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HOT DEFORMATION OF COPPER AND COPPER ALLOYS

Heating of copper alloy extrusion billets, procedures and possibilities for energy conservation, facilities and problems

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1 Introduction

Worldwide >100 billet heaters are installed. To get an idea of the dimension of the global energy consumption, energy costs and CO_2-emission for billet heating the following production parameter are assumed: a global production rate of 25 x10^6 Mt/a, a mean extrusion temperature of the billets of 850°C, most of the billet heaters are fired with natural gas at a mean efficiency of 65%; a gas price 0,04 €/kWh (based on european energy costs) and emission of 0,2 kg CO_2/$kWh_{natural\ gas}$. The outcome of this case study is a global energy consumption for heating of copper alloy extrusion billets of 0,4 x 10^9 kWh at total energy costs of 15 x10^6 €/a causing a CO_2-emission of 73 x 10^6 t/a.

This paper gives a survey of procedures for billet heating and possibilities for energy conservation, which shall be helpful for companies to take a decision when buying, modernizing or exchanging a billet heater. The focus is placed on gas fired billet heaters.

2 An overview of the billet heaters

Basically billet heaters are distinguished in those heated with natural gas and those heated with electric power. The transport mechanism is a further distinctive feature. The resulting and established procedures are listed in the table of **fig.1**.

<u>Gas fired billet heaters</u>

The gas fired billet heaters are usually directly heated. The heat is produced at the billet surface by convective heat transfer from the flue gas to the billet surface and by radiant heat transfer from flame and furnace inside walls to the billet surface. Usually gas fired billet heaters are built for quasi continuous operation where a column of billets is transported step by step in direction of the billet axis through the furnace. Some gas fired billet heaters have a “passive” preheating section between the billet inlet and the main heating section, which is heated only with the still hot flue gas of the burners of the main heating section. Here a part of the remaining energy of the hot flue gas is transferred to the billets by forced convection. This is achieved by blowing the hot flue gas through nozzles on the billet surface. The flow circuit is driven by hot gas fans.

There are two established transport mechanism. Billet transport by pushing a column of billets on a roller conveyor through the furnace is appropriate up to about 800°C maximum billet temperature. At higher temperature sticking of billets one front surface to another due to the axial pressure is an obstacle. For higher temperatures the walking beam is the adequate solution. The latter solution enables to leave a gap between the individual billets, which are advantageous in case the production parameters change.

A new concept is the heating of billets in gas fired single chamber furnaces.

Electrically heated billet heaters

The heat is produced inside the billet by electrical eddy currents created by induction or magnetic effects due to Maxwell's equations and the Lorentz force law. Induction releases the heat in the outer shell of the billet. The so called skin depth depends on the frequency of the induction field, the lower the frequency the thicker the skin depth. The size of the induction coil has to be matched to the billet diameter.

A new concept is the magnetic heater. The billet rotates in a static magnetic field, which is generated by superconducting magnets which deliver a strong magnetic field. The superconducting magnet dissipates nearly no energy. Most of the motor power, needed to rotate the billet, is dissipated in the billet as heat. The energy is released in the bulk, hence the temperature gradient in the billet is small. The total efficiency of this concept is 2-times higher compared to conventional induction heaters.

2.1 Energy efficiency

Energy efficiency of thermoprocessing plants has to be investigated from two points of view, the environmental aspect of CO_2-emission and the energy costs.

The amount of CO_2-emission depends on the consumption of primary energy and on the energy source. In case electric power is used for heating the CO_2-emission depends strongly on the mix of energy sources used to generate electric power. Brown coal power plants have the highest emission with about 1 kg CO_2/kWh, anthrazite power plants have 0,78 kg CO_2/kWh and gas fired power plants using a combined cycle at high efficiency >60% emit still 0,35 kg CO_2/kWh. This are rather high emission rates compared to heating with natural gas, which produces "only" about 0,2 kg CO_2/kWh. Having a look to electric power generation in those countries which have considerable capacities of extrusion plants, electric heating causes about 3-times higher CO_2 emissions compared to natural gas heating. Of cause in Germany and in the USA the balance is more positive. This is due to the higher share of nuclear power plants.

Looking to costs electric power is more expensive compared to natural gas, in most countries the costs are about two times higher.

Of course a forecast of the global energy production for this century shows a significant increase of electric power from solar energy starting from the middle of the century. The energy data are summarized in **fig.2**.

The following case study compares the billet heating procedures with focus on energy efficiency:

For a reference production rate of 25.000 t/a billet heater for copper extrusion products with an extrusion temperature of 1000°C the procedures are compared with respect to energy consumption, energy costs and CO_2-emission based upon today energy data, see **fig.3**. The comparison shows that electrically heated furnaces produce about 3 to 6 times more CO_2 and energy costs are 50% to 150% higher compared to gas fired furnaces.

As long as a significant rate of electric energy is produced from fossil resources, the fossil resources should be used directly for heating and not indirectly via electric power. Probably there will be a change in this century as forecast in the diagram of fig.2.

2.2 Investment costs, maintenance and operational aspects

For the evaluation of billet heating procedures a lot of additional aspects have to be considered besides energy efficiency. A brief overview concerning investment costs, maintenance and operational aspects is given in **fig.4**. Regarding investment costs gas fired billet heaters are by far the best solution. Since periodic cleaning of the furnace chamber depending on the amount of scale, spalling from the billets, maintenance causes more effort in case of gas fired billet heaters. The production flexibility of gas fired facilities depends on the billet transport mechanism. A walking beam is more flexible compared to a pusher mechanism because of the variable gap which can be left between billets. Generally electrically heated billet heaters and the single chamber furnace are more flexible since each billet is heated up individually. In case of induction heaters it has to be taken into account that the induction coil has to fit to the size of the billet. The generation of a taper (this is a temperature gradient along the billet, to compensate the temperature increase of the billet during the extrusion process) is possible for all procedures. Solutions, which achieve the taper by local heating of one end of the billet are preferable to those, who create a temperature gradient by cooling. The atmosphere in case of gas fired billet heaters is flue gas, whereas billets in induction ad magnetic heaters can be kept under protective gas atmosphere.

3 Problems and solutions for gas fired billet heaters

The evaluation of procedures shows clearly that gas fired billet heaters are still a very outstanding solution as well as related to energy costs as to environmental aspects. This is a good motivation to put effort on the minimization of the obstacles of directly fired billet heaters by analysing the problems and the finding of innovative solutions. It is demonstrated, that almost all obstacles and problems with gas fired billet heaters can be solved with state of the art technical solutions.

3.1 Furnace atmosphere

Obstacle:

For Cu and some Cu-alloys such as CuNi with high extrusion temperatures oxidation leads to formation of oxide scale on the billet surface. This causes the following problems:

- Scale deposits on transport mechanism and causes longer standstill times for cleaning of the furnace. For cleaning the furnace has to bee cooled down and partially disassembled.
- Before extrusion the scale has to be removed by mechanical means or by thermal spalling induced by water quenching of the scale.
- Measuring errors occur at the contact free temperature measurement by pyrometer. Reasons are variations of the emission coefficient of the surface, parasitic radiation from the furnace walls or from the burner's flames reflected onto the sensor. A billet with scalefree surface and a billet surface with scales are assumed to have both the same physical temperature. A pyrometer assembled will measure a lower temperature on the surface with scale (up to some 10 K). This might be disastrous, since sometimes Cu billets have to be heated up close to melting temperature! A water cooled protection tube for each pyrometer pushed on the billet surface while measuring is mandatory.

What are the conditions, leading to oxidation? At about 1000°C formation of CuO occurs at an O_2-concentrations > 0,01% and CuO_2 forms at an O_2-concentrations > 0,001%. Obviously in a directly heated furnace the atmosphere is similar to the composition of the flue gas. Flue gas of natural gas burners adjusted to □ (excess air) of 1,05 consists of about 18 Vol.-% H_2O, 19 Vol.-%CO_2, 71 Vol.-%N_2 and 1 Vol.-%O_2. Thus the O_2-concentration is much higher then required to avoid oxidation. A significant reduction of □□□is not practicable because the CO-concentration will increase dramatically. Since CO is toxic, its concentration has to be kept << 100 ppm. Additionally it has to be taken into account, that the housing of a billet heater is not gastight, what is due to the billet inlet opening, the outlet and the transport mechanism in case of a walking beam. Resuming the design goal can only slowed down scale formation as much as possible by avoiding an additional increase of the O_2-concentration by leakage or by bad □ adjustment.

Solutions:

1. Choice of the burner type

The requirements for mixing of gas and combustion air are very high. To achieve constant excess air conditions a variable air/gas ratio control based on pneumatic control, see **fig.5**, is mandatory. This is state of the art and works very well for on/off burners as well as for infinitely variable burners. An important feature is, that the combustion air supply for each burner has to be equipped with a gas-tight valve to avoid air being purged into the furnace, while the burner is switched off. In the case a burner type has been chosen, which is supplied with preheated combustion air coming from a central recuperator, a gas tight valve, which can be a butterfly valve in case of continuously variable burners, is very expensive. Additionally the use of preheated air requires a control valve for □-control in order to compensate the variation of the air mass flow, which is due to the temperature dependency of the air density. This compensation requires a sophisticated closed loop control usually implemented in the PLC.

2. Temperature control

Operating conditions, where all burners of the furnace are switched off, should be avoided, because a continuous flue gas production is needed to avoid air leakage into the furnace. Obviously this can not be totally avoided since tool exchange at the press or other events require standby times of the furnace, where burners have to be switched off in order to avoid billet overheating or even melting. But there are several means to minimize this problem:

- in case on/off burners are used, the hotter sections of the billet heaters can be equipped with some small burners, with a power tuned to the insulation loss of the furnace. These burners can be operated continuously.
- in case continuously variable burners are used, these burners should have a wide turn-down range (1:10).
- The temperature control of the individual sections can be cascaded from hotter to cooler sections. The purpose is to achieve long on-time for the burners in the hotter sections. Therefore overheating of billets in the cooler sections has to be avoided.

3. Gas tightness

Total gas tightness can not be achieved, since billet inlet, billet outlet and walking beam represent technically unavoidable leakages. The design goal is the minimization of these leakages with respect to inrush of air and leaking of flue gas. As a basic principal the coexistence of two “big” leakages, i.e. one at the inlet and one at the outlet of the furnace should be avoided, since for such a situation uncontrollable drought can occur, even influenced by accidental conditions like an open gate of the shop floor.

Remedial actions are:

- a vestibule with two alternately opening gastight doors at the billet inlet
- if a convective driven preheating zone is used, care has to be taken at the design of the nozzles close to the inlet. The induction of a forced gas flow along the billets into the direction of the inlet gap between billet and housing has to be avoided. The volume flow of this leakage can exceed the volume flow of flue gas produced from the burners and as a consequence air will be sucked into the furnace. This design task is a challenge with respect to fluid dynamics.
- Frequent opening of the furnace door at the billet outlet is unavoidable. The intake of air can be minimized by door burners or by a blocking nozzle arrays.
- Leakages at the walking beam can be minimized by covering of the walking beam beneath the furnace in a housing. This is filled with inert gas at a pressure slightly higher compared to the pressure of the furnace chamber. In the case recuperator burners are used, 10% of the flue gas can be sucked off

over the walking beam housing instead of purging of the housing with inert gas.

4. Pressure control of the furnace chamber

A small overpressure of some N/m² shall be reached in the furnace. Higher overpressure has to be avoided to prevent flue gas polluting the ambient of the furnace. Pressure control is carried out by speed control of the flue gas fan. An additional butterfly valve in the flue gas pipe driven by a fast actuator makes the response behaviour of the pressure control more dynamic. Pressure control is more complicated for conventional burners, since the flue gas is sucked through one outlet of the furnace, usually placed close to the billet inlet, where the furnace temperature is the lowest. As a matter of physics a pressure gradient along the furnace is necessary to induce the gas flow.

Self recuperative burners are advantageous, because the flue gas produced by one burner is sucked through the recuperator of the same burner and only when the burner is operating.

5. Further methods

A possibility to reduce the O_2-concentration is the controlled injection of hydrogen, H_2. A H_2-volume flow of max. 10 Nm^3/h is sufficient to significantly reduce the O_2-concentration in the hotter furnace sections below 0,1% by oxidation of H_2 to H_2O. Of course some safety aspects have to be observed:

- The place of H_2 injection has to be in a part of the furnace chamber, where the combustion of the natural gas is completed. Otherwise the CO production during the combustion process will increase significantly.
- The H_2-volume flow has to be limited to a value, to ensure that an explosive mixture in the furnace as well as in the exhaust gas system is avoided.
- H_2 is only injected into a furnace section when the related burners are switched on and when the self ignition temperature of H_2 in the related section is exceeded.

Additionally a reasonable feature can be a mass flow control of the H_2 injection of H_2. The control variable is the O_2-concentration of the furnace atmosphere, measured with a sensor.

3.2 Energy conservation

The objective of any energy conserving activity is the energy recovery from the flue gas. Standard methods are:

In case standard burners are used:

a) **Convective preheating sections**. In case standard burners are used, the flue gas is lead from the gas fired sections into the preheating section. The heat transfer form the flue gas to the billet is increased by forced convection driven by hot gas fans
b) **Central recuperators** are used to transfer energy from the hot flue gas to preheat the combustion air. The preheating temperature is limited to about 400°C, due to economic aspects with respect to the size of the recuperator and the available armatures
c) **Selfrecuperative burners**. Depending on the recuperator design an efficiency of 80% at 1000°C furnace chamber temperature is state of the art

The efficiency is related to the flue gas temperature which is achieved certainly before any cold air is mixed to the flue gas flow.

The use of self recuperative burners, on/off controlled, is advantageous compared to conventional burners combined with a central recuperator. As a matter of fact the efficiency, of the latter is lower. This is due to the smaller temperature difference between air and flue gas in the central recuperator, because of the mixture of gas from hotter and cooler sections. Additionally the gas management of selfrecuperative burners can be carried out with standard components. PLC controlled valves to stabilize the gas/air ration are not necessary. Hence the maintenance of a firing system based on selfrecuperative burners is easier.

4 Summary

The modern energy efficient gas fired billet heater is described in the brief specification:

Features:

- Walking beam in N2-purged housing
- No preheating zone, only short passive inlet section
- Main burners on/off, selfrecuperative, high efficiency, up to 80%
- Advanced temperature control, master/slave, cascading, master is last heating zone

in case a low O_2-concentration is required:

- entry vestibule, purged with flue gas
- Partly small burners, with $P_{heat} = Q_{Insulation}$ in hotter sections
- $C_{Oxygen} < 0,1\%$ by controlled reduction with hydrogen

A feasible billet heating concept can be also the combination of gas fired and electrically heated billet heaters. The gas fired billet heater heats up the billets to a certain temperature, the final heating is done by induction or magnetic heater. The design of the individual heaters has to be matched with the cycle time of the press. An advantage of such a combined concept is a higher operational availability since the production can be sustained even in case one of the heaters has to be shut down for maintenance.

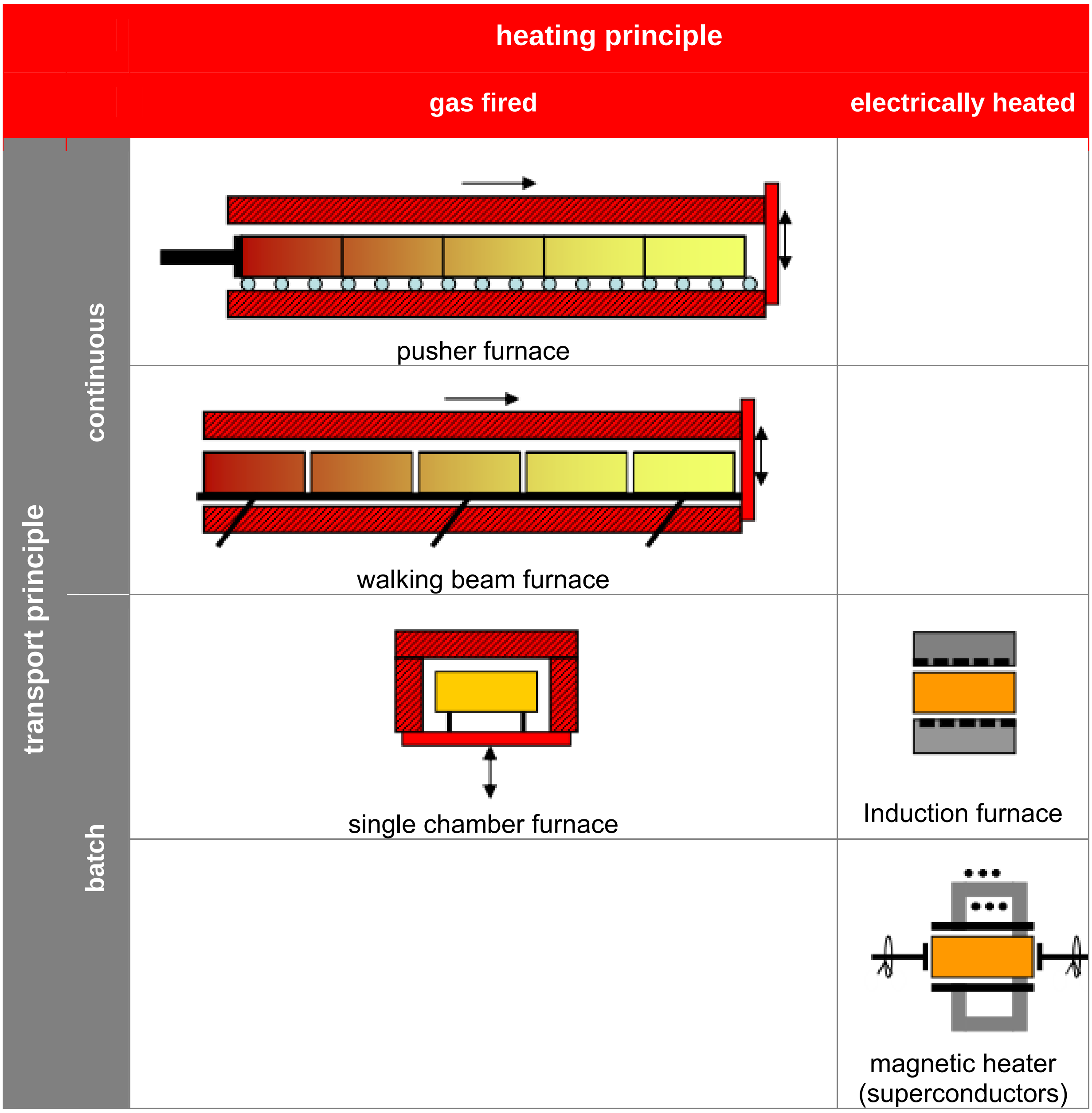

Fig. 1: overview of billet heating procedures

	electric power							natural gas	
	fossile	**nuclear**	**regene-rative**	**rest**	**CO_2-emission fossile**	**CO_2-emission mix**	**costs el. power**	**CO_2-emission**	**costs natural gas**
	%	%	%	%	**kg/kWh**	kg/kWh	€/kWh	kg/kWh	€/kWh
Germany	58	23	16	4	**0,78**	0,43	0,09	0,2	0,04
Italy	79	0	21	1	**0,75**	0,59	0,09	0,2	
Greece	85		13	3	**0,75**	0,64	0,06	0,2	
China	75	3	22		**0,75**	0,56	0,00	0,2	
USA	71	21	8		**0,75**	0,54	0,07	0,2	
India							0,00	0,2	
Russia							0,00	0,2	

Sources: www.agenda21-treffpunkt.de, www.amerika-auf-einen-blick; www.erdgas.ch; statistisches Bundesamt

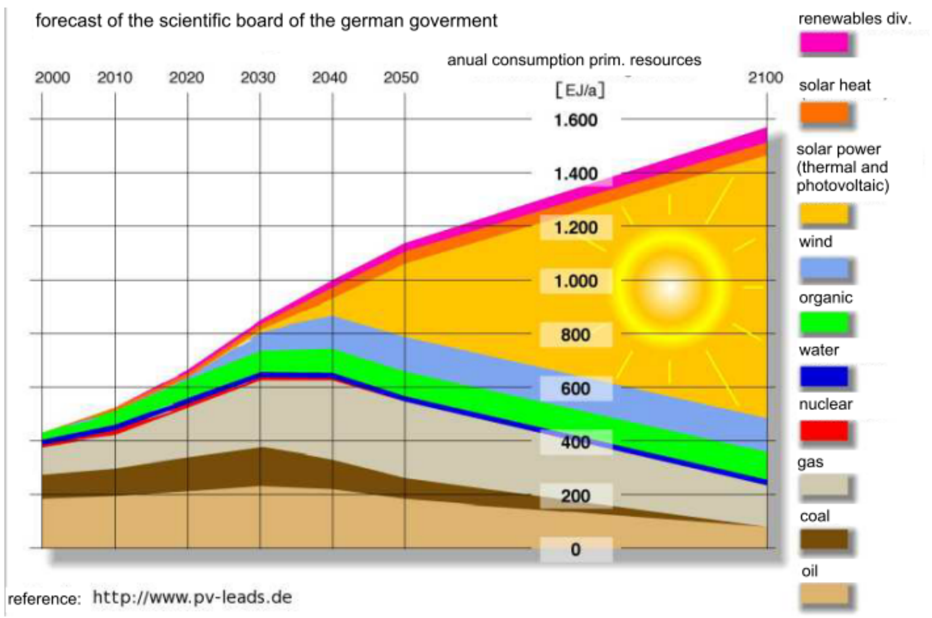

Fig.2: selected energy data and forecast of global energy production

	gas fired billet heaters		electrically heated billet heaters	
assumptions: CO_2-production rate for power generation: 0,75 kg/kWh energy prices : 0,04 €/kWh (natural gas) 0,08 €/kWh (electric power)	**walking beam**	**single chamber**	**inductive**	**magnetic**

production data					
extrusion temp.	°C	1.000	1.000	1.000	1.000
net. energy consumption	kWh/t	116	116	116	116
yearly prod. hours	h/a	5.000	5.000	5.000	5.000
prod. per hour	t/h	5	5	5	5
yearly production	**t/a**	**25.000**	**25.000**	**25.000**	**25.000**
brutto energy cons.					
electrical power	kWh/t	10	10	300	150
natural gas	kWh/t	170	155	0	0
total consumption	**kWh/t**	**180**	**165**	**300**	**150**
total efficiency	**%**	**64**	**70**	**39**	**80**
Environment					
CO2-production (el.-fossile)	kg/t	8	8	225	113
CO2-production (nat.gas)	kg/t	34	31	0	0
CO2-production total	**kg/t**	**42**	**39**	**231**	**115**
Energy costs (assumption)					
spec. costs for energy	**€/t**	**7,6**	**7**	**24**	**12**
yearly costs for energy	**€/a**	**190.000**	**175.000**	**600.000**	**300.000**

Fig. 3: comparison of energy efficiency of billet heating procedures for a reference production of Cu-billets of 25.000 t/a

	gas fired billet heaters		electrically heated billet heaters	
	walking beam	**single chamber**	**inductive**	**magnetic**
principle	quasi-continuous	batch	batch	batch
investment costs	low	?	high	higher
maintenance costs	medium – high (pollution by scale)	?	low (changeover time for change of coildiameter)	low
flexibility				
• **billet dimensions**	variable in diameter (1:2) and length	variable	one diameter one coil, variable length	variable
• **change of extrusion temperature**	gap between billets depending on temperature change, or "blind billet"	individual	individual	individual
• **taper**	possible	possible (quenching)	possible	possible
process atmosphere	flue gas, $C_{O2,min}$ = 1% (l=1,05)	flue gas, $C_{O2,min}$ = 1% (l=1,05)	air	air, protective gas

Fig. 4: features of billet heaters

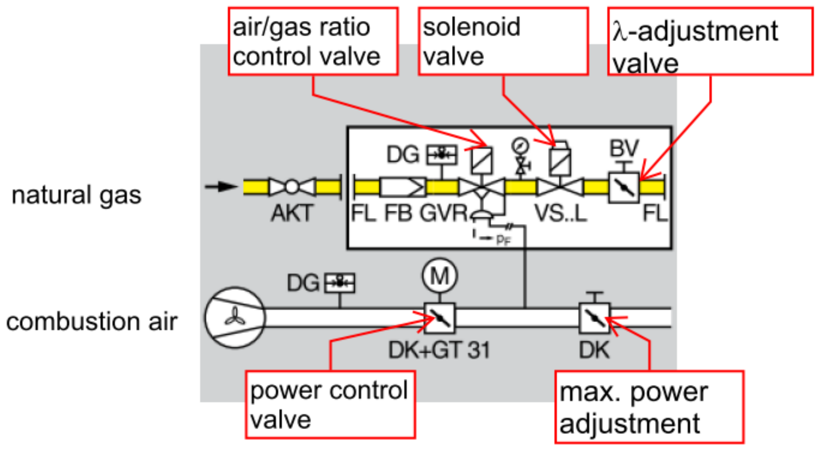

Fig. 5: Schematic drawing of the gas/air ration control (Kromschröder):