Crucible monitoring in induction furnaces

Depending on the furnace size, the thickness of this ceramic lining varies between 10 and 15cm, diminishing noticeably as a result of wear or crucible erosion. Inductor insulating materials such as insulating varnish and bandages are heat resistant up to approx 150 - 200°C.

If overheating occurs at this point, the insulation may become damaged or even electrically conductive, resulting in intermittent short-circuiting of the coil. The coil repair effort involved in this case will render the furnace inoperative for several days, even if a spare coil is on hand. In the worst case, although rarely documented but feasible, the melt might penetrate through to the water-cooled coil with attendant risk of a furnace breakdown and ultimately, a steam explosion.

These considerations, together with furnace users' economically motivated demands for a maximum service life of the ceramic furnace lining, call for a technology which permits a 'visual' inspection of the gap between the ceramic furnace lining and the induction coil. Addressing this requirement, various technical solutions for monitoring the crucible were proposed and implemented in the past.

**Earth leakage monitoring**
The most important of these is the classic earth leakage monitoring system. In this technology, a dc or ac voltage of a defined, fairly low frequency is applied to the induction coil and the system measures the current flow to earth. For this purpose the molten metal bath must be earthed via an earthing rod in the bottom of the crucible. This earth fault monitoring system, although by now a standard feature on virtually all induction furnaces, has a number of disadvantages.

For one, it is not selective as defined tests and

![Fig. 1: Typical crucible structure with OCP sensor grid](image1)

**Furnaces**

![Fig. 2: Visualization of the crucible monitoring system](image2)

Laser technology can now be used for interference free crucible monitoring. One key design feature distinguishing induction furnaces from other heating equipment is the fairly thin ceramic lining between the live water cooled copper conductor and the molten metal bath.

or in any other part of the equipment, such as in the switchgear or even in the water re-cooling system. Another disadvantage of this earth leakage monitoring technique is that in the event of infiltration or penetration of molten metal to the coil, an indication is given only fairly late. As a result, the furnace must be emptied quickly if a current flow between the melt and the coil is detected. In any event, minor damage to the coil may have been caused already.

Despite these drawbacks, earth leakage protection systems remain an essential safety tool in the operation of coreless induction furnaces and are unlikely to be supplanted by more recent measuring technology. Earth leakage monitoring will always remain in use as an ultimate safety feature since naturally, the entire furnace including the switchgear and water re-cooling system must be continuously checked for earth leakage.

**Spot measurement thermocouples**
The use of thermocouples between the hot face lining and the coil levelling mix, as well as in the furnace bottom, is another technique employed. However, this method can yield only spot measurements (at least if the cost and effort involved is to be kept within reasonable limits) and is therefore not capable of monitoring the entire crucible.

In the past, wire netting in various geometrical configurations has been placed between the coil levelling mix and hot face lining. The idea is to detect an electrical continuity between an advancing tip of molten metal and the net. One particular disadvantage of this technique is that it provides no trend indication - no advance warning is given. Moreover, it is virtually impossible to identify the fault location and numerous spurious faults are detected since the net, as an electrical measuring device, is subject to many stray voltages and current effects in the magnetic field of the induction furnace.

A further process in industrial use relies on the use of sensor grids comprising an array of metallic electrodes in a comb type configuration. These electrodes are used to measure the electrical resistance of the ceramic lining. As this resistance is temperature related, it is
functionality is obtained.
However, given the resistance based nature of the measurement, the system must be adapted to the specific ceramic material used. The readings obtained will be affected by any change in the composition of the ceramic lining, moisture effects, and furnace induced magnetic interference influencing the electrical resistance measurement.

**Laser light detection**

OCP (optical coil protection) is a temperature measuring and monitoring system employing optical fibre sensors of the latest generation. Thanks to their measuring characteristics these sensors lend themselves particularly well for interference free crucible monitoring in induction melting furnace applications (fig. 1).

Based on an optical fibre, the system utilises a quantum mechanical effect, the so called Raman effect, for temperature measurement. The system injects laser light of suitable wavelength and modulation frequency into the optical fibre. This laser light scatters on the bonding electrons of the solid state structure over the full fibre length and is detected as a backscatter spectrum. This spectrum contains the Raman lines, the intensity of which is a function of vibration levels in the solid state fibre structure, which in turn depend on temperature.

A new, patented ‘optical radar’ technique makes it possible to detect these lines locally and to measure an exact, high resolution temperature profile around the crucible circumference online. Thus OCP is a unique crucible monitoring system making it possible for the first time ever to determine the temperature field in the induction furnace irrespective of refractory type and design. By selecting a radial resolution of 60 measuring points, it is possible to represent the temperature curve in the manner of the familiar analogue clock face (fig. 2).

By adopting an appropriate configuration of the sensor grids, the crucible can be further divided into a bottom/centre/top area, although only a single optical fibre is used in all cases. Points of particularly high temperature such as those due to infiltration, erosion or cracking in the crucible, can thus be accurately localised and checked for potential hazards to the coil insulation.

**Multiple benefits**

Temperature accuracy of this method is about ± 5°C.
System benefits can be summarised thus:
- Full protection against operational breakdown due to coil damage, bodily injury, and equipment damage due to molten metal breakthrough.
- Recording and visualisation of temperature profile over the entire crucible campaign; indication of developments and trends of refractory wear or metal penetration; possibility to take action in good time to extend refractory life.
- Direct temperature measurement, not resistance based; fully operational with a vast range of refractories and immediately after relining.
- Optical measuring method, as distinct from electrical, eliminates false signals or even sensor grid damage by the magnetic field of the induction furnace.
- One single evaluator can monitor two furnaces, for

of an eight tonne furnace crucible, like the second marks on a clock face.
- Temperature measurement with an absolute accuracy of ± 5°C.
- This distributed fibre optic temperature measuring method represents a mature technology which has been giving excellent results as a central safety system in over 300 installations worldwide. (4, 5)

Indeed, the crucible monitoring system outlined above has been extensively tested and refined in the manufacture of coreless induction furnaces. OCP is highly cost effective since the sensor grid can be permanently installed in the coil levelling mix or the permanent lining. The grid may thus remain in place when the furnace is relined. In a retrofit application, a ‘lost’ sensor grid may be placed between the coil levelling mix and the crucible until the final grid is fitted permanently during the next scheduled coil overhaul.

Needless to say, the sensor grid and the associated evaluation technology are also suitable for use in channel type induction furnaces (fig. 3). Here the grid might be used to provide temperature monitoring between the inductor cooling shell and the ceramic lining. Naturally, other applications would be conceivable. The innovative fibre optic monitoring system is suitable for any industrial furnace application involving temperature measurements in the 20 to 300°C range, whether over an extended area or in a linear pattern.

**References**