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Induction Billet Heaters with Enthalpy Controlled Zone Heating

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Abstract

This paper describes the advantages of induction billet heaters with enthalpy controlled zone heating where each coil is fed by one separately controlled power supply, in contrast to conventional induction billet heaters where all coils are powered by a single power supply. In order to apply these advantages in practice, a control method is required which enables a target-oriented override of the temperature profile. The temperature distribution in the billets at the outlet of the heater line can then be adapted to different requirements with regard to temperature uniformity, scaling rate and energy consumption.

Introduction

In the forging industry is advantageous to achieve a homogeneous billet temperature at the outlet of the heater with the shortest possible coil line installation length while at the same time minimizing the scaling rate and energy consumption. These objectives should be obtained not only for the nominal billet diameter and throughput but also for smaller billets and throughputs. Since these requirements are partly in conflict the solution generally involves reaching a compromise.

1. Comparison of the different basic designs

In principle there are three basic designs for billet heaters:

- linear heater
- non-linear heater
- enthalpy controlled zone heater.

The advantages and disadvantages of these approaches will be explained by an typical installation consisting of four coils each, all 1500mm long, designed for 100mm nominal billet diameter and nominal throughput of 5000kg/h.

1.1. Linear Heating

Linear heating is the oldest and simplest method. It is characterized by coils with an equal number of windings which are connected to a single power supply. Therefore the frequencies and the voltages of the coils are equal so that only due to the ferromagnetic properties of the billets the power of the first coil is higher than that of the others. The energy consumption is comparatively small due to the low surface temperature during the heating process, but the temperature uniformity in radial as well as in axial direction is not completely satisfactory for this installation length, as can be seen in Fig. 1.

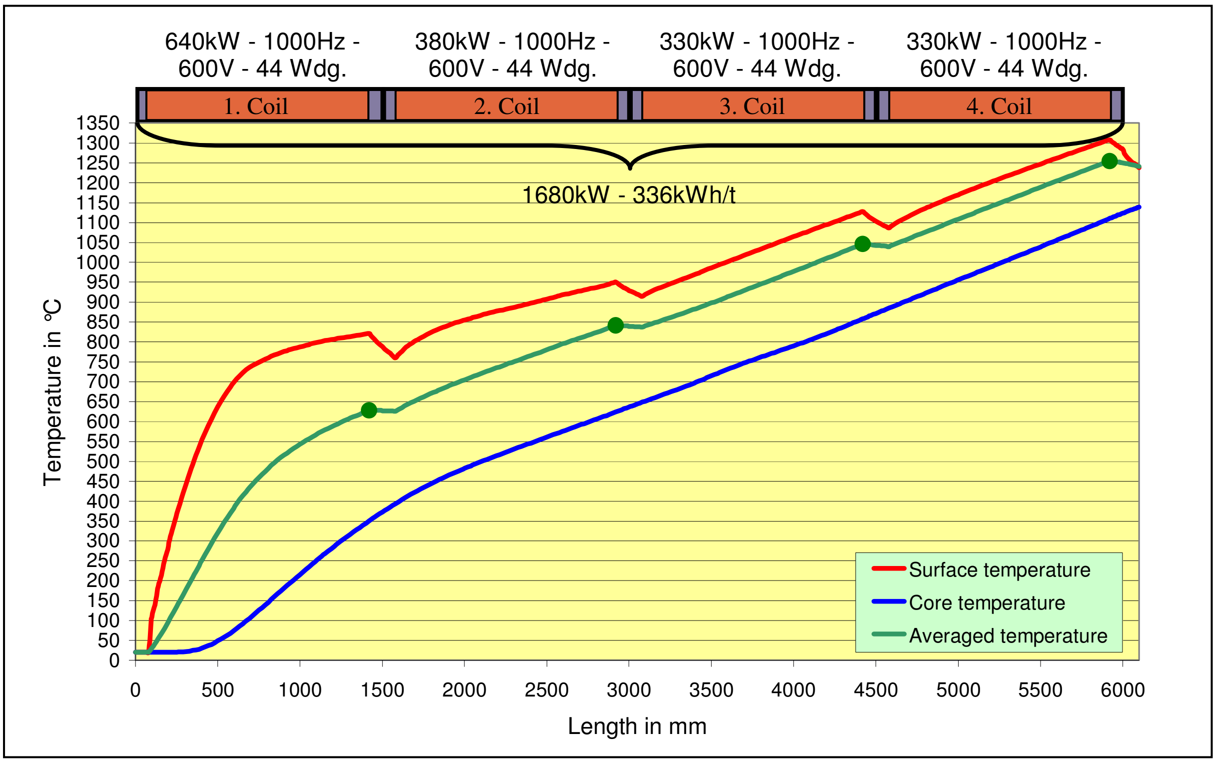

Fig. 1. Typical temperature profile of linear heating at 100% throughput

1.2. Non-Linear Heating

The temperature uniformity within the billets at the outlet of the heater can be improved by increasing the temperatures at the outlet of each coil by increasing the power of the first and decreasing the power of the last coils in an appropriate manner as shown in Fig. 2.

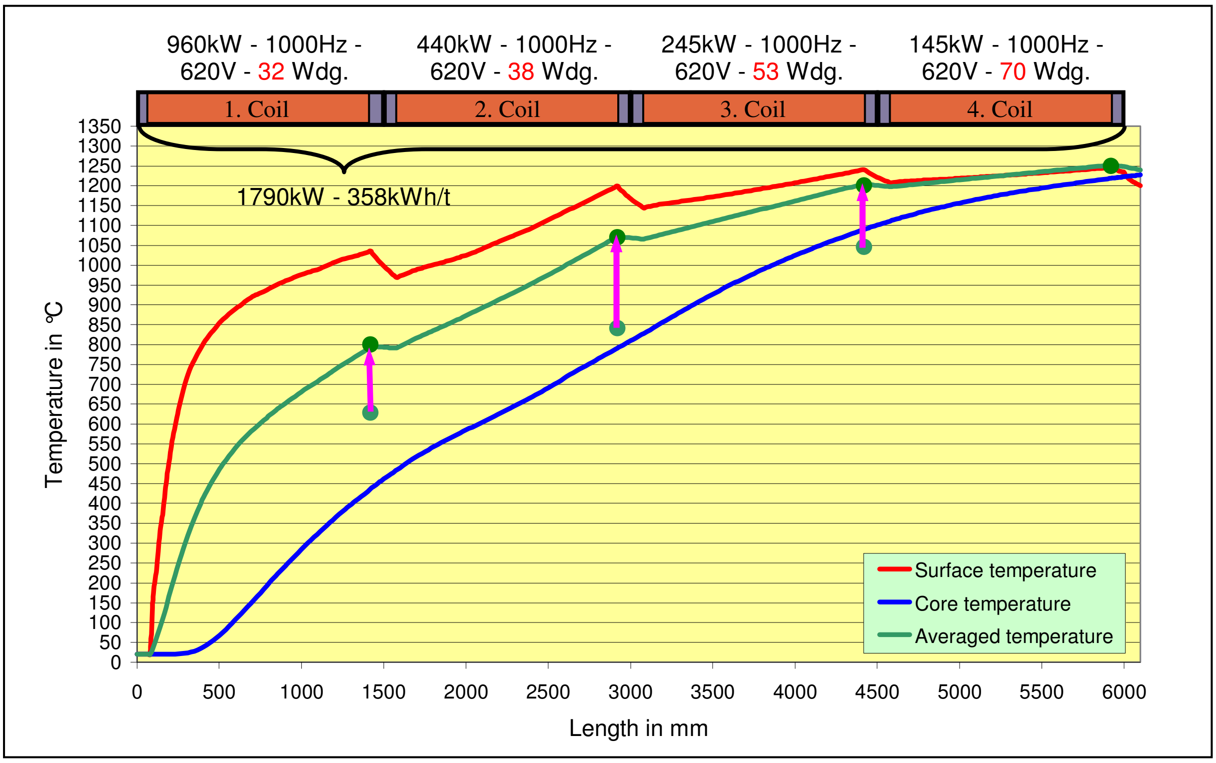

Fig. 2. Typical temperature profile of non-linear heating at 100% throughput

Since all coils are connected to the same power supply this power adaptation can usually be realized only by changing the number of windings in each coil, so that the coils become different to each other. Because of higher surface temperature in comparison to the linear heating more scaling is generated and the energy consumption is also slightly higher as a result.

Usually it is not possible to operate this heater system with throughputs lower than 50%, because the billets would be superheated at the outlet of the 3rd coil, as shown in Fig. 3.

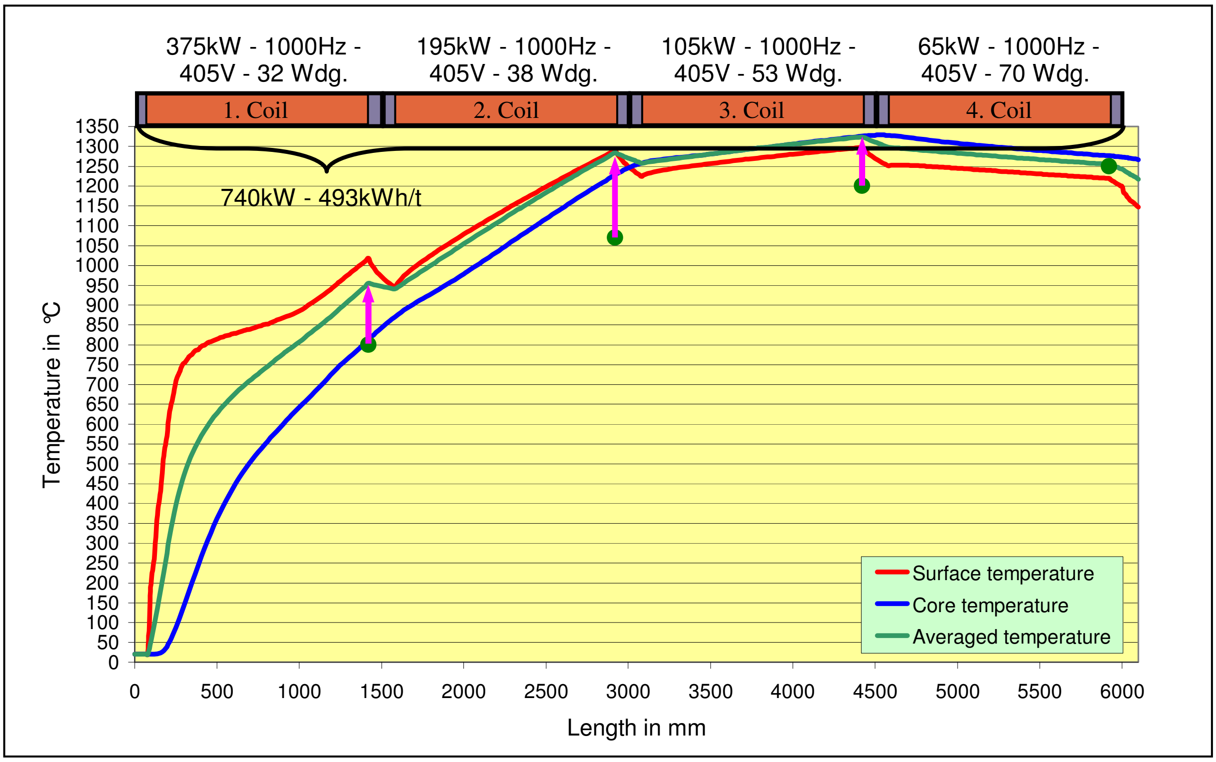

Fig. 3. Temperature profile of non-linear heating at 20% throughput

1.3. Enthalpy controlled zone heating

At the first view the temperature profile of the enthalpy controlled zone heating (Fig. 4) looks equal to the non-linear temperature profile. But in this case the different power rates of the coils are not achieved by different coil winding numbers but by powering the coils with separate power supplies, so that the power for each coil can be adapted individually.

Ideally the power supplies should be identical for all zones and the required coil voltage should be nearly the same for all coils under nominal operating conditions, when using parallel resonant circuits. To vary the power absorption and temperature pick-up in each coil, different frequencies can be used to obtain the required differences in power absorption in each coil zone. Because the power decreases with increasing frequency the required frequencies usually must increase from the first to the last coil of the heater. This leads to another positive effect, since comparatively low frequencies are desirable at the beginning of the heating process where the temperatures are below Curie-Temperature in order to obtain larger electromagnetic penetration depths and to avoid superheating of the billet surface or excessive temperature differences between core and surface, which can lead to cracks in the billets. In the last zones where the temperatures are higher than Curie-Temperature, higher frequencies are necessary for lower energy absorption and to concentrate the applied power near the surface, in order to avoid a surface temperature drop by directly compensating the radiation losses on the surface of the billet.

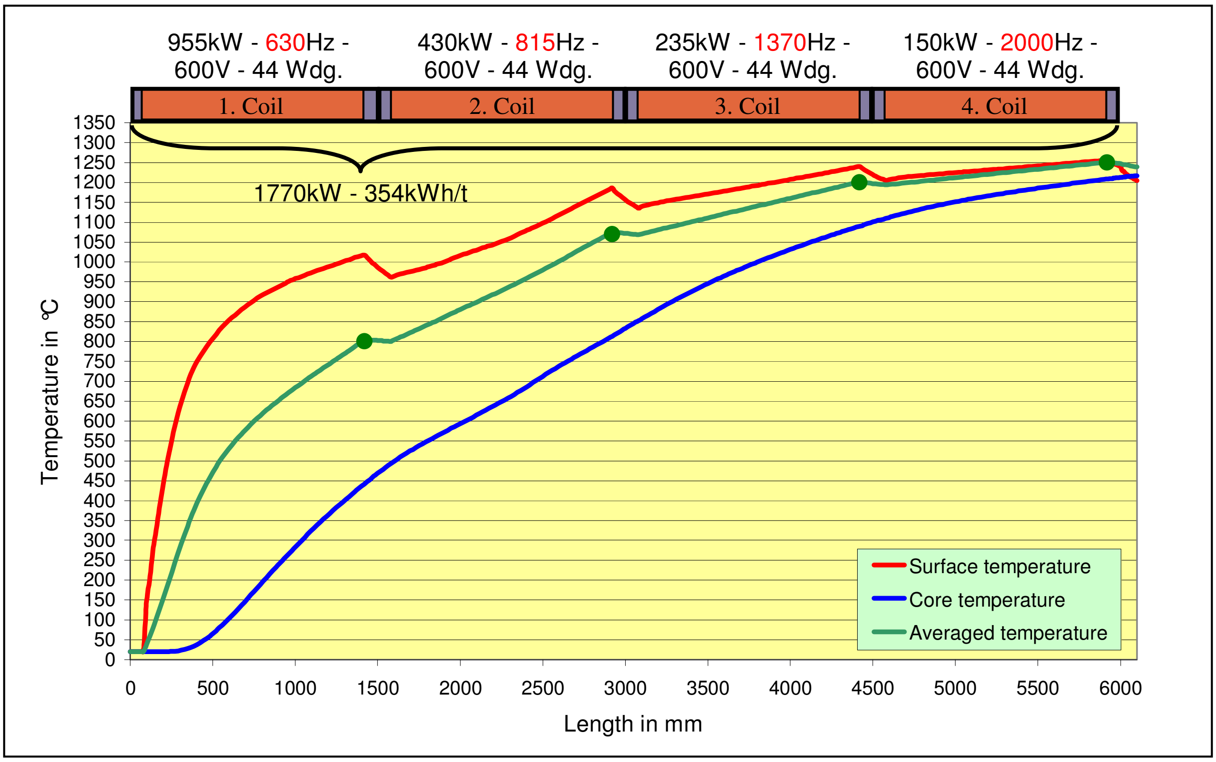

Fig. 4. Typical temperature profile of enthalpy controlled zone heating at 100% throughput

By controlling the power supplies in an appropriate way, the nominal temperature profile is always kept independent of billet diameter and throughput.

2. Advantages of enthalpy controlled zone heating

Due to the independently powered coil and the separately controlled power supplies the following advantages result.

2.1. Prevention of superheating at low throughputs

The reason that the billets can superheat at low throughputs as shown in Fig. 3 for non-linear heating is demonstrated in Fig. 5. The red bars in the back series show the required induced power ratings for each coil at nominal throughput (100%) which are necessary to obtain the non-linear temperature profile that was shown in Fig. 2. In this graph all bars for the single coils are normalized to the induced power of the first coil at 100% throughput. The sum bars are normalized to the sum of the effective power at 100% throughput. The blue bars show the thermal losses which rise with the billet surface temperature. If these are subtracted from the corresponding induced power ratings the effective power ratings remain which cause the temperature rises in the billets as they pass through the respective coils.

If a throughput of only 30% is desired, the sum of the effective power of all coils must be reduced down to 30% of the sum of the effective power for 100% throughput. In order to keep the temperature rise in each coil equal to that of 100% throughput the induced power of each coil has to be reduced individually in order to get an effective power of 30% for each coil. This is possible only by separately fed coils and separately controlled power supplies. In case of a single power supply for all coils, the total induced power of all coils can only be reduced proportionally. Due to that the induced power of the last coil drops under the amount of the thermal losses of the billet in that coil, so that the effective power becomes negative. This means that the cross-section averaged temperature of the billets drops while they pass through this coil. So a superheating of the billets occurs at the outlet of that zone where the effective power of the following zone becomes negative.

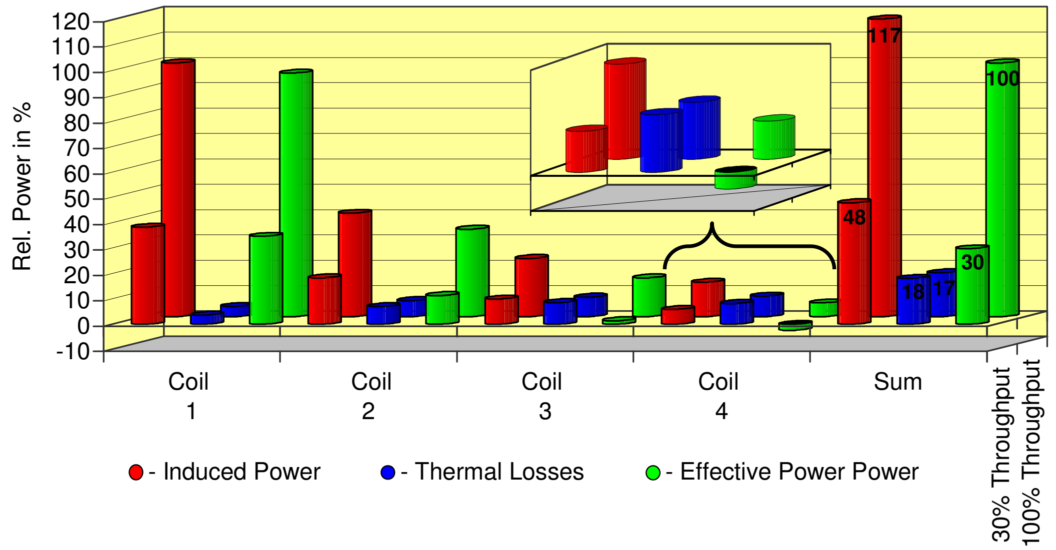

Fig. 5. Coil power distribution for non-linear heating

Because the common power supply for all coils is the reason of superheating at low throughputs, this problem applies not only for non-linear heating but also for linear heating. But for linear heating this effect is not so obvious because the induced power of the coils are not so different. As a result the effective power of the last coil becomes negative only at a very low throughput.

2.2. Improvement of transition behaviour at throughput changes

In case of a short-term failure or break of the forging process the heater throughput is usually reduced as much as possible in order to minimize the number of heated but not needed billets. When the production shall be restarted the throughput must be increased back to its production rate as fast as possible. But depending on the time that elapsed with low throughput, some billets may be superheated after resuming normal operation.

Like it was already explained in the last paragraph, the cross-section averaged temperatures rise with decreasing throughput. This means that these temperatures are higher than needed when the throughput is increased back to normal levels. If the coils are fed from the beginning with the power levels that are required for the higher throughput, it leads to a corresponding superheating of these billets which are located in the heater at the moment of throughput change, once they reach the heater outlet. By a switch on delay or power ramp the superheating at throughput changes can be lessen a little but it can’t be sufficiently compensated in total for all possible combinations of throughputs and billet dimensions.

The amounts of the temperature deviations for the stationary states are shown in Fig. 6 for the three types of heater systems. As can be expected from the explanation in the last paragraph, the deviation of the non-linear heating is the highest. Enthalpy controlled zone heating shows the lowest deviation due to its operating principle of constant cross-section averaged temperatures at the outlet of each coil. Linear heating lies somewhere in-between.

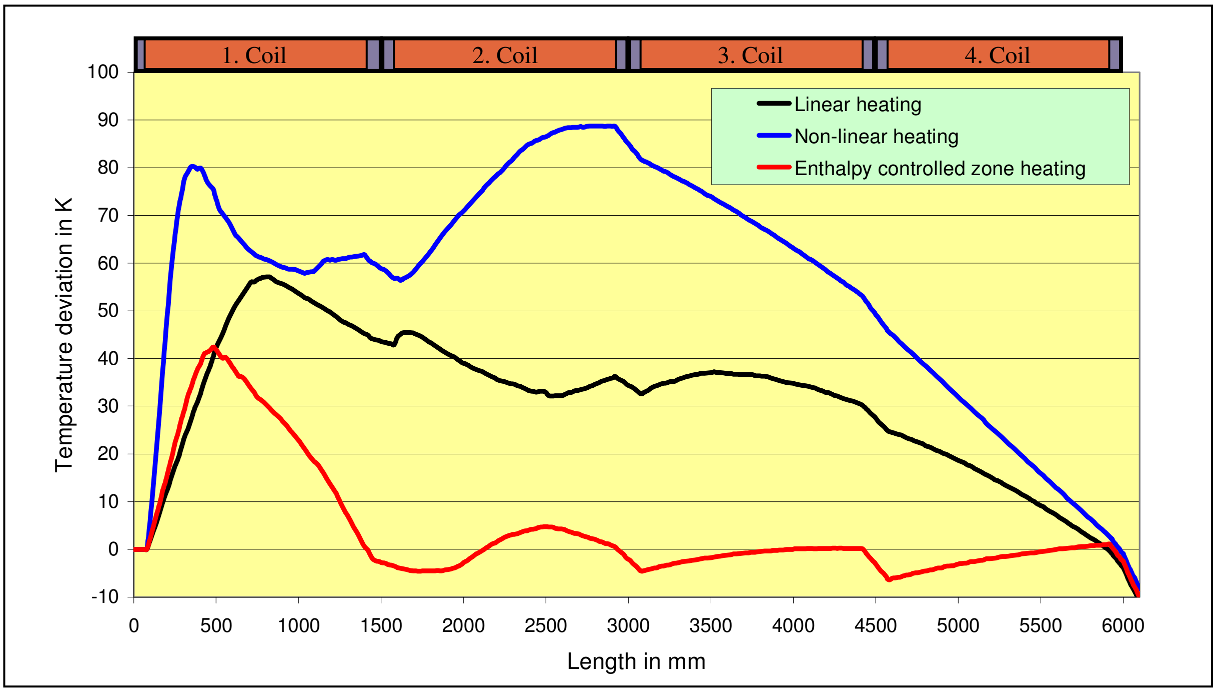

Fig. 6. Temperature deviation between 50% and 100% throughput

Of course this method of estimating the transition behaviour is coarse because it compares only the stationary temperature distribution for both throughputs, but it shows very clearly the reason for the superheating when a throughput change occurs.

2.3. Override of the temperature profile

Enthalpy controlled zone heaters ensure that the cross-section averaged temperatures are independent of billet diameter and throughput at the outlet of each coil zone. With the aid of a suitable control interface this heater system provides the potential to change these temperatures and therefore the temperature profile within technical limitations as shown in Fig. 7. The shape of the temperature profile influences the

- axial and radial temperature distribution in the billets
- energy consumption
- scaling rate
- billet sticking.

The strongly converging curve provides low axial and radial billet temperature differences at the outlet of the heater. But because of the high cross-section averaged temperatures within a long part of the heater the billets can tend to stick. Furthermore the billets can crack due to the high temperature differences between core and surface caused by the high temperature rise in the first coil. Since the surface temperatures are also high for this profile, the scaling rate is higher and the radiation losses are stronger which makes the energy consumption worse. Since the slightly converging temperature profile provides just the opposite an individual compromise can be found for the different requirements.

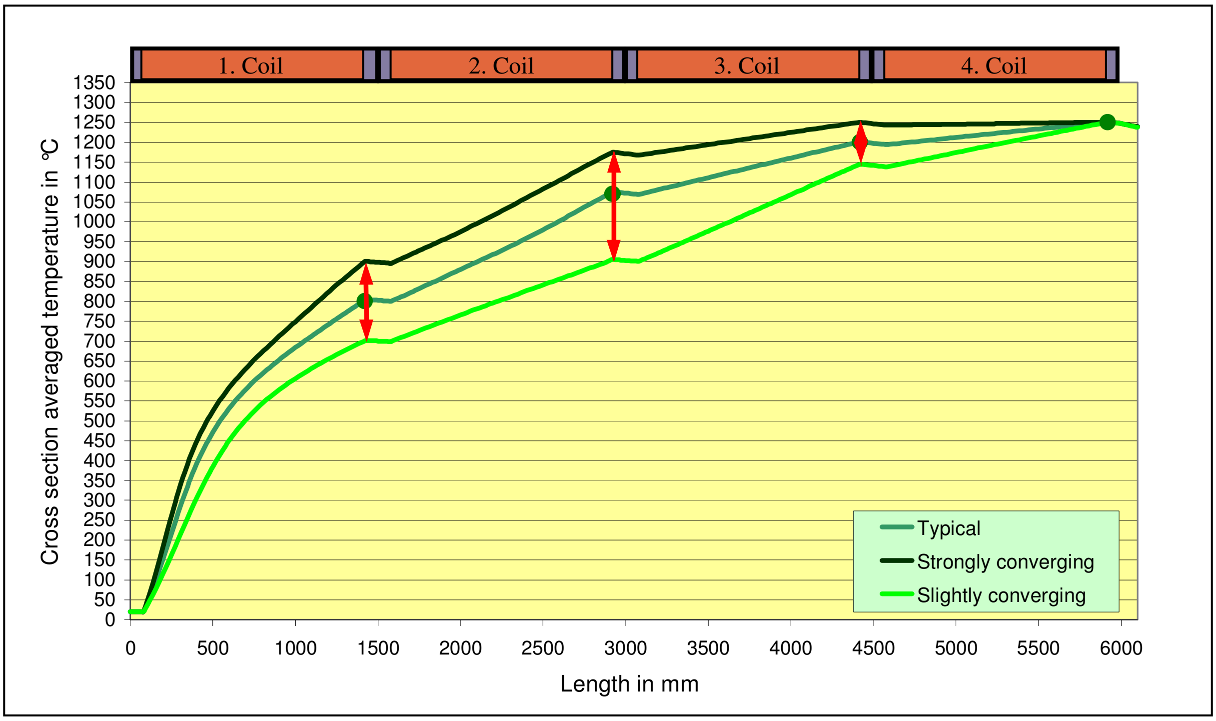

Fig. 7. Range of possible temperature profile override of an enthalpy controlled zone heater

Conclusions

In contrast to conventional billet heaters, enthalpy controlled zone heaters keep the workpiece cross sectional average temperature equal and independent of the actual throughput and billet dimensions. Due to that evenness this technique avoids superheating at low throughputs and reduces the number of rejected billets after a short-term failure or break of the forging process. With the aid of a suitable control program the temperature profile can be modified in order to find the best compromise between low billet sticking and scaling rate, uniform temperature distribution within the billets and low energy consumption.

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