Investing in the future

New melting technologies VIM - ESR - VAR



ThyssenKrupp VDM GmbH
Plettenberger Strasse 2, D-58791 Werdohl
Phone: +49 (02392) 55-0, Fax: +49 (02392) 55-2217
E-mail: info@tks-vdm.thyssenkrupp.com
www.thyssenkruppvdm.com

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The VIM process at ThyssenKrupp VDM

- Michael Sedlmeier, Production Manager VIM at the Unna works

The new vacuum induction furnace at ThyssenKrupp VDM's melting plant in Unna, type VIDP, represents an innovative, alternative furnace generation with the classic VIM technology for the production of metals and alloys in the highest possible degree of purity.

The basic engineering and the coordinated design of the sealed vacuum furnace with transfer launder were the work of ALD. The first plant of this type went into operation in 1988. Since then, the VIDP furnace type has almost completely replaced the older chamber-type design in new investment projects on the world market for vacuum induction furnaces in the 1-to-30-tonne class.

The VIM furnace is an investment in the future of our company: ThyssenKrupp VDM now has an ultramodern, extremely versatile melting unit at its disposal that guarantees superb quality for the special alloys we produce. The plant was totally customized to our production requirements and locational conditions. That means the plant combines low operating costs and high productivity. What's more, upgrading operating comfort and automation options in line with future needs will be no problem at all.

Together with its modern steelmaking plant, ESR and VAR plants, ThyssenKrupp VDM now has all the facilities needed to produce the ultra-pure alloys with the lowest possible trace element contents demanded by today's aerospace, gas turbine and petrochemical industries.

ThyssenKrupp VDM GmbH operates the world's largest VIM furnace, type VIDP, at its Unna melting plant.

Deep vacuum degassing of the liquid melt.

The advantages of ThyssenKrupp VDM's VIM concept at a glance

- All the process steps – from raw materials charging to casting the liquid metal – take place under vacuum or in a protective atmosphere. Alloys produced in this way satisfy the most exacting demands in terms of analysis precision. Gases and trace elements are practically completely removed.

- Separating valves between the charger, melting, launder and mould chambers support flexible handling and high productivity.

- Optimal control of the atmosphere above the bath surface by minimizing or eliminating undesired gases from water or hydraulic leaks, desorption from the furnace surfaces, crucible degassing, etc.

- The compact design with minimized chamber volumes provides for improved overall cost-effectiveness thanks to shorter evacuation times, reduced inert gas consumption during flooding, more efficient operation of the vacuum pumps and significantly reduced installation space requirements.

- The incorporation of the latest developments in electromagnetic stirring, inert gas flooding, automatic frequency adjustment and automated process control are further features that put the plant on the cutting edge of technology.

- The transfer launder ensures end products with a significantly higher degree of purity, thanks to more precise temperature control and optimized arrangement of the slag weirs and ceramic filters.
- The lower furnace section is mobile. This helps save time during alloy change-overs as well as relining, repair and maintenance operations. The external tilting mechanism, energy and media connections ensure easy access and reduced maintenance cost.

VIM plant – brief description
The plant consists essentially of a melting chamber, charging equipment, launder system, a mould chamber, vacuum pumping system, pouring tunnel, and diverse additional supply and control systems.

Process functions
At the process start, the VIM furnace is charged with solid or liquid material in air or with solid material under vacuum. Melting and solid recharging take place under vacuum or in a protective atmosphere.

Devices for temperature measuring and melt sampling allow the melting process to be completed quickly, cost-effectively and precisely in line with the specified alloy formula.

A three-phase electromagnetic stirring device speeds up the degassing process and provides for optimum homogenization of the melt.

Tapping can be started as soon as the chemical composition of the alloy and its temperature are exactly right.

VIM process steps
To carry out the process as planned and to achieve the specified analysis values, specific steps have to be set for the VIM furnace. The entire process sequence is remote controlled from a control room.

Evacuation/flooding
The vacuum pumping station has several mechanical pumps. As an option, oil jet pumps can be subsequently installed. The melting and casting chambers and the locks can be individually evacuated.

A porous plug in the furnace base allows quick inert gas flooding of the melting and casting chambers for process control purposes and for rapid pressure surges to counter any disturbances such as boiling of the melt.

Charging
The crucible allows both open charging and charging under vacuum.

Melting
The melting process uses the principle of induction heating.

The melting vessel, a crucible built with refractory bricks, is installed inside a cylindrical induction coil. Alternatively, prefabricated monolithic or segmented crucibles or crucibles made from sintered ramming mix can be used.

A static frequency converter connected to the 50 Hz three-phase network generates the maximum-frequency (200 Hz) single-phase alternating current required for energy supply.

Temperature measurement
Temperatures are measured by thermocouple heads which are immersed into the melt either with the aid of an automatic temperature measuring lance or with the lifting device of the charging chamber. The measured values are digitally displayed and recorded. Optical temperature measurements can also be taken using a pyrometer. In this case, the measurement results are read via a peephole.

Sampling
For sampling, the sampling mould is hung into the mount of the temperature measuring lance. The operating steps are the same as for temperature measurements and can also be carried out using the charging chamber lifting device.

Alloying
The alloying process steps are similar to those of vacuum charging but with a specially designed alloying basket which has a smaller charge volume.

Degassing
Degassing takes place on the surface, at the interface between the vacuum and the bath. The objective is to speed up the degassing process by a continuous movement on the melt surface. This is achieved through using coils with a very large diameter which ensure a large bath surface at all times.

The frequency of the MF current supply is selected with a view to optimizing the stirring effect which, in conjunction with the large liquid metal surface, makes for a high degassing rate.

The three-phase electromagnetic stirring device significantly improves bath mixing, especially during the degassing and refining phases.

Homogenizing
The bath must be stirred to ensure that it has a homogeneous temperature and all the alloying agents and additions are evenly distributed. This is achieved by the electromagnetic stirring effect of the MF current.

Tapping
The hot metal is poured into a transfer launder and it passes through a water-cooled pivot bearing on its way to the casting station which is designed for casting both ingots and electrodes. The launder is combined with a downstream tundish.

On completion of the pouring process, the launder is returned to its initial position and the tapping valve is closed. The melting and casting chambers can thus be operated independently, and a new melt can be started while the moulds are being removed from the casting chamber.

The mould chamber dimensions have been adjusted to the sizes to be cast (rounds: 330 to 980 mm, square and rectangular ingots: 1.5 t to 14 t). Such optimized chamber volumes help to speed up evacuation and keep operating costs low.

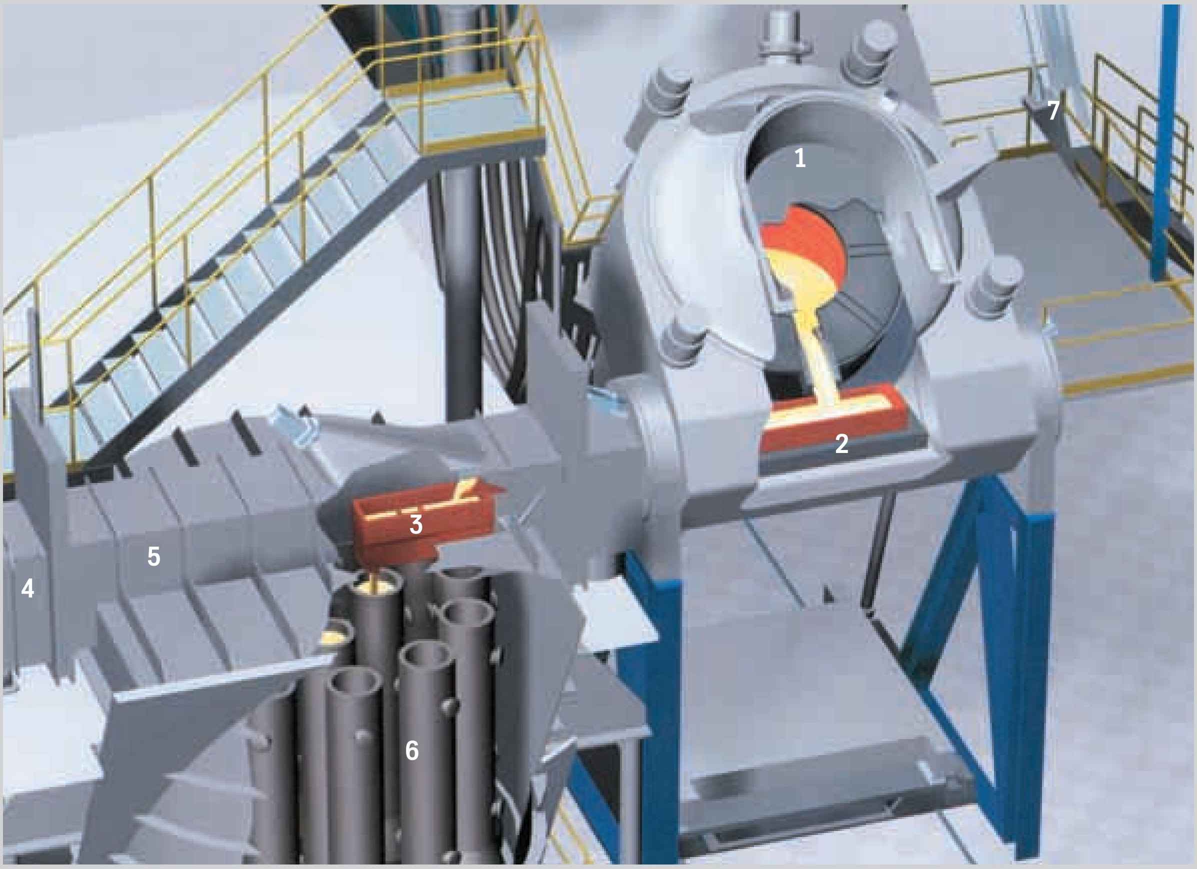
Furnace changes
The VIM concept allows quick hot furnace changes: the furnace bottom complete with coil and crucible can be replaced within less than 1 hour. With three bottom sections available in all, the plant can be optimally adjusted to capacity requirements, so output and production flexibility can be significantly increased.

Electric system/ low-voltage distribution
All plant processes are controlled and monitored via SPC.

The low-voltage distribution line feeds all the VIM plant's power consumers with the exception of the melt flow supply (MF), which is fed separately via a high-voltage

Legend

1 VIM furnace: Pouring the melt
2 Launder
3 Tundish
4 Launder lock
5 Casting chamber
6 Moulds
7 Temperature measurement Sampling



transformer directly from the high-voltage network.

Control and monitoring

All plant processes are controlled and monitored from a central, air-conditioned control stand. The control personnel communicate with the furnace operators via an interactive visualizing system.

Additional terminals with the necessary monitoring displays have been installed for specific function groups.

Process parameters and state variables of all the major plant functions are displayed in flow charts on the PC monitor. In addition, important data are documented in printouts.

Interfaces connect the furnace control system with ThyssenKrupp VDM's global process control system.

The liquid bath and the casting process are monitored with the aid of special furnace-proof video cameras and separate monitors. In addition, peepholes are provided at all relevant points.

Typical VIM alloys, markets and products

Precipitation-hardening nickel-base alloys	Aerospace Power Engineering Automotive Oil and Gas	Turbine components Engine and exhaust components
Soft-magnetic alloys	Electronics	Magnetic cores
Martensit-hardening steels	Aerospace	Car body components
Cobalt-base alloys	Aerospace Power Engineering	Turbine components

Cooling water

The VIM plant's internal cooling water system is subdivided into three sections: power supply, furnace coil, and plant components.

The cooling water system forms a closed circuit with heat exchangers, recirculation pumps, and a compensation tank.

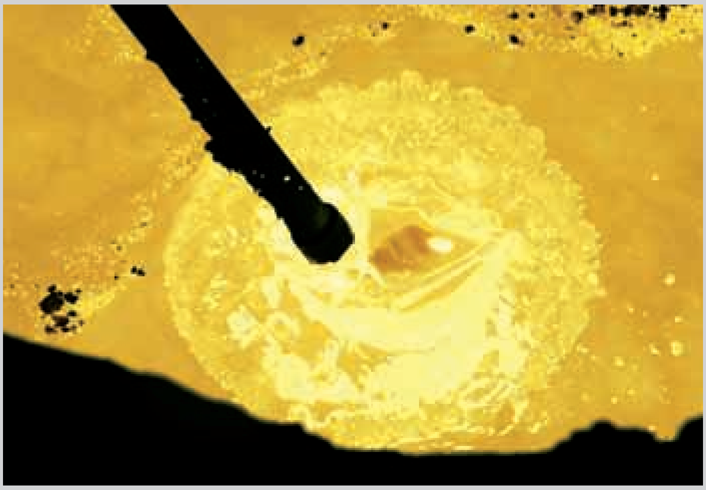
Any cooling water shortage or overtemperature in the coil circuit triggers an optical and acoustic signal, and the melt flow is automatically cut off. An emergency cooling system has been integrated into the plant.

Transformer for electrical stirring (10 MVA).

Technical Data

Melting and pouring capacity	
Maximum melting temperature	max 1,750°C
Heat weight	16 to 30 t
Capacity of the crane	100/35/8 t
Furnace pressure	0.001 to 1,000 mbar
Dimension of the VIM plant	
Length	abt. 30.0 m
Width	abt. 28.0 m
Height	abt. 12.0 m
Dimension of the 20 t furnace	
Inside diameter of the furnace	1.397 m
Inside diameter of the electric coil	1.778 m
Height of the melt	1.750 m
Freeboard	0.650 m
Capacity	16 to 20 t
Electrical datas	
Melting power	
Electric power of the transformer	7,000 kVA
Electric power of the frequency inverter	5,000 kW
Transformer for electrical stirring	
Electric powr of the transformer	max 10,000 kVA
Evacuation time	
for melting, casting	
and charging chamber	< 10, 22 and 3 min
Volume of the chamber	20, 120 and 10 Nm^3
Ingots	
Electrodes	
Diameter	330 to 980 mm
Length	max 4,500 mm
Weight of the ingots	2,9 to 20 t
Square/rectangular ingots	1,5 to 14 t

Temperature measurement under vacuum.



Bottom:
Pouring the melt from the furnace into the launder.

Re-melting Processes ESR and VAR in comparison

- by Eike Schmilinsky, Production Manager of ESR/VAR at the Unna works

ESR-specific process parameters ESR – Electro Slag Re-melting	VAR-specific process parameters VAR - Vacuum-Arc-Re-melting

Common features

In brief

A self-consuming electrode of the ingot or continuous casting is re-melted in a water-cooled copper mould.
After the manual starting phase the re-melting takes place fully automatically.
ESR and VAR provide very good reproducible characteristics for demanding alloy applications.

ESR	VAR
At normal pressure (under protective gas) metal trickle will be purified when passing through the liquid slag.	Metal trickle will be degassed in vacuum (0.005 mbar). The melt will be purified by flotation.

Aim

Homogeneous, poor in segregation, dense re-melting ingot with increased purity and uniform good technological characteristics in longitudinal direction and across

ESR	VAR
as well as a good (smooth) surface. Purification process: Metal purification through slag reactions, physical floating and separation of oxides and nitrides in the active slag.	as well as with lowest gas concentrations (nitrogen, hydrogen). Purification process: Metal purification by degassing, flotation and displacement to the edge of the ingot.

Input Material

Electrodes from the new Unna VIM furnace,
ground base of ingot.

ESR	VAR
Unworked ingot with water-covered or burnt top or continuous cast slab.	Metallic bright ingot (ground surface, sawn top).
Electricity supply: alternating current Protective gas atmosphere: nitrogen and/or Argon under normal pressure	Electricity supply: direct current Protective gas atmosphere: for special alloys = nitrogen or Argon as top gas = reduced loss e. g. of Manganese

Melting Crucible

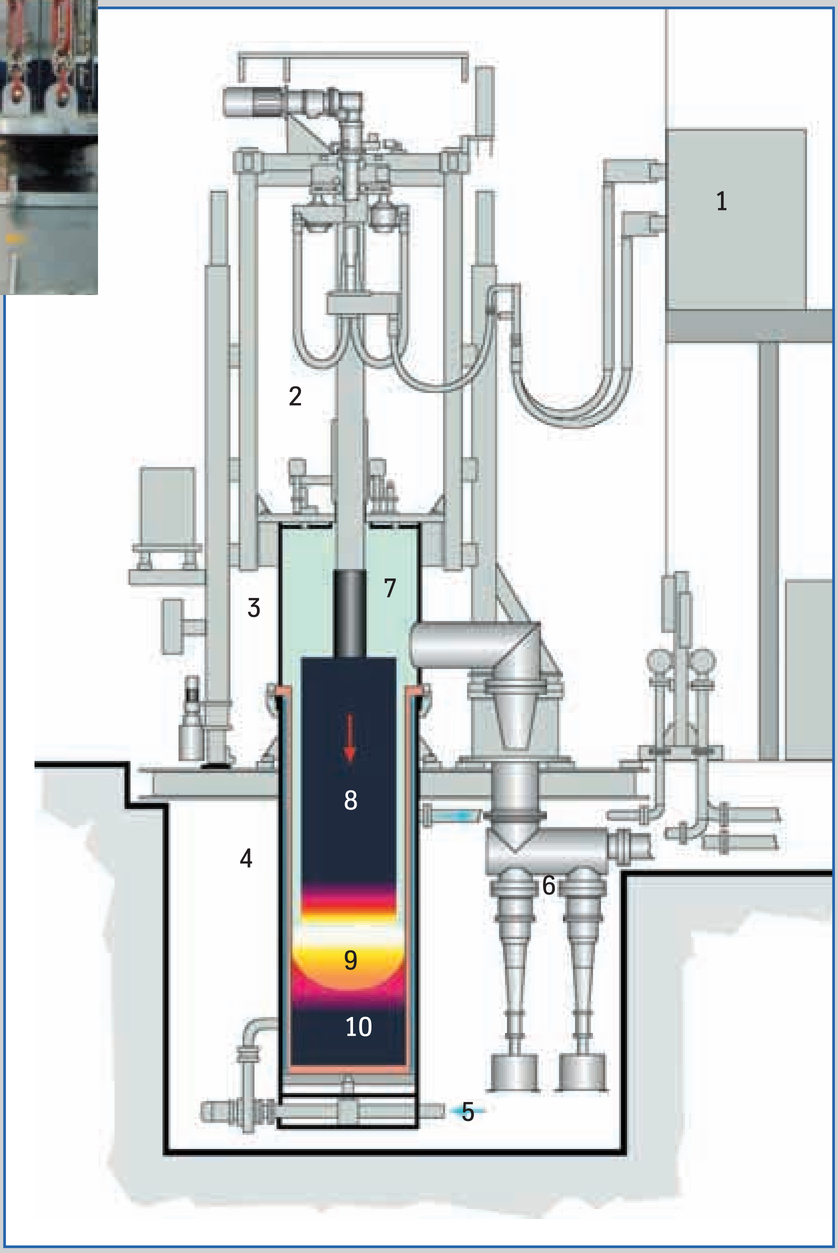
Copper moulds with screwed on base plate of copper

ESR	VAR
422 mm dia to 1,024 mm dia (3,150 mm long) 320 mm x 1,200 mm and 3,750 mm long 320 mm x 900 mm and 3,400 mm long	400 mm dia to 1,000 mm dia (approx. 3,000 mm long) 1,000 mm dia and 3,800 mm long

The new VAR-unit in the Unna melting shop is designed for ingot sizes up to 1,300 mm.

Explanation of VAR diagram below

1 Electricity supply (direct current)
2 Electrode bar (with gas-tight lead-in, in 3)
3 Furnace shell
4 Water-cooled upright mould
5 Cooling water feed
6 Oil diffusion pump (altogether 7 different vacuum pumps)
7 Stub (hitched to 2), welded to electrode and re-usable
8 Electrode
9 Liquid metal sump
10 Solidified finished ingot



Diffusion pump for maintaining the operative vacuum from 10^{-3} to 10^{-4} mbar.

ESR-specific process parameters

Heat source and input pattern:
The liquid slag (mixture of lime, alumina, fluorite) has a high ohmic resistance thus achieving a temperature exceeding the alloy's melting point. The tip of the electrode heats up and metal trickle will be released which, passing through the slag, reach the liquid sump.

Weight of finished ingots:

from 422 mm dia mould	→ abt.	2.5 tonnes
from 565 mm dia mould	→ abt.	4.4 tonnes
from 794 mm dia mould	→ abt.	7.3 tonnes
from 1,024 mm dia mould	→ abt.	14.3 tonnes
from 320 mm x 1.200 mm mould	→ abt.	6.4 tonnes
from 320 mm x 930 mm mould	→ abt.	6 tonnes

VAR-specific process parameters

Heat source and input pattern:
An arc burns in the vacuum which heats the front end of the electrode forming droplets which in contact with the liquid sump break up (short circuit).

Weight of finished ingots:

from 400 mm dia mould	→ abt.	2.0 tonnes
from 490 mm dia mould	→ abt.	3.3 tonnes
from 650 mm dia mould	→ abt.	4.4 tonnes
from 870 mm dia mould	→ abt.	11 tonnes
from 1,000 mm dia mould	→ abt.	11,5 tonnes

Examples of Alloys for Production

Typical ESR-alloys		Typical VAR-alloys
Nicrofer 4722 Co - alloy X	Strip	Cronifer 1525 Ti
Nicrofer 5120 CoTi - alloy C-263	Sheet and Plate	Nicrofer 5120 CoTi - alloy C-263
Nicrofer 5219 Nb - alloy 718	Bars/Forgets	Nicrofer 4412 - alloy 901
NiCr2MnSi	Wire	Pernifer 50 - alloy 52

Further processing (ESR):
Direct use in the rolling mill or forging press.

Further processing (VAR):
Oxide layer of ingot has to be removed before hot forming.

Triple Melt Process

Production route for alloys with highest purity combining the advantages of both processes.
Optimum process route: VIM → ESR → VAR, i.e., an ESR ingot serves as electrode in VAR.

Goals

Further improvement of product quality, economics and reproducibility.
Opening new markets in the field of stationary respectively rotating gas turbines.
Certification of new (for VDM) production routes VIM → ESU and/or VAR.

Advantages

Controlled progressive solidification, inert (oxygen-free) atmosphere and mould, minimum segregation, increased density.

ESR:

- By melting under protective gas tighter analyses tolerances
- Refinement through metallurgically active slag with an elevated thermic inertia
- No loss by evaporation
- High flexibility of processes and operations (different slags and sizes)
- Excellent macro-purity, good micro-purity
- Very good ingot surface and high yield

VAR:

- Lowest gas concentration (nitrogen, hydrogen), impurities and trace elements (e.g. lead)
- Constant composition over the length
- No slag
- Inert heat source (arc) without influence on ingot analysis
- Compositional limits with extremely tight tolerances
- Good macro-purity, excellent micro-purity
- Very small melts possible

Disadvantages (ESR):

- Analysis tolerance between bottom and top of finished ingot (through reaction with slag)
- Limited melt size (risk of freezing slag)
- No degassing – problem with hydrogen
- Partial loss of reactive elements

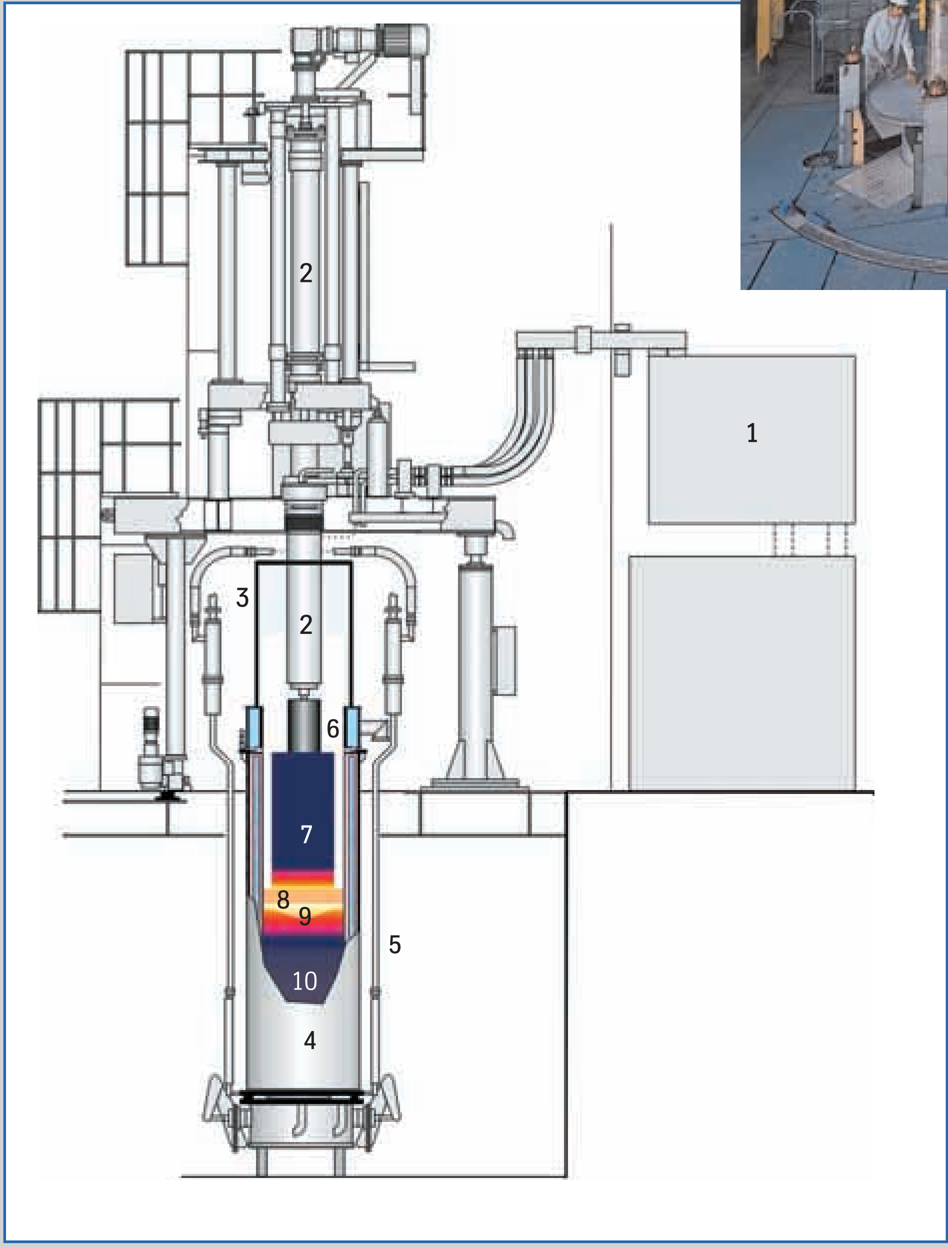
Disadvantages (VAR):

- Turning of electrode and finished ingot → low yield → relatively low productivity
- Loss through evaporation e.g. Manganese
- Low thermic inertia

New 20 tonne ESR-unit in the Unna melting shop. Upright mould with furnace lid enabling re-melting in protective gas atmosphere.

Explanation of ESR diagram below

1 Electricity supply (alternative current)
2 Electrode bar (with gas-tight lead-in, in 3)
3 Furnace shell (filled with Argon and/or nitrogen)
4 Water cooled upright mould
5 Coaxial, i.e. almost symmetrical current feedback (4 stilts round the furnace)
6 Stub (hitched to 2) welded to electrode and re-usable
7 Electrode
8 Liquid slag (abt. 110 to 130 mm high)
9 Liquid metal sump
10 Solidified finished ingot



Below:
The first ESR rectangular ingot from Unna. At the top of the ingot one can see the solidified cake of cinder.