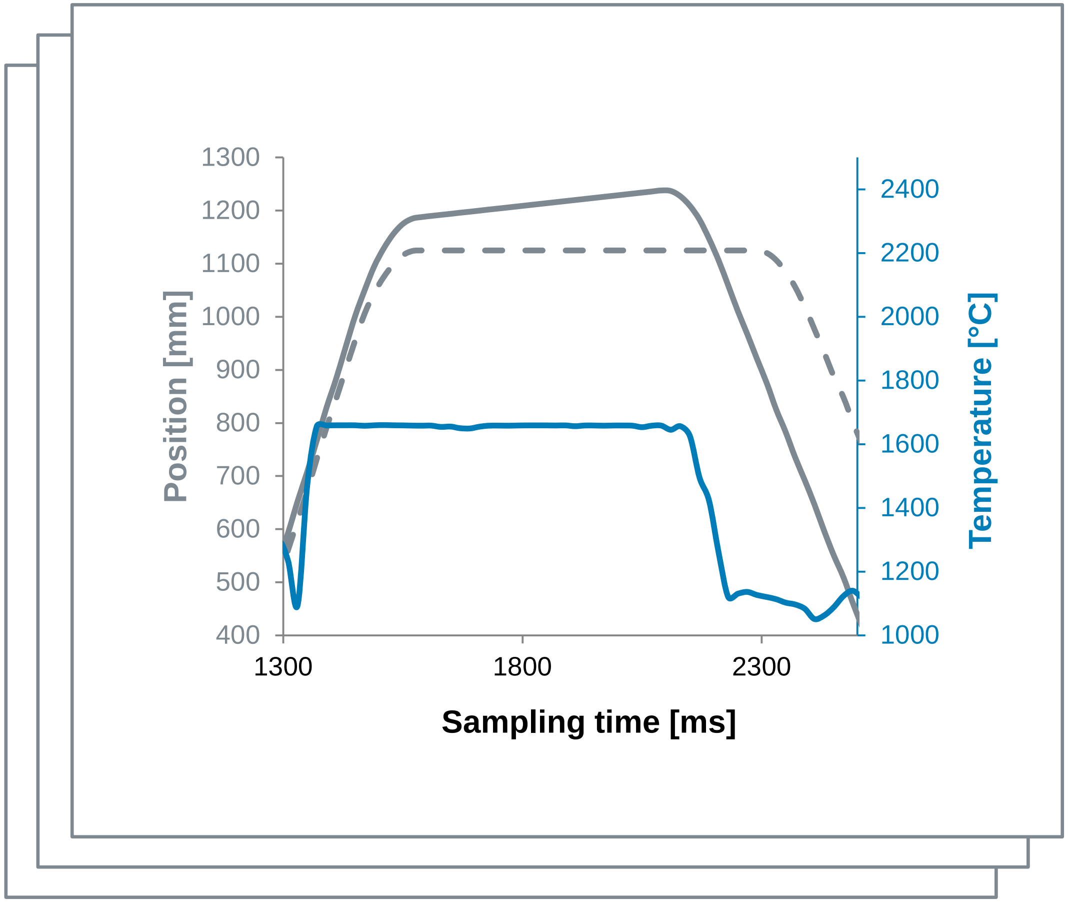
## 3 parameters determine temperature and quality of measurement

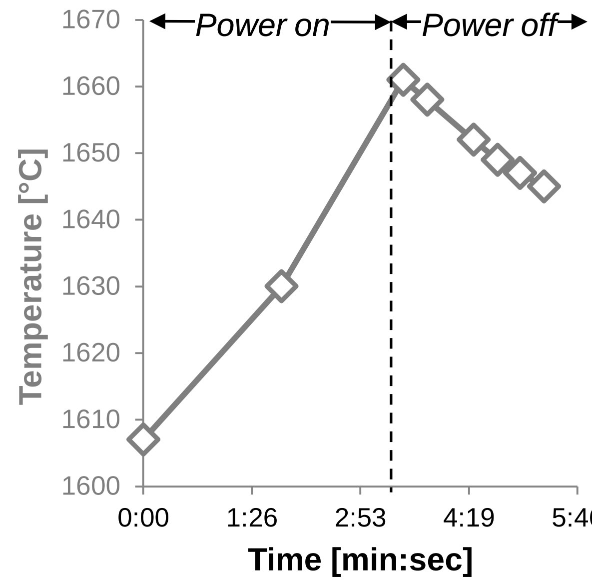



- Temperature is determined as the best plateau of the measured values during immersion phase

- Exact position of shielding tube and fiber are tracked to determine quality of measurements:
  - Sufficient immersion depth
  - Potential interference with residual solid scrap in liquid steel
  - Sufficient exposure of fiber to liquid steel
  - Bending of fiber

# A semi continuous temperature profile can be constructed through a sequence of optical measurements




Target measuring frequency : 20 sec

# New optical temperature measurements offer several clear advantages over current standard sampling techniques

| | Description | Advantage |
|---|---|---|
| 1 **Increased sampling frequency** | • More accurate temperature profile at end of melting cycle<br>• Increased availability versus standard measuring systems | • Superheated production cycles can be avoided through better operational control of furnace<br>• Decreased energy consumption in EAF due to lower tapping temperature |
| 2 **Limited impact on foamy slag conditions** | • Temperature measurement without opening slag door<br>• Foamy slag conditions can be maintained until the end of melting cycle | • Increased energy efficiency of furnace during final phase of melting<br>• Decreased costs in EAF for energy and consumables from improved operational performance |
| 3 **Residual solid scrap assessment** | • Accurate temperature profile allows for assessment of remaining fraction of solid scrap at end of power-on time | • Strongly increased accuracy in predicting liquid steel temperature in ladle after tap<br>• Lower occurrence of freezing in EBT zone during tapping of liquid steel |

# For a typical high powered, high productivity EAF a conservative estimate of 3,2 USD per ton of savings can be made

| Value in use levers | | Key assumption |
|---|---|---|
| **1** Decreased energy consumption by **avoiding superheated cycles** | 1,0 | • Increased frequency of temperature measurements allows for better furnace control near end of melting cycle<br>• Avoiding superheated production cycles lowers tapping temperature by 10°C on average |
| **2** Improvement of energy related KPI's through **increased efficiency** of furnace | 1,5 | • Optical temperature measurement allows for 2 additional minutes of power-on time under deep slag foaming conditions<br>• Thermal arc efficiency is increased by 30% vs non deep slag foaming conditions |
| **3** Lower production losses due to **avoiding tap hole blockages** | 0,7 | • Semi-continuous temperature profile allows for assessment of residual solid scrap at end of melting cycle<br>• Avoiding blockages of tap hole reduces average tap-to-tap time by 0,5 mins |

Value in use of optical temperature measurement in EAF (levers 1–3)