Preiskave potisne peči za ogrevanje slabov

Examination of the push-type slab reheating furnace

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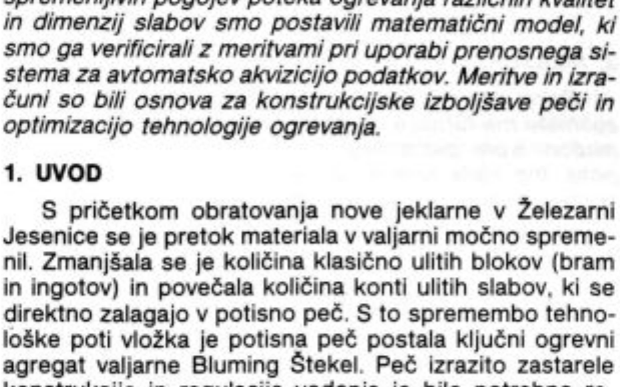
V okviru sodelovanja Metalurškega inštituta in FNT Montanistike v Ljubljani z Železarno Jesenice smo izvedli toplotnotehnične preiskave potisne peči za ogrevanje slabov pred rekonstrukcijo peči in po njej. Za simulacijo spremenljivih pogojev poteka ogrevanja različnih kvalitet in dimenzij slabov smo postavili matematični model, ki smo ga verificirali z meritvami pri uporabi prenosnega sistema za avtomatsko akvizicijo podatkov. Meritve in izračuni so bili osnova za konstrukcijske izboljšave peči in optimizacijo tehnologije ogrevanja.

1. UVOD

S pričetkom obratovanja nove jeklarne v Železarni Jesenice se je pretok materiala v valjarni močno spremenil. Zmanjšala se je količina klasično ulitih blokov (bram in ingotov) in povečala količina konti ulitih slabov, ki se direktno zalagajo v potisno peč. S to spremembo tehnološke poti vložka je potisna peč postala ključni ogrevni agregat valjarne Bluming Štekel. Peč izrazito zastarele konstrukcije in regulacije vođenja je bilo potrebno rekonstruirati. Pred tem je peč obratovala samo občasno z zelo visoko specifično porabo energije in slabo kvaliteto ogrevanja slabov. Napake na površini kot posledica neurejenih razmer pri ogrevanju, so bile vzrok dodatnim težavam pri valjanju in slabši kvaliteti toplo valjanih trakov.

2. PODATKI O PEČI

Na **sliki 1** je prikazana potisna peč firme Rust pred izvedbo rekonstrukcije. Peč je imela tri cone: zgornjo in



Slika 1
Prerez potisne peči pred rekonstrukcijo

Fig. 1
Section through slab reheat furnace before the change of design

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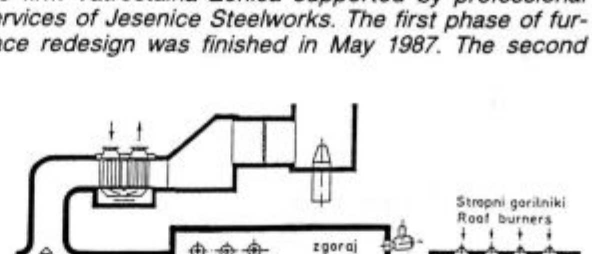
Together with Metallurgical Department of the University of Ljubljana and Jesenice Steelworks the Institute of Metallurgy examined the push-type slab reheating furnace before and after its design change. For the simulation of variable heating conditions under slabs of different qualities and dimensions the mathematical model was constructed and verified by measurings using the transferable system for data acquisition. Measurements and calculations served to improve the furnace design and the reheating technology.

1. INTRODUCTION

The new steel making plant in Jesenice Iron and Steelworks changed profoundly the slab transfer course in the rolling mill. The classically cast block yield decreased heavily while continuously cast slabs charged directly into the push-type reheating furnace, increased in yield. The change of slab manufacture made the push-type reheating furnace the main reheating aggregate of Bluming Štekel rolling mill. The furnace of evidently obsolete design and control had to be redesigned. Prior to this, the furnace operation was subject to vast specific energy consumption, and poor slab reheating which resulted in surface layer defects causing poor quality of hot rolled band.

2. FURNACE CHARACTERISTICS

Figure 1 *shows the push-type reheating furnace produced by the firm RUST prior to redesigning. The furnace is divided into three zones; the upper and lower heat zones and the soak zone equipped with head burners for natural gas. Design change was performed by the firm Vatrostalna Zenica supported by professional services of Jesenice Steelworks. The first phase of furnace redesign was finished in May 1987. The second*



Slika 2
Prerez potisne peči po rekonstrukciji

Fig. 2
Section through slab reheat furnace after furnace redesign

spodnjo ogrevno cono in cono izenačevanja, opremljeno s čelnimi gorilniki za zemeljski plin.

Rekonstrukcijo peči je izvedla Vatrostalna Zenica v sodelovanju s strokovnimi službami Železarne Jesenice. Prva faza rekonstrukcije peči je zaključena v maju 1987. Maja 1990 je potekala druga faza rekonstrukcije: zamenjava drsnih tračnic in izdelava sistema za odstranjevanje škaje.

Pri rekonstrukciji peči so glede profila izvedene samo minimalne spremembe. V coni izenačevanja so vgrajeni stropni gorilniki firme Bloom (Type 2110) razporejeni enakomerno po površini stropa v dve regulacijski coni (leva in desna). Ogrevna cona peči je spremenjena, tako da je podaljšan ravni del stropa s prehodom v dodatno postavljeno zgornjo in spodnjo predgrevno cono s stranskimi gorilniki firme Bloom (Type 1200). Na ta način je peč z rekonstrukcijo dobila 6 regulacijskih con z možnostjo bolj natančne porazdelitve celotne toplotne obremenitve peči. K temu primerno je izveden tudi razvod cevovodov plina in zraka z ustreznimi regulacijskimi elementi. Zamenjan je tudi ventilator za zrak. Zastarela in neučinkovita pnevmatska regulacija je zamenjana z mikroprocesorsko, sistema TDC 5000. V okviru predvidene rekonstrukcije ni bilo možno povečati dolžine peči zaradi prostorskih in drugih problemov. S podaljšanjem peči bi najbolj uspešno rešili probleme storilnosti in specifične porabe toplote ter odpravili sedanje konstrukcijske pomanjkljivosti na vstopni in izstopni strani peči.

3. MERITVE

V okviru preiskav peči smo opravljali meritve, potrebne za ugotavljanje storilnosti peči in pregretosti slabov, ker sta ta dva pojava med sabo odvisna. Uporabili smo prenosni sistem za avtomatsko akvizicijo podatkov data logger (Solartron Schlumberger) s prenosom podatkov na PC računalnik. Peč je obratovala diskontinuirano in z neustaljenim ritmom izvlačenja slabov, kar je otežkočalo določiti maksimalno storilnost peči. Z izdelavo matematičnega modela, prirejenega za osnovne karakteristike potisne peči, ugotovljene z meritvami, je bilo možno simulirati različne pogoje ter s kombinacijo meritev in izračunov spremljati potek ogrevanja različnih vrst jekel in formatov vložka. Pred verifikacijo modela ogrevanja slabov smo izvedli meritve temperatur v slabu z »vlečnimi« termoelementi.

3.1 Kontrola zgorevanja

Kontrolo zgorevanja smo opravljali s kontinuirnimi plinskimi analizatorji (CO, CO_2, O_2). Posebej uporabna v praksi se je pokazala plinska kisikova sonda na bazi stabiliziranega cirkonovega oksida. Z visokotemperaturno plinsko kisikovo sondo merimo vol. % O_2 v vlažnih dimnih plinih. Pri opravljanju meritev smo uporabljali tudi nizkotemperaturno plinsko kisikovo sondo in vmesno komoro lastne konstrukcije. Prednost metode je, da je cirkonova celica sonde z lastnim ogrevanjem postavljena v posebno konstruirano komoro v neposredni bližini merilnega mesta, kar zagotavlja relativno hiter odziv in ščiti sondo pred mehanskimi in termičnimi šoki. Na ta način lahko merimo vol. % O_2 v dimnih plinih tudi na konstrukcijsko težko dostopnih delih zgorevnega prostora peči. Na **sliki 3** je označeno optimalno področje razmernika zraka, ki smo ga na rekonstruirani peči lahko dosegli in vzdrževali. Nastavljeni razmernik zraka spreminjajo tudi glede na kvaliteto jekla. Pri vseh meritvah smo opazovali delo-

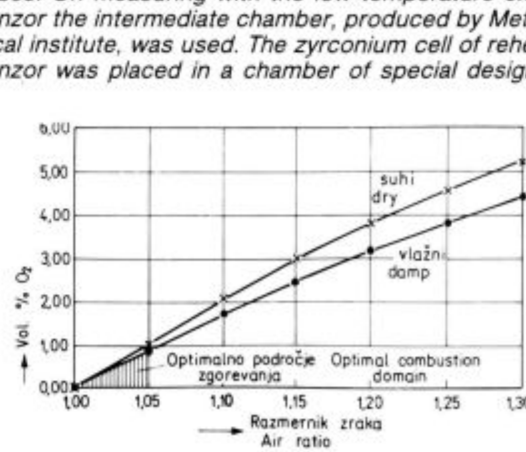
phase was started in May 1990 including skidrail exchange and manufacture of scale removing system. Design changes were minimal. The soak zone was equipped with roof burners produced by the firm Bloom (Type 2110) symmetrically distributed into two regulation zones (the left one and the right one). The flat part of the ceiling in the heat zone of the furnace was extended into a newly built upper and lower preheat zone with sideburners of the firm Bloom (type 1200). Thus the redesign contributed to obtainment of 6 regulation zones which have provided more uniform distribution of heat within the furnace. The gas and air pipelines with suitable regulation elements were arranged correspondingly. Air ventilator was exchanged, too. The obsolete and ineffective pneumatic regulation was replaced by microprocessor of TDC 5000 system. The redesign planned a prolongation of the furnace which would mean an efficient solution to the problems of throughput and specific heat consumption and to the design deficiences found on furnace input and output but was omitted due to room shortage.

3. MEASUREMENTS

Being correlative, the measurements necessary to estimate the furnace throughput and the slab soak estimation, were performed simultaneously. For this purpose the data acquisition system (Solartron-Schlumberger) with the immediate transfer of data into computer, was used. The estimation of the maximum yield was hindered by discontinuity of furnace operation and unsteadiness of slab extraction. The development of a mathematical model created to suit the basic characteristics of the push-type slab reheating furnace verified by measurements, made possible the simulation of divers conditions and followed the reheat process of various steel grades and slab dimensions by measurements combined with calculations. Before the slab reheating model was verified slab temperatures were measured by thermocouples.

3.1 Combustion Check

The combustion was checked by continuous gas analysers (such as CO, CO_2, O_2). In this case the oxygene senzor based on stabilized zyrconium oxide proved to be of extraordinary use. The high temperature oxygene senzor estimates volume % of O_2 of damp flue gases. On measuring with the low temperature oxygen senzor the intermediate chamber, produced by Metallurgical institute, was used. The zyrconium cell of reheated senzor was placed in a chamber of special design set



Slika 3
Odvisnost vol % O_2 od razmernika zraka

Fig. 3
Relationship between vol. % of O_2 and excess air

vanje regulacije tlaka v peči. Predvidene konstrukcijske izboljšave v sistemu regulacije tlaka v peči bodo omogočile bolj natančno delovanje drugih regulacij v področjih minimalne toplotne obremenitve peči.

3.2 Meritve temperatur v slabu

Na sl. 4 je prikazan izmerjeni potek temperatur slaba dinamo kvalitete pri prehodu skozi peč. Meritve smo izvajali z vlečnimi termoelementi pred rekonstrukcijo peči. Primer meritev na **sliki 4** kaže, da je na peči kljub nastavljeni maksimalni temperaturi cone 1290° C nastopalo pregrevanje površine materiala neposredno po končanem daljšem zastoju. Naglo dvigovanje temperature neposredno pred začetkom ponovnega valjanja je pri zastareli konstrukciji peči in regulaciji vodenja povzročalo neposreden vpliv plamena na površino materiala. Temperatura površine slaba se je pri prehodu slaba skozi cono izenačevanja znižala, tako da iz končnega stanja temperature slaba na izstopu iz peči ni bilo možno ugotoviti nedopustno visoke temperature površine slaba v peči.

Na **sliki 5** so prikazani rezultati meritev temperatur v slabu po prvi fazi rekonstrukcije potisne peči. Meritve smo opravljali pri ogrevanju nerjavnega jekla kvalitete ACRONI 11 in pri temperaturah peči (1250—1320° C). Meritve na kvaliteti DINAMO nismo nadaljevali, ker se ta kvaliteta po rekonstrukciji peči zalaga v potisno peč v toplem stanju. Pri meritvah se je pokazalo, da se slabi v coni izenačevanja ne ogrevajo enakomerno. Posebni problemi so nastopali zaradi ohlajanja slaba na 21. poziciji oziroma neposredno pred izstopom slaba iz peči. Potek temperatur v odvisnosti od časa zadrževanja slaba na zadnji poziciji smo izmerili in registrirali z optično kamero (3). Problem je uspešno rešen z vgraditvijo dodatnih gorilnikov, prečno usmerjenih vzdolž čelne hladne stene peči neposredno nad izstopno drčo. Iz poteka temperatur na merilnih mestih št. 2 in št. 3 je razviden

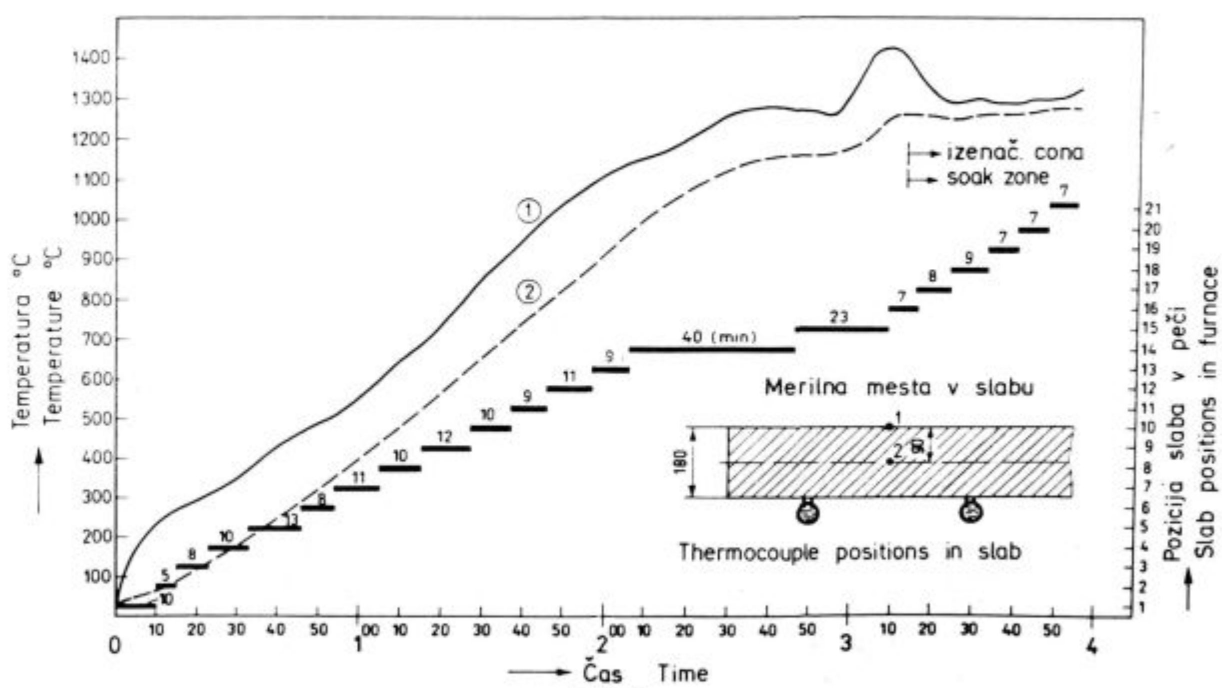
close to the measuring location providing mechanical and thermal shock protection and ensuring relatively quick response. Thus, the volume % of O_2 could be measured even in the combustion chamber of the furnace which is difficult of access.

***Figure 3** shows the optimum domain of air ratio which could be achieved and maintained in the redesigned furnace. The air ratio set point is changed according to steelgrade. All measurements estimated the pressure regulation in the furnace. The planned design improvements in the furnace pressure regulation system will make the operation of other regulations during the minimum heat load more accurate.*

3.2 Slab Temperature Measurement

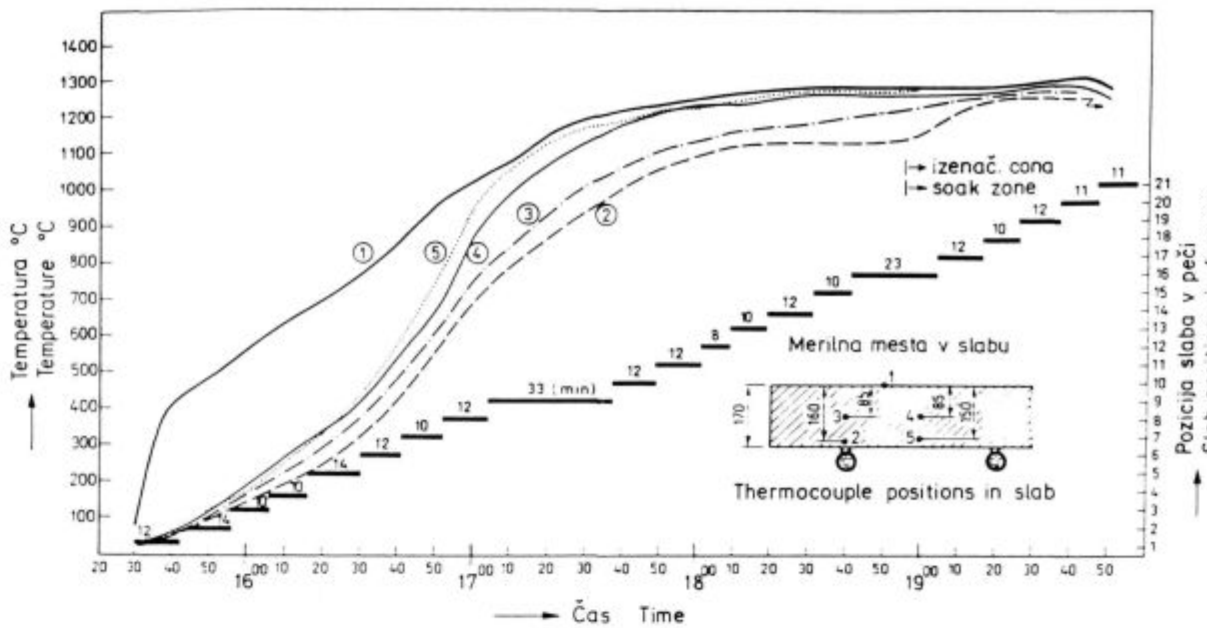
***Figure 4** shows the measured temperature course of the electrical steel slab on passage through the furnace. These measurings were carried out by "drag" thermocouples before the furnace was redesigned. The example of measurements shown by **Figure 4** was performed to prove that directly after a longer standstill an overheating occured on the material surface inspite of the maximum zone temperature of 1290° C.*

The quick temperature raise, directly before the rolling was started anew, caused the flame to affect the material surface directly in the old furnace model. The slab surface temperature decreased during the slab transition through the soak zone, thus giving no evidence of such extraordinary high slab surface temperatures in the furnace. Figure 5 shows the results of slab temperature measurements after the first phase of the push-type slab reheating furnace redesign was finished. The measurements on the ACRONI 11 (AISI 304) stainless steels were performed at furnace temperatures between 1250 and 1320° C. The measurements on the electrical steels were not performed at all as after the furnace design was changed these qualities of steel

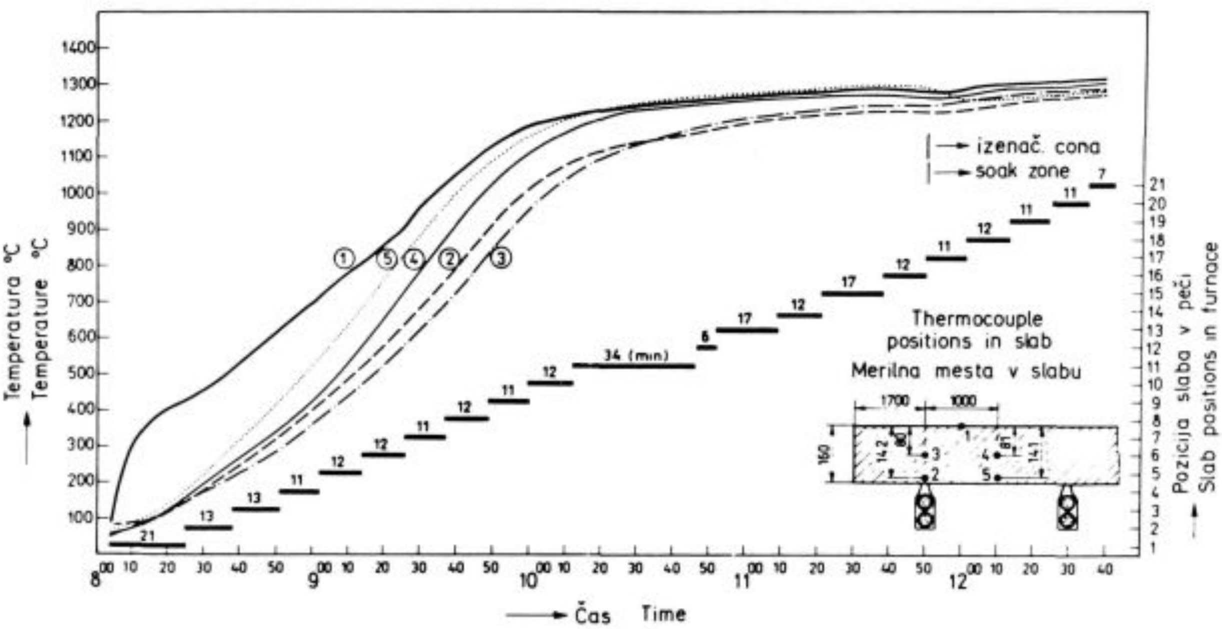


Slika 4
Izmerjene temperature na površini in v sredini slaba pri prehodu slaba skozi peč

Fig. 4
Measured temperatures at the surface and within the slab on passage through the push-type furnace



Slika 5
Izmerjene temperature v slabu pri prehodu skozi potisno peč (po rekonstrukciji)
Fig. 5
Measured temperatures of the slab surface on passage through the pusher furnace after design change



Slika 6
Izmerjene temperature v slabu pri prehodu skozi potisno peč (nove drsne tračnice)
Fig. 6
Measured temperatures of the slab surface on passage through the pusher furnace (New skidrail)

močan vpliv vodno hlajenih tračnic, ki v prvi fazi rekonstrukcije peči niso zamenjane. **Slika 6** kaže potek temperatur v slabu po izvedeni drugi fazi rekonstrukcije peči oziroma po zamenjavi vodno hlajenih drsnih tračnic. Slika kaže bistveno izboljšanje poteka ogrevanja slaba na merilnih mestih št. 2 in št. 3, ki potrjuje teoretične simulacije z dvodimenzionalnim matematičnim modelom[1]. Meritve kažejo na možnost skrajšanja časa prehoda slaba skozi peč oziroma povečanja storilnosti peči in s tem znižanja specifične porabe toplotne energije.

have been charged into the furnace, when hot. The measurements showed no uniformity of slab reheating in the soak zone. The slab cooling on the position 21 caused problems i. e. directly before the slab left the furnace. The temperature course depending on the period of time spent by the slab on the last position was measured and registered by an optic camera[3]. The problem was successfully solved by installation of additional transversal burners mounted along the forehead of the cold furnace wall directly above the furnace exit. The

3.3 Razvoj in verifikacija matematičnih modelov

3.3.1 Model rekuperatorja

Za simuliranje prenosa toplote od dimnega plina, ki izstopa iz peči, na zrak v rekuperatorju smo izdelali matematični model[2]. Količino izmenjane toplote v rekuperatorju smo računali po enačbi (1).

$$Q = k F \Delta \vartheta_{sr} \quad (1)$$

v enačbi je:

k toplotna prestopnost (W/m^2K)
F površina za izmenjevanje toplote (m^2)
$\Delta \vartheta_{sr}$ logaritemska srednja temperatura (K)

Za izračun izstopne temperature dimnih plinov in izstopne temperature zraka potrebujemo še enačbo za toplotno bilanco izmenjave toplote med dimnim plinom in zrakom:

$$V_{dp}\eta(\vartheta_{dpv}c_{dpv} - \vartheta_{dpi}c_{dpi}) = V_{zr}(\vartheta_{zri}c_{zri} - \vartheta_{zrv}c_{zrv}) \quad (2)$$

V enačbi (2) je:
η — izkoristek toplote dimnih plinov,
V — pretok,
ϑ — temperatura,
c — specifična toplota
indeksi:
dp— dimni plini,
zr — zrak,
v — vstop,
i — izstop

Simulacija izmenjave toplote poteka po naslednji shemi: predpostavimo izstopno temperaturo zraka, izračunamo izstopno temperaturo dimnih plinov iz rekuperatorja, izračunamo izstopno temperaturo zraka in postopek izračuna ponavljamo, dokler se predpostavljena in izračunana temperatura zraka ne ujameta. Na podlagi opisane osnovne sheme smo izdelali matematični model za igličasti rekuperator in simulirali različne možne pogoje pretokov zraka in dimnih plinov. Iz rezultatov simuliranja različnih pogojev temperatur in pretokov dimnega plina in zraka smo ugotovili, da je pri normalnem delovanju regulacije vleka dimnih plinov in pri pretakanju zadostne količine dimnih plinov možno z obstoječim rekuperatorjem pri dobrem vzdrževanju doseči izstopno temperaturo zraka 400°C. Na podlagi meritev in simulacij različnih pogojev z modelom smo ugotovili, da zamenjava obstoječega rekuperatorja ni nujno potrebna.

3.3.2 Model prenosa toplote v sistemu dimni plin—stena peči—vložek

V algoritmu prenosa toplote v peči sta upoštevana prevajanje toplote v steni peči in v slabu ter prenos toplote od dimnih plinov na steno peči in slab ter izmenjava toplote med steno in slabom. Peč razdelimo na navidezne segmente in predpostavimo, da je temperatura dimnih plinov in stene peči v posameznem segmentu konstantna. Izhodiščni podatek je poznana temperatura notranjega površja stene. Čas ogrevanja razdelimo na kratke časovne intervale. Čas prehoda slaba iz enega v drugi navidezni segment peči je določen s časom zadrževanja slaba v posameznem segmentu, ki je tudi znan in je lahko od segmenta do segmenta različen. Temperaturo dimnih plinov v posameznem segmentu peči izračunamo samo enkrat, ker bi bilo računanje sicer prezamudno, če bi jo računali v vsakem časovnem intervalu. Za določitev toplotnih prestopnosti moramo poznati temperaturo dimnih plinov, temperaturo površja stene segmenta in temperaturo površja slaba.

*temperature at measuring points 2 and 3 **(Fig. 5)** shows how strongly it was affected by the water cooled skidrails which have not been exchanged during the first phase. **Figure 6** shows the slab temperatures after the second phase of redesign i. e. after the water cooled skidrails have been exchanged for new ones. The improvement is clearly seen at the measuring points 2 and 3 verifying the theoretical simulation by two dimensional mathematical models[1]. The measurements indicate a possibility of shortening the time the slab needs for its passage through the furnace which would increase furnace throughput and reduce the specific energy consumption.*

3.3 Development and Verification of Mathematical Models

3.3.1 Recuperator Model

A mathematical model[2] for simulation of exhaust gases heat exchange in the recuperator was designed. The quantity of exchanged heat in the recuperator was calculated by the following equation:

$$Q = k F \Delta\vartheta_{sr} \quad (1)$$

k = heat transfer coefficient
F = heat exchange area (m^2)
$\Delta\vartheta$ = logarithmic average temperature difference (K)

To calculate the flue gas output temperature and the air output temperature another equation is necessary, accounting for the heat balance between flue gases and air. The equation is as follows:

$$V_{dp}\eta(\vartheta_{dpv}c_{dpv} - \vartheta_{dpi}c_{dpi}) = V_{zr}(\vartheta_{zri}c_{zri} - \vartheta_{zri}c_{zri}) \quad (2)$$

meaning:
η — flue gas heat efficiency
V — flow
ϑ — temperature
c — specific heat
indexes:
dp— flue gases,
zr — air,
v — input,
i — output

Simulation of heat exchange is carried out according to the following concept: First, an output air temperature is presumed and the agreement between the presumed and estimated air temperature is achieved by successive approximation. A mathematical model for acicular recuperator was created and the simulations of its performance for various air and flue gas flows were carried out on the basis of the described basic concept. The results obtained by simulation proved that the existing recuperator if well maintained could produce the output temperature of 400°C providing the flue gas draft regulation operates normally and the amount of flue gas flow is sufficient. Measurement results and simulations of various conditions showed the exchange of the existing recuperator would not be necessary.

3.3.2 Model of Heat Flow in the System Flue Gas—Furnace Wall—Slab

The model of heat transfer within the furnace chamber considered the heat conduction inside of the furnace wall, and the slab together with the heat radiation from the flue gases to the wall and the slab, as well as the heat radiation between the wall and the slab.

The furnace was divided into 21 fictitious zones the flue gas temperature in each individual fictitious zone was presumed to be constant, and the temperature of the interior of the furnace wall was given. The heating

Temperatura površja stene segmenta je merjena. Za temperaturo površja slaba vzamemo temperaturo, ki jo je imel slab na površju, ko je vstopil v segment peči. Temperaturo dimnih plinov predpostavimo in nato izračunamo iz pogoja, da je vsota toplotnih tokov na steno peči in od stene peči enaka nič. Pri tem upoštevamo karakteristike stene peči oziroma nestacionarno prevajanje toplote v steni peči, vrsto uporabljenega goriva, razmernik zraka, debelino plinske plasti in razmerje površin.

3.3.3 Model prevajanja toplote v slabu

Zanesljivost merjenja temperatur v coni izenačevanja z »vlečnimi« termoelementi je problematična. Termoelementi in zaščitna keramika so v coni izenačevanja (nad 1200° C) v takšnem stanju, da je med vodnikoma možen kontakt na površini slaba. V večini primerov termoelementi ne zdržijo na tej temperaturi do izstopa slaba iz peči. Izvedba meritev v primeru več merilnih mest je zelo zahtevna in draga. Zato je za celovit študij poteka ogrevanja potrebno kombinirati meritve in matematični model, ki je verificiran v zanesljivem področju merjenja temperatur. S tako verificiranim modelom lahko simuliramo različne pogoje in optimiramo storilnost peči glede na zahtevano končno temperaturo in temperaturno diferenco v slabu. Mejne pogoje na zgornji in spodnji površini slaba računamo z vnaprej opisanim modelom prenosa toplote v sistemu dimni plin—stena peči—površina vložka in nato temperaturno polje v slabu s Fourierjevo parcialno diferencialno enačbo za prevajanje toplote v neustaljenem temperaturnem polju, ki jo rešujemo numerično z metodo končnih diferenc.

$$\frac{\delta \vartheta}{\delta t} = a \frac{\delta^2 \vartheta}{\delta x^2} \tag{3}$$

V enačbi (3) je:
ϑ = temperatura, °C;
t = čas, sek
x = debelina slaba, mm;
a = temperaturna prevodnost, m^2/s.

Specifična toplota in toplotna prevodnost v modelu nastopata kot veličini, ki sta odvisni od temperature. Pri-

time was divided into short time intervals. The time interval of slab transition from one fictitious zone to another was estimated by the slab retention time interval in each individual fictitious zone which were known, too, yet might differ. The flue gas temperature of each fictitious zone of the furnace was calculated only once as the temperature estimation of each individual time interval proved to be a waste of time. To determine the heat transfer the temperatures of the gases, of the fictitious zone surface and of the slab surface have to be known. The temperatures on the inner surface of the side wall were measured. For the slab surface temperature the value was taken which it had at the entrance of the fictitious zone. The temperature of the flue gases was presumed and then calculated on condition the sum of heat flows taking direction to the wall and those radiating from the furnace wall equaled zero. In doing so, the furnace wall characteristics and unsteady-state conduction within the furnace wall, the fuel applied, air ratio, flue gas thickness and surface ratio were considered.

3.3.3 Model of Heat Conduction Within Slab

The temperature measuring by "drag" thermocouples within the soak zone is not entirely reliable. The heat can cause errors in measuring due to its effects on thermocouples (wire contact). The thermocouples are usually damaged before the passage is finished. Temperature evaluation at several measuring points is very expensive and difficult. This results in necessity of a detailed study of heat procedures based on measurements combined with mathematical models, the latter being verified at a reliable measuring range. Such a verified model may simulate divers conditions including the optimum furnace throughput considering the required end temperature and the temperature difference within the slab. The boundary conditions for the top and bottom slab surface are estimated by the previously described model of heat transfer in the system flue gas-furnace wall-slab surface.

Then the temperature field within the reference slab is estimated by the partial differential equation for heat

Tabela 1.: Primer zapisa podatkov o zgodovini ogrevanja slaba
Table 1: *Example of data plot or slab reheating history*

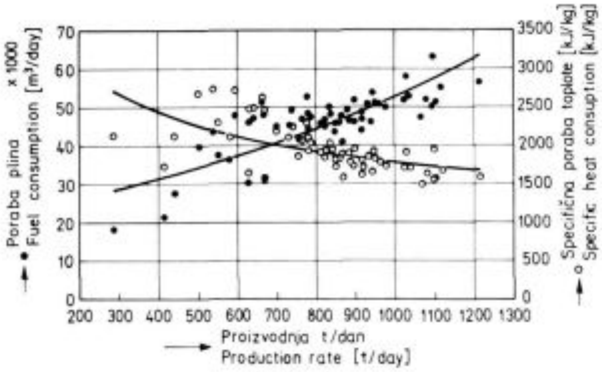
24. interval oz. slab;

odsek	časovni interval		ϑ	$\Delta\vartheta$	λ	c_p	ϑ_p	temperaturni profil v slabu °C						
	min	s	°C	K	W/mK	J/kgK	°C							
1	11	0	89	245	15.0	484	850	55	40	37	48	84	157	282
2	8	30	137	287	15.7	508	850	77	65	70	95	147	232	352
3	8	30	182	303	16.4	528	850	108	99	109	143	201	288	402
4	10	0	232	304	17.0	545	850	151	144	158	195	256	340	447
5	9	10	276	292	17.7	554	850	196	189	204	241	300	381	481
6	11	50	339	249	18.5	563	850	295	270	273	302	355	428	519
7	10	10	487	405	20.5	577	1150	503	416	382	402	474	603	787
8	11	0	634	329	22.2	599	1150	687	589	544	553	616	725	873
9	8	10	749	248	24.0	615	1150	870	745	678	669	712	798	916
10	9	40	864	201	25.2	639	1150	998	887	819	797	819	880	971
11	8	0	971	208	26.4	674	1280	1105	994	922	897	920	990	1103
12	10	50	1071	145	27.8	716	1280	1163	1086	1036	1018	1035	1086	1162
13	8	10	1123	108	28.7	740	1280	1192	1135	1097	1084	1097	1135	1192
14	8	0	1169	106	29.2	762	1320	1214	1171	1143	1135	1149	1185	1241
15	9	0	1205	83	29.5	781	1320	1233	1203	1184	1180	1193	1222	1263
16	12	0	1238	59	29.8	793	1320	1252	1233	1223	1222	1232	1253	1281
17	10	40	1243	31	29.9	795	1280	1234	1234	1235	1239	1245	1254	1265
18	8	0	1247	31	29.9	796	1280	1236	1237	1239	1244	1250	1258	1267
19	8	0	1250	29	29.9	797	1280	1240	1241	1243	1247	1253	1260	1269
20	8	40	1253	26	30.0	798	1280	1243	1244	1247	1251	1256	1262	1270
21	10	0	1256	24	30.0	799	1280	1247	1248	1250	1254	1259	1264	1271

mer izračuna poteka ogrevanja slaba pri prehodu skozi peč z dejanskim časom zadrževanja slaba na posamezni poziciji v peči je prikazan v **tabeli št. 1**.

4. SPECIFIČNA PORABA TOPLOTE

Specifična poraba energije na potisni peči že vrsto let konstantno pada kot posledica različnih ukrepov v proizvodnji in povečanega deleža toplo založenih slabov. Najizrazitejši padec je bil po rekonstrukciji peči. V letu 1986 je znašala povprečna letna specifična poraba toplotne energije 2739 kJ/kg. Rekonstrukcija peči je bila izvedena v letu 1987. V letu 1989 je bila povprečna letna specifična poraba toplote 2230 kJ/kg. V treh mesecih v letu 1989, pri sistemu pet dni obratovanja in dva dni »slepega« kurjenja (sobota in nedelja), je dosežena povprečna specifična poraba toplotne energije 2025 kJ/kg. V letu 1990 se tendenca znižanja specifične porabe nadaljuje in je močno odvisna od dosežene povprečne storilnosti peči. Odvisnost specifične porabe toplotne energije potisne peči od storilnosti peči za obdobje maj—julij 1990 je prikazana na **sliki 7**. Pri storilnosti peči 900—1200 t/dan je imela peč specifično porabo toplote med 1500 in 2000 kJ/kg (sl. 7). Glede na relativno kratko dolžino peči in nekoliko višjo končno temperaturo ogrevanja slabov so doseženi rezultati primerljivi z rezultati uvajanja nove tehnologije ogrevanja na podobnih pečeh v svetu[1].



Slika 7

Odvisnost specifične porabe toplote od storilnosti peči

Fig. 7

Relation between specific heat consumption and furnace throughput

Nadaljnje znižanje specifične porabe toplote na potisni peči bo možno s povečanjem deleža vroče založenih kontinuirno ulitih slabov, skrajšanjem časov ogrevanja oziroma zvišanjem storilnosti peči in z uvajanjem procesnega računalnika v sistem vodenja peči, kar je v Železarni Jesenice v fazi realizacije.

5. ZAKLJUČKI

V okviru raziskave, z uporabo sistema za avtomatsko akvizicijo podatkov, smo izvedli toplotno tehnične meritve pred rekonstrukcijo potisne peči in po njej. Potek temperatur v slabu v celotnem času ogrevanja smo spremljali z matematičnim modelom in z meritvami temperatur na različnih mestih po preseku slaba. Rezultati meritev so pokazali izboljšanje kvalitete ogrevanja slabov in znižanje povprečne letne specifične porabe energije za ca. 20 %. Z realizacijo projekta vodenja potisne peči s procesnim računalnikom bo omogočena nadaljnja optimizacija tehnologije ogrevanja slabov z minimalno porabo energije.

transfer in an unsteady temperature field by Fourier solving it by the numerical method of finite differences.

$$\frac{\delta \vartheta}{\delta t} = a \frac{\delta^2 \vartheta}{\delta x^2} \qquad (3)$$

ϑ = *temperature in °C*
t = *time in sec*
x = *slab thickness in mm*
a = *temperature conductivity in m^2/s*

Specific heat and heat conductivity represent values depending on temperature. ***Table 1*** *shows an example of reheating process calculation of the slab passing through the furnace considering the actual intervals of the slab retention in each individual fictitious zone.*

4. SPECIFIC HEAT CONSUMPTION

The specific energy consumption of the push-type slab reheating furnace has been reduced constantly in the past years which is considered to depend on regulations concerning the process of manufacturing and increased rate of hot charged slabs. The most significant decrease in energy consumption occured immediately after the redesign was completed. In 1986, the average yearly specific heat consumption amounted to 2739 kJ/kg. In 1987 the furnace was redesigned, and the year 1989 showed 2230 kJ/kg of specific heat consumption. The furnace was heated seven days a week while operating five days (Saturdays, Sundays idle heating). In the first three months of 1989 the average specific heat consumption amounted to 2025 kJ/kg. The tendency towards reduction of specific heat consumption is even more emphasized in 1990, but greatly dependent on the furnace average throughput. Figure 7 shows the dependence of the specific heat consumption on the push-type slab reheating furnace throughput from May through July 1990. The furnace throughput of 900—1200 t/day equaled the specific heat consumption of 1500 to 2000 kJ/kg ***(Fig. 7)****. Considering the relatively short size of the furnace and the higher slab reheating final temperature the obtained results could be ranked among those of new heating technology of similar furnaces abroad[1]. The reduction of specific heat consumption of the push-type slab reheating furnace will be furthered by the increasing share of hot continuously cast slabs by shortened heating time and higher throughput of the furnace, respectively, as well as by introduction of a process computer to furnace control which is being installed in the Jesenice Steelworks, at the moment.*

5. CONCLUSION

Research of the push-type slab reheating furnace was performed by automatic data acquisition before and after the furnace redesign. The temperatures within slabs were checked by the mathematical model and temperature measurements at several measuring points along the slab cross section surface. The measurement results showed improved slab heating and an average yearly specific heat consumption reduced for about 20 %. The process computer control of the push-type reheating furnace will reduce the energy consumption to minimum and improve the slab reheating technology considerably.

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