DIN EN ISO 50001 – Opportunities for the international forging industry

by **Dirk M. Schibisch, Loïc de Vathaire**

The much cited "Energiewende" has ambitious goals: as well as reducing greenhouse gas emissions by 80 % compared to 1990, the aim is to provide more than 80 % of Germany's electricity from renewable energy sources by 2050. One of the measures taken to finance the energy transition was the passing of the German Renewable Energy Act (EEG), which aims to spread the costs of distributing electricity generated from renewable sources to end users by means of the EEG reallocation charge. Manufacturing industries certified to DIN EN ISO 50001 with high energy consumption rates have the opportunity of reducing their electricity costs in order to maintain their international competitiveness. Measures to ensure sustainable growth in energy efficiency are crucial for the certification process and lowering energy consumption. The aim of this article is to highlight examples of this potential, which is of particular interest for energy-intensive businesses in the forging industry.

With the 2012 amendment and related fact sheets from the Federal Office of Economics and Export Control (BAFA), the Renewable Energy Act allows for special equalization scheme measures for energy-intensive businesses. Manufacturing industries with an energy consumption level of more than 1 GWh/yr and annual electricity costs of at least 14 % of the gross value added can apply to have the amount of the EEG surcharge limited to 90 % of the electricity portion of the EEG surcharge or more. One condition is that certification to EN ISO 50001 applies for cases where there is an energy consumption level of more than 10 GWh/yr [1].

DIN EN ISO 50001 describes management system standards with the aim of achieving a continual improvement in energy performance and focuses on the processes within the organization. The aim is to reduce greenhouse gas emissions and other environmental impacts as well as to lower energy costs. At a higher level, the application of this standard worldwide contributes towards more efficient utilization of available energy sources as well as improved competitiveness. [2, pp. 54ff].

Essentially, the crux of this standard is to bring about an improvement in energy efficiency, defined in DIN EN ISO 50001 as the relationship between achieved performance and energy used, i.e., energy consumption. [2, p. 57].

DIN EN ISO 50001 provides a summarised description of energy management systems aimed at promoting energy efficiency as an awareness of social responsibility, reducing energy costs and achieving financial benefits by complying with statutory requirements.

The standard deals with all forms of energy, including natural gas, water and compressed air. However, this article focuses exclusively on electrical energy, the primary form of energy used in induction technology.

First, definitions are provided for relevant terms, followed by an illustration of the opportunities to bring about lasting improvements in energy efficiency and thus lower energy costs and reduced emissions by optimizing the design of induction plants.

The apparent power or connected load indicates the electric power being fed in or to be fed in to an electrical consumer. The apparent power S is taken from RMS values of the electrical current intensity I and voltage U, and is made up of the actual applied active power P and an additional reactive power Q_{tot} [3].

$$S = U \cdot I = \sqrt{P^2 + Q_{tot}^2}$$

It is not just the active power that energy-intensive businesses, in particular – such as those in the forging industry –

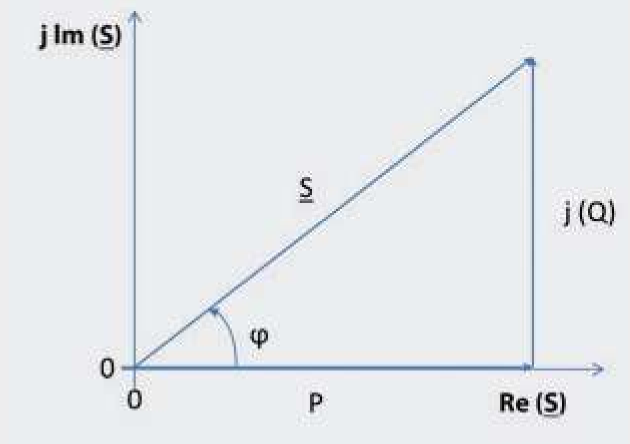

Fig. 1: Correlation between active power (P), reactive power (Q), apparent power (S) and phase angle (φ)

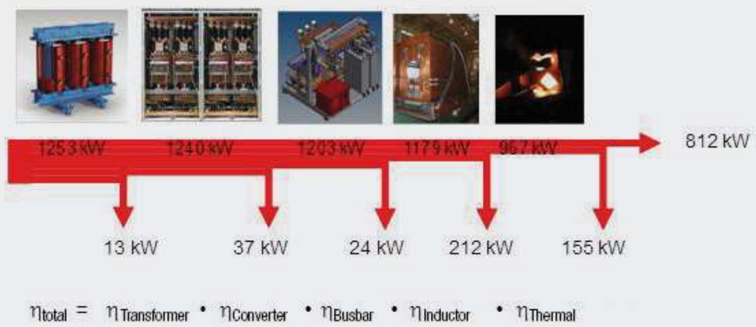

Fig. 2: Grid energy consumption; example: throughput: 3,500 kg/h, network consumption: 358 kWh/t, workpiece temperature: 1,250 °C

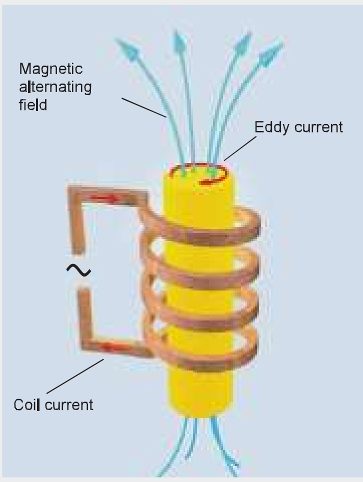

Fig. 3: Induction heating of forging blanks using a copper coil

are interested in, but the reactive power which is generated when the current and voltage are not in phase with each other. Alternatively, the portion of active power is shown over the phase angle or its cosine (cos φ) and is also called the power factor. The following rule of thumb applies: a power factor cos φ of 0.9 roughly corresponds to the statement "reactive power = 50 % of the active power" (**Fig. 1**).

Active power P is taken from the supply network, if the voltage and current have the same sign, and fed back into this same supply network as a function of the working point of the electrical consumer, either fully or in part, as reactive power Q when the signs are opposing. To counteract the reactive power-related additional losses in the network supply, larger wire sizes are required in the supply lines as well as larger generators and transformers. Large-scale industrial electrical consumers have to pay for the reactive energy they use as well as the active energy they use [4]. Therefore it is in the interest of those energy-intensive businesses to limit the reactive power as far as possible, if not eliminate it completely. To limit this, reactive power compensation systems are used, however these, in turn, have a negative impact on the energy balance.

A better option here is working point-independent optimisation of the consumer power factor cos φ to a constant value close to 1 (barely any reactive power), by choosing suitable circuit topologies and thereby achieving a lasting increase in energy efficiency, which is explained in greater detail below.

IMPACT OF DIN ISO 50001 ON THE FORGING INDUSTRY

The forging industry is one of Germany's most energy-intensive sectors. It is for this reason that it is closely following the trends associated with the energy transition which is marked, among other things, by rapid price hikes, higher network charges, increasing levies and above all great uncertainty with regard to the general situation in future.

Despite the competitive advantages modern forging businesses have in terms of quality, innovation and precision, the proportion of energy costs relative to the added value is becoming hugely significant. To ensure long-term survival in today's world of rising energy costs, every plant owner would be well advised to control and optimise his energy costs.

Although induction heating plants are particularly energy-efficient compared to other technologies due to the way they operate, they continue to account for the majority of the energy costs incurred. Therefore plant owners want to ensure that their plants are making the best use of the energy fed in. In practical terms the following questions often arise:

- What definition of energy efficiency applies to the specific production framework?
- What influence does the production range have on energy consumption and what opportunities does an optimum production strategy offer?

The definition of the energy efficiency and operating efficiency of induction heating plants is analysed in detail below.

We will also look at the overall efficiency of a heating plant and its auxiliary units to show how important choosing the correct measuring point is. **Fig. 2** clearly shows that various measuring points necessarily result in entirely different energy consumption levels being recorded. The actual measurement itself is performed using standard energy meters, which were either already installed in the induction plant by the manufacturer or fitted subsequently.

An induction-related energy audit takes into account the overall production situation, identifying the optimum machine setup and providing information on the best production sequence – from an energy point of view – for the various material dimensions. The values provided by the energy meter installed are evaluated as a basis for this. The induction-related energy audit also examines the design of the induction plant and the components that have a lasting influence on energy consumption. The next point gives a detailed insight into some of these influencing factors.

INDUCTION HEATING OF FORGING BLANKS

Generally speaking, the industrial application of DIN EN ISO 50001 is primarily about lowering energy consumption overall, reducing the reactive power and increasing the overall efficiency of a production plant, e.g., a plant used for the induction heating of billets or bars upstream of forging units. In order subsequently to better evaluate the individual energy drivers or energy efficiency drivers, one needs to take a brief look here at the principles involved.

With induction heating upstream of forging units, the metal blank (bar, billet or block) is exposed in a non-contact manner to an electromagnetic field generated by a coil (**Fig. 3**). The operating frequency determines the depth of current penetration. Eddy currents are thereby induced in the material and heat is generated. All this happens directly in the blank itself, therefore it does not need to be heated up in a conventional furnace using heat radiation. As a result, heating times are particularly short and the temperature can be very precisely adjusted.

The overall efficiency of an induction heating plant is the product of the individual efficiency levels of the various single components, namely the medium-voltage transformer, frequency converter, bus bars and inductor (also called the "coil"), as well as the thermal degree of efficiency.

The individual efficiencies are not equal here. Rather, there are components where an improvement has a significantly positive influence on the overall efficiency. Whereas the medium-voltage transformer, for example, has a high operating efficiency of around 99 %, the induction coil – with an individual operating efficiency of close to 75 % – has a considerable impact on the overall efficiency.

The example given in Fig. 2 shows a real situation in a forge shop: Of the 1,253 kW grid energy consumption only 812 kW are provided for heating a workpiece to 1,250 °C, corresponding to an overall efficiency of just under 65 %. The energy losses of the individual components of the heating plants total 441 kW, of which the inductor makes up for a good 200 kW of power loss. It is worth taking a close look at this, in order to identify the factors which have a positive effect on the overall result.

The induction coil

The following, therefore, deals with the copper induction coil in more detail. The following energy efficiency formula clearly shows the correlation between the internal diameter of coil D and the diameter of the material to be heated d. The smaller the difference between the coil diameter D and heating material diameter d, the greater the energy efficiency.

$$\eta_{electrical} = \frac{P_i}{P_i + P_{Cu}} = \frac{1}{1 + \frac{D}{d} \cdot \frac{l}{h} \cdot \sqrt{\frac{\varrho_{Cu}}{\varphi_r \cdot \varrho \cdot f_{Cu}}} \cdot \frac{1}{m}}$$

P_i power induced in the workpiece
P_{Cu} coil current heat losses
d workpiece diameter
D coil internal diameter (D<<l)
l coil length
h height of cyl. insert
f_{Cu} copper fill factor of coil
ρ_{Cu} spec. elec. resistance of inductor
ρ spec. elec. resistance of material
μ_r permeability

What now becomes interesting is the influence of the electromagnetic penetration depth. According to Lenz's law, the eddy current builds up a field which opposes the inductor current. The overlay of both fields results in a diminishing of the magnetic field in a radial direction inwards. The associated current intensity also drops. The depth at which the current intensity has fallen to 37 % of its maximum value is known as the penetration depth. [5]

$$\delta = \sqrt{\frac{\rho}{\pi \cdot f \cdot \mu_r}}$$

ρ spec. elec. resistance of material
μ_r permeability
f frequency

The formula shows that the penetration depth depends substantially on the frequency of the induced current. As the frequency increases the current penetration depth is reduced. In the case of heating operations where optimum through heating of the entire material cross-section is required, a low frequency should be chosen. As shown

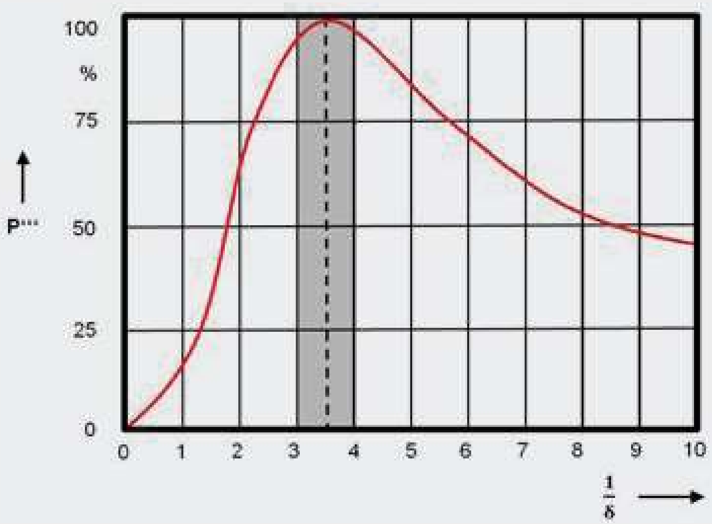

Fig. 4: Induced volume power density P''' as a function of the ratio 1/δ at a constant frequency and variation of the workpiece diameter [6]

Fig. 5: Varied heating/through heating at constant frequency and material parameters as a function of the workpiece geometry [7]

in **Fig. 4**, very rapid, homogeneous temperature distribution is achieved over the cross-section when the cylindrical workpiece diameter is around 3.5 times greater than the penetration depth. These conditions are the result of a trade-off between direct, consistent heating over the cross-section with a correspondingly low frequency and increasing energy efficiency at high frequency [6].

Impressive evidence of this elementary connection was demonstrated in trials performed decades ago. Here cylinders of different sizes were introduced into a coil. With the varying colouration it is easy to see that both excessively small and excessively large diameters do not produce optimum through heating. Interestingly, this effect by far overrides the influence of the position of the material being heated within the coil. That is to say, although the optimum diameter, **Fig. 5** bottom left, is not centred in the middle of the coil, it nevertheless produces the best result in terms of through heating.

Ideally, this would result in the induction coil being perfectly matched to each material diameter. However since this is neither a practical nor cost-effective option for most applications, the forging shop product spectrum needs to be analysed precisely and grouped into reasonably practicable diameter ranges. The design of the coil, therefore, always represents a compromise between perfect matching and a high degree of flexibility [8].

The copper material

In addition to the operating frequency and coupling distance, i.e. the ratio of coil and workpiece diameter, another efficiency driver is the material quality of the coil.

As can be clearly seen in the formula for the electrical efficiency, this also depends on the material properties of the inductor. The specific electrical resistance of the inductor ρ_{Cu} made from copper varies depending on the quality of the ultra-pure electrolytic copper.

Table 1 shows the key difference for the two copper grades used regularly in electrotechnical components. Essentially both grades differ in terms of the copper content and machinability, which is particularly important for the manufacturers of coils made from this material.

Coils made from Cu-DHP and Cu-HCP do not differ from a purely external point of view. Overall, however, Cu-DHP can be more easily worked, both mechanically and with regard to welding and soldering. Therefore some coil manufacturers choose this material grade with a slightly less copper content.

However if one compares the specific electrical resistance ρ_{Cu} of both these copper grades, it can be seen that the Cu-HCP material with the higher copper content of > 99.95 % shows a lower value. Over the temperature trajectory too, which is of particular interest for copper coils when used as an induction tool, the specific electrical resistance ρ_{Cu} of Cu-HCP is around 30 % below that of Cu-DHP at every temperature point. Hence fewer losses are incurred when using higher-grade material, such that the electrical resistance is correspondingly higher. For induction coil manufacturers, the use of the Cu-HCP material does mean higher material costs on the one hand, with more labour-intensive working due to the inferior material properties on the other hand, however for users in the forging shop, the energy-efficient properties of the higher-grade Cu-HCP

Table 1: Comparison between Cu-DHP and Cu-HCP [7]

	Cu-DHP	Cu-HCP
Full description	Deoxidized High Residual Phosphorus	High Conductivity Phosphorus
Material no.	CW024A	CW021A
Proportion of copper	> 99.9 %	> 99.95 %
Weldability and solderability	Very good	Good
Machinability	Very good	Good
Energy efficiency	Good	Very good

represent an interesting option for saving energy due to the considerably lower specific resistance (**Fig. 6**).

The converter technology

In the example given in Fig. 2, the operating efficiency of the converter is the third biggest influencing factor – after the inductor and thermal efficiency – that is influenced substantially by the duration of the heating process and thus by the length of the heating zone.

As shown in the example, the newly developed generation of converters with a converter efficiency level of 0.97 % and with an L-LC oscillating circuit is already in use. To some extent conventional converter topologies have far lower efficiency levels. L-LC denotes the wiring at the output of the inverter. With an uncontrolled rectifier, intermediate circuit capacitor, IGBT inverter and output choke, this converter features a constant cos φ of > 0.95 within all partial load ranges. [9]

The L-LC circuit features two points of resonance: one with parallel and one with series resonance. Depending on the desired circuit properties and application, both may be used. To control the inverter, special algorithms have to be used to find the desired point of resonance (parallel or serial) and clearly establish the working point. For this the L-LC circuit has the advantage that both the frequency and power can be controlled via the inverter. [10]

Using the L-LC converter topology as a basis, SMS Elotherm has further developed the iZone™ intelligent zone control system with high efficiency levels and improved energy efficiency.

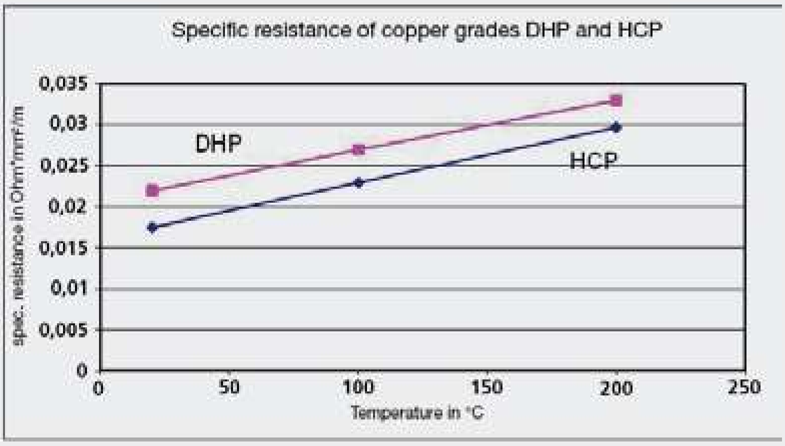

Fig. 6: Specific resistance of DHP and HCP-copper as a function of the temperature [7]

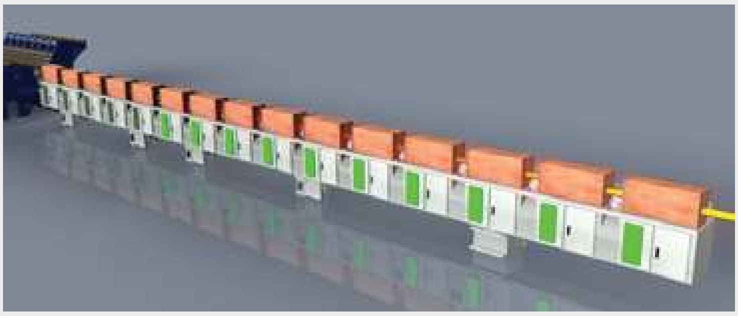

Fig. 7 [9]: Part throughput rates: Manufacturing operation (green bar = inductor energized, the first 5 coils remain de-energized); Bar diameter 300 mm, selected part throughput: 6 t/h; Nominal throughput: 9 t/h; Energy savings with iZone™ compared to a conventional solution: approx. 20 %

Table 2: Bar diameter / tonnage

Bar diameter (mm)	Tonnage/year
25	620
28	3.150
32	850
> 32	150
Total	4.770

Table 3: Bar diameter / grid consumption

Bar diameter (mm)	Grid consumption (kWh/t)
25	515
28	430
32	370
36	361
40	353

Table 4: Grid consumption according to different bar diameters

Bar diameter (mm)	Grid consumption with inductor for bars ø 28 mm (kWh/t)	Grid consumption with inductor for bars ø 32 mm (kWh/t)
25	369	376
28	361	367
32	(not possible)	358

Table 5: Two optimisation strategies for the production

	Optimisation strategy 1: Production with 2 sets of inductors	Optimisation strategy 2: Production with 3 sets of inductors
Required induction coil sets	Set 1: Existing set for diameters > 32 mm Set 2: New induction coil for the 25 to 32 mm range	Set 1: Existing set for diameters > 32 mm Set 2: New induction coils for 32 mm Set 3: New induction coils for the 25 to 28 mm range
Potential energy cost savings	approx. 294 MWh/year	approx. 318 MWh/year
Average industry electricity price 2012/kWh (incl. taxes)	€ 0,14	€ 0,14
Potential energy cost savings	41.160 €/year	44.520 €/year
Set-up costs	Low	High

Throughput-related plant design

In terms of compliance with the requirements of DIN EN ISO 50001, the possibility of flexible adjustment of the heating plant in line with the various part throughput levels offered with the innovative L-LC converter topology and the iZone™ technology should be highlighted here.

Using the data input by the operator, the iZone™ control system makes a direct, online calculation of the best heating strategy with resource-efficient energy consumption. In the case of bars with a diameter of 300 mm and a part throughput rate of 6 t/h, energy savings of around 20 % compared to conventional solutions can be achieved (**Fig. 7**) [9].

RESULT OF AN INDUCTION AUDIT

Below is a specific example of how a sustainable reduction in grid consumption – and thus increased energy efficiency – can be achieved with the optimal design of an induction heating plant.

In the example shown, a forge shop has an induction heating plant with a nominal power of 1,500 kW in use upstream of a horizontal multi-stage press. Bars within the 25 to 40 mm diameter range are heated to 1,250 °C over a section comprising five induction coils. The existing inductors are used for the entire product range.

The particular benefits of such flexible induction coils are immediately visible, as the inductors do not require changing. The following data was gathered in the induction-related audit: The bar diameter in a ratio to the tonnage per year (**Table 2**) as well as the bar diameter in a ratio to the grid consumption (**Table 3**).

This data clearly shows that the grid consumption increases substantially if the coil diameter and material diameter are no longer ideally coordinated.

Given the annual tonnage, optimised heating of the type 28 bars, in particular, is desirable. The calculation of the induction coil designed for a 28 mm and 32 mm diameter shows that the grid consumption is as in **Table 4**. This results in two optimisation strategies in which the energy cost savings and the set-up costs may vary: the production can be optimised with two or three sets of inductors (**Table 5**). In this example optimisation strategy 1 proves to be the optimal result of the induction-related audit.

More than € 40,000 can be saved every year with just one additional set of induction coils. The additional investment in a further set of coils would increase the savings made by just around 10 %, therefore in terms of the additional set-up costs and the average investment costs it would not be cost-effective. Since bars in the > 32 mm diameter range make up just a small proportion of the annual output (~ 3 %), they should be produced wherever possible using intelligent production schemes, to keep changeovers to a different set of coils to a minimum.

As far as the aims of DIN ISO 50001 are concerned, this result – in real terms – means savings of around 166 t CO_2 per year. The conversion factor of 1 KWh electricity to 0.566 kg CO_2, published by the German Environment Agency for 2011, forms the basis for this figure. [11]

CONCLUSION

The subject of DIN ISO 50001 is, for a variety of reasons, gaining a lot of attention at the moment. As well as increasing awareness of energy efficiency as an aspect of social responsibility and complying with legal requirements, the aim in the industrial sector is to gain financial benefits to increase one's own competitiveness by reducing energy costs and adhering to specific key figures.

This article has dealt primarily with those aspects of economic interest relating to the reduction in energy consumption and the improvement in the overall efficiency and power factor of an induction heating plant. For these electroheat plants in particular, manufacturers have a variety of possibilities on offer for increasing part efficiency levels through intelligent plant design.

In addition, the specific calculation given above shows that long-term energy cost savings can be made by optimising just one partial aspect, in this case the coordinated coil set, and that significant success can be achieved with regard to a reduction in emissions. All of which also takes into account the economic framework parameters to help ensure that competitiveness is improved by implementing such measures.

In the short term, energy efficiency audits can be used to work out and implement practical solutions which directly improve the energy efficiency of individual induction heating plants upstream of forming equipment and thereby bring about an immediate reduction in energy consumption.

Over the long term the costs of implementing a DIN ISO 50001 energy management system are worthwhile, given the continual increase in the energy efficiency of the company overall.

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IZONE™ - INTELLIGENT ZONE CONTROL OF FORGE HEATING PLANTS

The overall concept of this heating system is based on the further development of the zone technology which has been in use since the early 1990s and known today as iZone™. iZone™ was developed by SMS Elotherm for the process control of modern induction heating plants. Long-term optimisation of the process results can be achieved in conjunction with an integrated computer system. With the dynamic energy management system, single heating coils or groups of them can be controlled individually, resulting in much lower consumption rates and thereby fully meeting current requirements with regard to long-term energy savings.

Benefits of this innovative technology:

- Implemented heating strategies
- Interactive process optimisation
- Setting of individual heating curves
- Control of individual inverters
- Intuitive user guidance
- Integrated expert system
- Holding mode with identical coils / reversing mode
- Fast run-in for start-up
- Calculation and setting of optimum heating section
- Scale minimization program
- Intelligent energy management
- Iterative job control
- Automatic de-activation of coils
- Optimised energy consumption
- Extensive data backup
- Formula and process data administration

The database-supported expert system automatically calculates the parameters required for the heating process, always aiming at the highest level of energy efficiency and the greatest possible reduction in scale. The resulting process parameters are then transferred directly into the plant system.

The graphics function integrated into iZone™ is another tool used to safeguard the process.

Using the heating curves individually generated by the operator, the system automatically calculates the process parameters and transfers these directly into the machine control system.

Production can then be started straight away at the push of a button. Standard optimisation variants are already integrated.

Another advantage is the running of bars with residual heat. Up until now one had to wait until the bars had cooled down to room temperature. The heating system featuring iZone™ technology enables the bars which are still warm to be re-heated even before cooling down to room temperature. For this the bars are automatically transferred back to the induction heating system and the amount of energy required for through heating is calculated and applied. In terms of energy efficiency, this means that not only is the heat already introduced not wasted, but the plant adjusts flexibly to the quantity of heat remaining and only applies the energy required to ensure the optimum forming temperature.

SMS Elotherm uses this pioneering control system in both billet and bar heating plants and in large-scale quench and temper lines, that is the heat treatment lines for long products.