USE OF ULTRA-LOW FREQUENCY FURNACES FOR FERROALLOYS MELTING

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ABSTRACT

Development of the technique of ferroalloys melting using charge materials of small fraction fines, production wastes and gas cleanings dust is one of the major environmental and economic problem facing the metallurgical industry.

Various techniques of processing fine-dispersed charge materials were developed at "ZFP" PJSC using the furnaces of alternating current and furnaces of direct current.

The growth trend of sales volumes of ferroalloys cut of 10-50 mm, 10-80 mm predetermined significant increase in the volume of fraction screenings of 0-10 mm.

Possibilities of selling fractionating screenings are limited. The traditional way to process the screenings - melting of screenings by adding the appropriate grade of alloy to the composition of the charge in the ore-smelting furnaces is accompanied by quite substantial losses through the waste and loss. Depending on the volumes of uploaded screenings on the mouth, the losses reached 15-20%.

Technique for processing of fractionation screenings of ferrosilicon and ferrosilicomanganese was worked out by "ZFP" PJSC on different types of furnaces. At the plant, there was a unique opportunity to work out the technique of screenings of ferrosilicomanganese МнС17 processing on the same furnace at its operation under alternating current and ultra-low frequency and to compare the obtained results with the proven technique of processing of МнС17 screenings on direct current furnaces. While working out the technique on ultra-low frequency furnace better results on extraction, loss, consumption of electricity etc. were achieved.

In this study, the various ferroalloy furnaces are compared with ultra-frequency furnaces. Advantages and disadvantages, important design solutions for ensuring the required technique are presented in details. The peculiarities of introducing the technique for direct current and ultra-low frequency furnaces are estimated.

KEYWORDS: *ultra-low frequency furnace, direct current furnace, processing of fractionation screenings, ore-thermal melting.*

1. INTRODUCTION

"Zaporizhzhia Ferroalloy Plant" PJSC ("ZFP" PJSC) is one of Europe's largest producers of ferroalloys. The plant was put into operation on October 10, 1933. "ZFP" PJSC is one of Europe's largest producers of ferroalloys, and the only one that smelts a wide range of manganese and silicon ferroalloys as well as metal manganese. At the plant, 31 ore-thermal electric furnaces with transformers of installed power from 5 to 27.6 MVA are being operated.

Prospects of the enterprise are guaranteed by the proximity of raw and power bases of Dnipro region with well-developed transport systems.

The plant produces 400-450 thousand tons of high-quality ferroalloys per year, namely ferrosilicon, ferrosilicomanganese, ferromanganese.

At the same time, stringent requirements for the breakup of ferroalloys have been established in the market of ferroalloys in recent years. This situation has identified the need to develop techniques for processing (melting) of fractionation screenings of ferroalloys.

Nowadays, direct current furnaces are the most widely spread for these purposes in the world practice. However, this technique in the reconstruction of the existing furnaces requires complete replacement of electric furnace of alternating current, furnace transformer and high capital costs for reconstruction.

2. FEATURES OF THE FURNACE OF ULTRA-LOW FREQUENCY

At "ZFP" PJSC, different processing techniques of ferroalloys fractionation screenings were considered and tested:

- on furnaces of alternating current of both low (7.5MVA) and high power (up to 27.6 MVA);

- in 2010 two furnaces of direct current - DShPT-5.0 were put into operation. The main difference between the furnaces of direct current DShPT-5.0 and known analogues is the absence of the bottom electrode;

- in 2014 the reconstruction of the PKO furnace – 7.4MVA was made with its transfer to the ultra-low frequency (RKOUNCh – 7.4MVA).

During the reconstruction the furnace was equipped with the reversible three-phase transducer V-TPZhR-3x10.5-205 UKhL4 by "Preobrazovatel'" PJSC which characteristics are shown in Table 1.

Table 1: Characteristics of the reversible three-phase transducer V-TPZhR-3x10.5-205 UKhL4

Serial No.	Name of characteristics	Measurement unit	Value
1	Rated voltage of the supply mains	кV	10
2	Rated power consumed by DC from network	кVA	6700
3	Rated output current of the electrode	A	3x18500
4	Rated output current of the transducer	A	3x10500
5	Permissible overload of the transducer of current with a fully operating thyristors	%	20
6	Rated voltage of the transducer	V	205
7	Rated line voltage of the electrodes	V	170
8	Rated active power of the furnace	kW	5500
9	Range of reverse frequency control	Hz	0.1-0.001
10	Number of steps of the off-circuit tap-changer transformer	pcs	7
11	Value of control step of the off-circuit tap-changer, not more than	V	6÷6.5
12	Efficiency factor of the rectifier in the nominal mode, not less than	%	94.0
13	Shear coefficient in the first harmonic of the rectifier in nominal mode (cos □1) at $\alpha = 0$, not more than		0.925
14	Transformation curcuit	3-phase paved reverse	
15	Depth of the smooth regulation of the output current	%	10-100
16	Accuracy of the output current maintaining, not worse than	%	2
17	Accuracy of the arc power maintenance, not worse than	%	5

Schematic of the power circuits of the ultra-low frequency furnace RKOUNCh – 7.4MVA in shown in Figure 1.

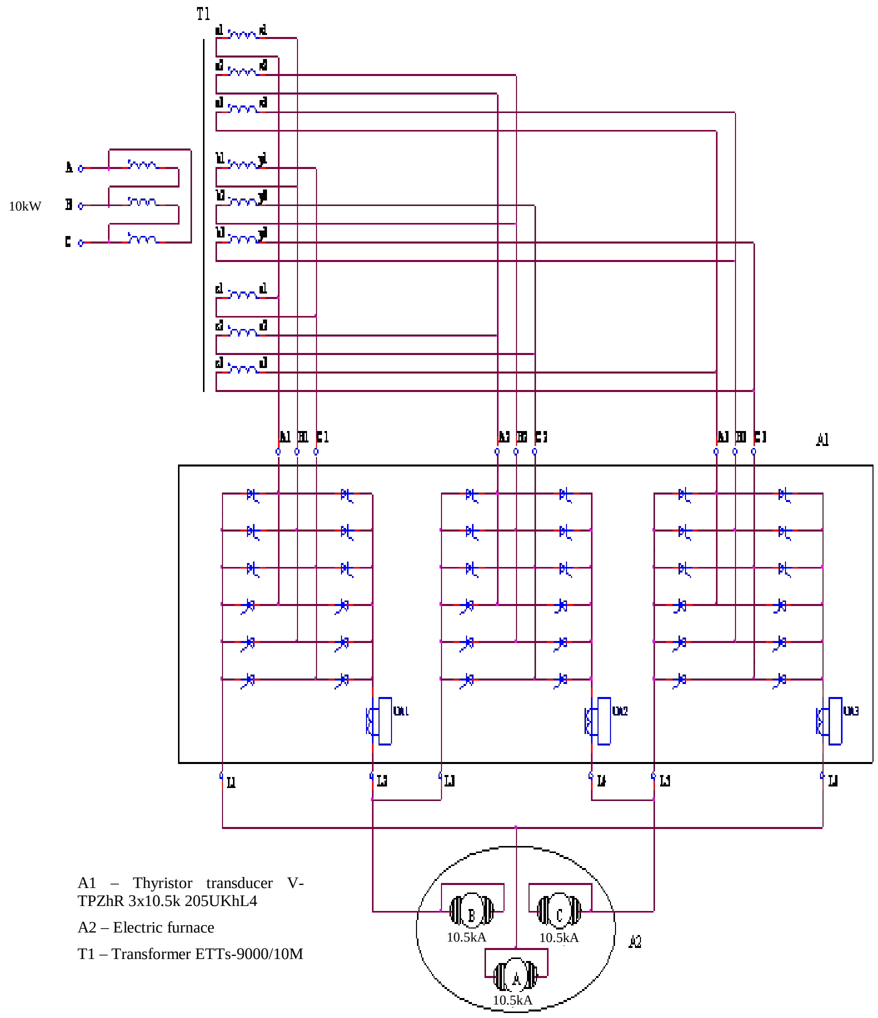


Figure 1: Schematic of the power circuits of ferroalloy ultra-low frequency furnace RKOUNCh – 7.4MVA

Figure 2 shows the current waveform of thyristor bridges and furnace electrodes that demonstrate the power supply operation.

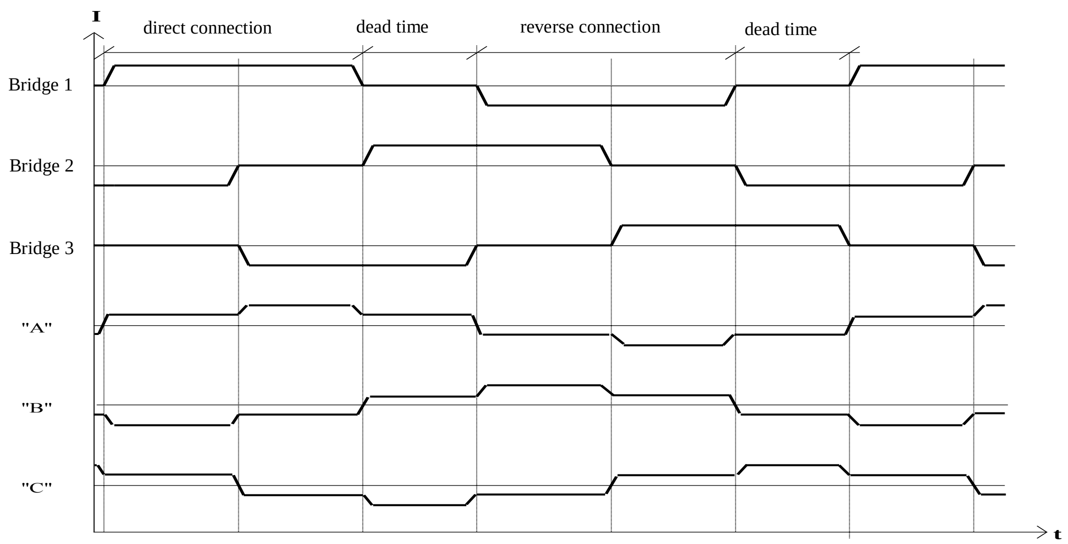


Figure 2: Diagrams of currents bridges and furnace electrodes

Effective current value of the furnace electrode is determined from the formula:

$$I_{lrms} = \sqrt{2} * I_d, \qquad (1)$$

where I_d – rectified current of each bridge.

The effective value of the voltage under the electrode is calculated by the formula:

$$U_{lrms} = \sqrt{2} * U_d / 3, \qquad (2)$$

where U_d – rectified voltage of each bridge taking into account the voltage switching decrease, angle of thyristors control and resistance losses.

Hence, active power introduced into the furnace:

$$P_d = I_{lrms} * U_{lrms} * 3 = 2 * I_d * U_d \qquad (3)$$

Alternation under the electrodes of the furnace of currents with changing amplitude by 2 times at a particular frequency of reverse leads to a rapid descent of the charge and mixing of the melt.

By adjusting the duration of current flow of each rectifier bridge the current can be changed separately in each electrode down to its shutdown in one of them. Symmetrical loading of supply mains phase is provided.

Stabilization of the current in each phase of low frequency allows at the same electrode currents keeping different voltages under them, and without symmetry breaking of the supply mains currents. In addition, the current stabilization provides a soft arc mode that reduces the metal loss, as well as creates favourable conditions of electrodes sintering, increasing their durability and reducing consumption.

Figure 3 shows the actual values of the electrodes currents.

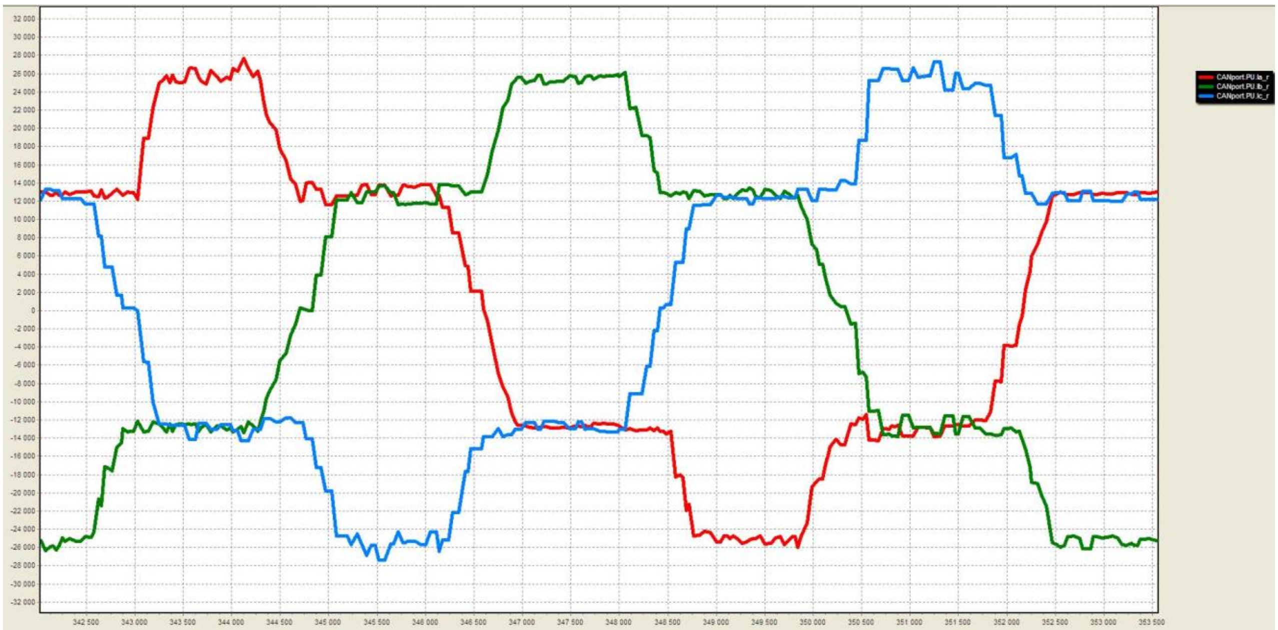


Figure 3: Actual values of the electrodes currents

3. FURNACES' PARAMETERS AT TECHNOLOGY WORKING OUT

For the fractionation screenings processing techniques allowing for the furnaces parameters were developed at "ZFP" PJSC.

Three types of furnaces are used:

- furnaces of direct current **DShPT-5.0**;
- furnaces of alternating current with frequency of 50Hz **RKO-7.4**
- furnace of ultra-low frequency **RKOUNCh–7.4.**

Table 2 shows the comparative characteristics of the furnaces.

Table 2: Main technical specifications of furnaces for screenings melting

Ser. No.	Name of parameter	RKO-7.4	DShPT-5.0	RKOUNCh–7.4
1	Frequency, Hz	50	0	0,1÷0,001
2	Number of electrodes	3	2	3
3	Type of electrodes	Self-baking	Graphitized	Self-baking
4	Diameter of electrodes, mm	600	300	600
5	Total power consumption of the circuit, kW	7400	5000	6700
6	Maximum active power of the furnace, kW	5600	4250	5500
7	Linear secondary voltage, V	139÷175	126÷161	139÷175
8	Electrode current of furnace, kA	26.5	15.5	30.0*
9	The diameter of the furnace bath, mm - on top - on-button	5800 3200	2650 1450	5800 3200
10	Height of furnace bath, mm	1620	1360	1620
11	Lining material	periclase	periclase	periclase

* maximum peak value is 2*Id

4. TECHNIQUE OF FRACTIONATION SCREENINGS MELTING

Ferrosilicomanganese produced by fractination screenings melting must meet the requirements of State Standard of Ukraine (DSTU) 3548-97 (Table 3).

Table 3: Requirements of State Standard of Ukraine (DSTU) 3548-97 to ferrosilicomanganese produced by fractionation screenings melting method

Alloy grade	Mass fraction of the element, %				
	silicon	manganese	carbon	phosphorus	sulfur
		Not less than	Not more than		
MнC17	15.0-20.0	65.0	3.5	0.6	0.03

Used at the time of reconstruction completion of the furnace **RKOUNCh–7.4**, the techniques of screenings processing were based on a periodic process of melting, heating and melt tapping.

The following components are used as charge materials:

- Screenings MнC17 sized 0-10 mm;
- BCM17 sized 0-100 mm (metal-containing secondary raw materials);

- coke and dust pellets.

Charge materials are fed into the melting housing from charge stock separately to the dosage unit of the furnace. On dosage unit charge materials are fed at the prescribed ratio to the hopper bucket (V-1,2 m^3) mounted on weighing cells automatically in turn on the vibrating chutes.

Uploaded bucket is delivered to the furnace hoppers by electric bridge cranes - the content is poured into the hopper. The charge is further fed to the furnace bath by feed chutes.

Metal and slag are tapped through the notch simultaneously into steel buckets mounted in cascade. Buckets have a skull of manganese metal slag. Tapping duration is 10-20 minutes. At the end of the melt tapping the notch is sealed with a refractory mixture. Buckets with a melt are delivered to a casting bay. After removing the slag from the metal surface it is casted into cast iron molds or cavities in the screenings.

The cooled metal is extracted from the molds and sent to the warehouse of finished products for further processing and shipment to the customer.

Bypass of self-baking electrodes is made 2 times a day when the furnace is turned off. The total bypass is 300-500 mm. Baking of the electrodes is carried out by a planned increase in current loads following specially established schedule shown in Table 4.

Table 4: Schedules of the planned increase in current loads for electrodes baking

Mode of electrodes coking after bypass in normal conditions. Duration of 1 h 10 min *(bypass of electrode by up to **200 mm**)*			
Duration of baking	Period	Stated current load, кА	Permissible peak values, (not more than)
10 min	10 minutes	**5.0**	**7000**
20 min	10 minutes	**7.5**	**10500**
30 min	10 minutes	**10.0**	**14000**
40 min	10 minutes	**12.5**	**17500**
50 min	10 minutes	**15.0**	**21000**
1 h 10 min	20 minutes	**17.5**	**24500**
further	-	**18.5**	**30000**

For several months of developing RKOUNCh-7.4 furnace two different alloying techniques were developed: a batch process and a continuous process with a closed furnace mouth. Processing of МнС17 screenings for alternating current furnace was adopted as a basic technique.

4.1 Мнс17 Screenings Processing Technique With An Open Periodic Process Of The Furnace Operation

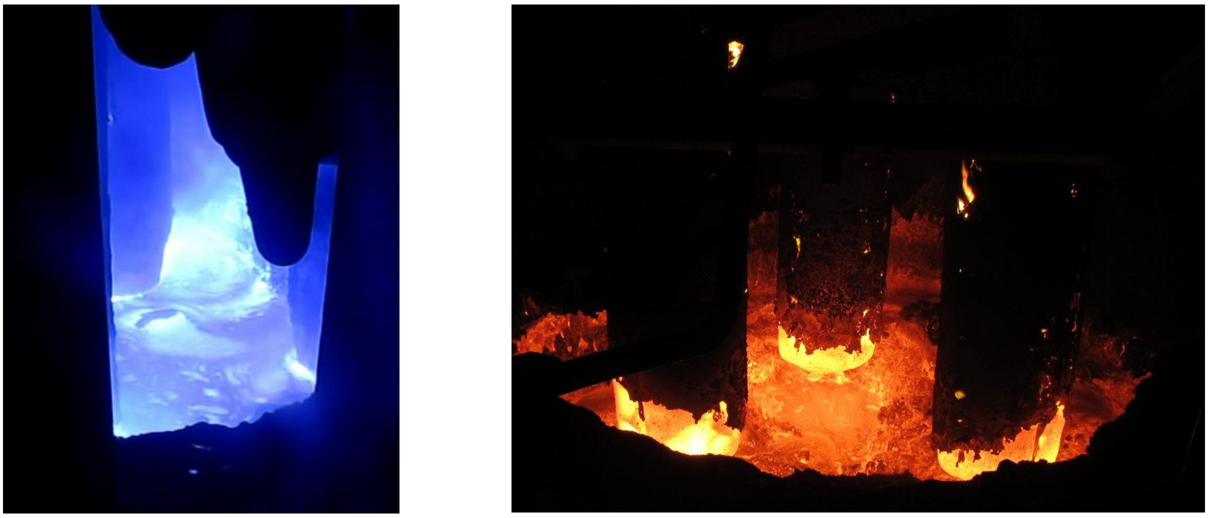
Composition of the charge for melting:
- screenings МнС17 - 5.0-6.0 tons;
- ВСМ17 - 1.7-1.9 tons;
- dust and coke pellets - 0.25-0.35 tons.

During the development of the furnace and working out of the technique more than 5 modes were tested that differ in the method of the charge uploading under the electrodes maintained by electric mode. The mode with the following features was chosen as the most optimal:

- the charge is uploaded in the furnace bath within 1-1.5 hours from the beginning of melting in small portions directly under the electrodes. Progress of melting is shown in Figure 4;

Figure 4: MнC17 screenings melting with an open periodic process

- voltage on the electrodes at the initial melting stage is maintained in the range of 35-45 V, after loading of all charge and the appearance of liquid phase around the electrodes, voltage increases by lifting the electrodes to 60-80 V and maintains until the end of melting automatically by adjusting the position of the electrodes;
- tapping of melt from the furnace – on disconnected furnace at a rate of 7,000-8,000 KWh. Processing of MнC17 screenings with an open periodic process of furnace operation is shown in Figure 5.



a) b)

Figure 5: Processing of MнC17 screenings with open periodic process of furnace operation:
a) active mixing of the melt during melting, b) the state of the furnace bath after the melt discharge

This technique allowed full melting of screenings and other components of the charge, active mixing of the liquid melt at the final stage, the normal discharge of the melt through the notch. The melt temperature on discharge was 1500-1570 degrees, and temperature of the metal at casting was 1250-1270 degrees.

Under these conditions, the furnace performance was about 38 base tons per day. Specific energy consumption was 1300 - 1330 kWh/base tons.

A distinctive feature was some reduction of active furnace power from 2.6 MW/h (AC) to 1.6-1.8 MW/hour (УНЧ furnace) by lowering the average value of the electrode current to 18.5 kA. This decrease is caused by the necessity to operate at lower values of the currents in the initial period of melting until formation of the crucibles under the electrodes.

4.2 Technique Of Мнс17 Screenings Processing In A Continuous Process With A Closed Furnace Mouth

Search of directions to further reduce energy consumption for the recycling process (alloying) of the screenings dictated the need to shift to the mouth operation mode, which in its turn was to reduce the loss of major elements with melting and eliminate heat losses through radiation from the molten liquid.

By selecting the ratio of the charge components as well as electric mode we managed to shift to a permanent technique of screenings alloying with a closed furnace mouth (Figure 6).

Figure 6: Processing of МнС17 screenings in a continuous process with closed furnace mouth

Composition of the charge has not been changed significantly: МнС17 screenings, wastes of own production, dust and coke pellets. To ensure continuity of the process and maintenance of the level, the charge was periodically (in 10-15) minutes fed on the mouth to the zone of maximum melting around electrodes. This method of uploading allows maintaining the level of the mouth at the same constant value. This provides the immersion of the electrodes in the mouth on 500-800 mm and the distance from the ends of the electrodes to the level of the notch does not exceed 500-600 mm.

The melt is taped when the furnace is turned on at power consumption of 6,000-7,000 KW/h, that is lower than the values of the melt tapping with the periodical open operation process by 1,000-2,000 KW/h.

The furnace performance indicators for 20 days of January 2015 of МнС17РБ screenings processing in a continuous process with a closed furnace mouth are shown in Table 5.

Table 5: The furnace performance indicators for 20 days of January 2015 of МнС17РБ screenings processing in a continuous process with a closed furnace mouth

Date	Number of melts	Total metall amount (t)		Weight of slag		Read of electricity (thousands kW)	Consumption of electricity on base t. (kW)
		(N. t)	(B. t)	Slag volume (N.t)	Mult.		
1	2	3	4	5	6	7	8
01.01.2015	7	52.080	55.48	11.00	0.21	48.0	865
02.01.2015	7	48.115	51.55	9.20	0.19	47.4	919
03.01.2015	7	54.300	58.19	10.00	0.18	49.2	845
04.01.2015	7	54.270	58.10	11.30	0.21	48.6	836
05.01.2015	7	50.455	53.95	10.60	0.21	46.2	856
06.01.2015	7	51.735	55.10	11.60	0.22	47.4	860
07.01.2015	7	49.600	52.80	11.50	0.23	51.0	965
08.01.2015	7	49.720	53.03	9.90	0.20	48.0	905
09.01.2015	7	47.995	51.12	11.20	0.23	46.2	903
10.01.2015	7	50.770	54.22	11.30	0.22	47.4	874
11.01.2015	7	47.055	50.12	13.30	0.28	47.4	945
12.01.2015	8	50.955	54.39	11.30	0.22	46.8	860
13.01.2015	7	53.550	57.19	8.80	0.16	48.0	839
14.01.2015	7	48.040	51.29	9.50	0.20	47.4	924
15.01.2015	7	50.780	54.72	12.20	0.24	49.8	910
16.01.2015	7	51.560	55.28	7.80	0.15	49.8	900
17.01.2015	7	56.890	60.85	9.20	0.16	48.6	798
18.01.2015	7	52.685	56.36	10.90	0.21	46.2	819
19.01.2015	7	47.170	50.50	7.90	0.17	48.6	962
20.01.2015	7	50.750	54.21	8.20	0.16	46.2	852

The technique of screenings remelting with closed mouth is still being improved. The efforts are focused on:

- increasing the mouth resistance, which will raise the furnace power and ensure an increase of the voltage on the electrodes without changing the depth of their immersion,
- ensuring the conditions for the continuous charge feeding on the mouth,
- exploring options for the melt tapping directly into the casting cavities.

Operation of RKOUNCh-7.4 furnace showed significant advantages of using ultra-low frequency currents for screenings melting technique. Along with an increase in furnace performance, reduction of specific energy consumption, reduction of screenings losses, more optimal conditions for the formation and operation of the electrodes are provided (Figure 7).

a) b)

Figure 7: Condition of electrodes: a) on RKO-7.4 furnace; b) on RKOUNCh-7.4 furnace

The main comparative industrial and technological indicators of the furnaces involved in the remelting of screenings at "ZFP" PJSC (Table 6).

Table 6: The main comparative industrial and technological indicators of the furnaces involved in the remelting of screenings at “ZFP” PJSC

Indicator	Measure-ment unit	Furnace DShTP-5.0	Furnace RKO-7.4	Furnace RKOUNCh-7.4	
				Periodical pro-cess	Continuous pro-cess with a closed furnace mouth
1	2	3	4	5	6
Performance	Bas. t/day.	21	44.5	38-40	45-51
Furnace power (daily aver-age)	MW/h	0.71	2.6	1.8-2.0	1.92-2.0
Specific energy consumption	kWh/bas t	860	1360	1300-1330	880-920
Consumption of electrodes / el. paste	kg/bas t	8.65	33.0	19.0	11.40
Loss of manganese	%	6.4	9.6	5-6	4.0
Loading of screenings for melting	t	5.0	5-6	5-6	Constant supply of burdering
Rated current strength on the electrodes	кА	10.0	22.0	18.5*	18.5*
Voltage on the electrodes	V	40-60	65-80	35-80	40-55
Electricity consumption for melting	thousand kWh	4.5-5	6-7	6-8	6-7
Duration of melting	h	4	2.5-3	2.5-3	3-3.5

*average operating current within oscillations is in the range of 12-30 kA

5 CONCLUSION

Application of reverse thyristor of three-phase transducer operating at ultra-low reverse frequency allowed us:

- to reduce the specific energy consumption compared with the furnace of alternating current;
- to significantly reduce losses and waste during remelting;
- to increase the reaction zone by 3 electrodes in comparison with the furnaces of direct current;
- to reduce consumption of electrodes;
- to organize mixing of the melt and intensive descend of charge by adjusting reverse frequency and changing the current waveform with the redistribution of power under the electrodes,
- to provide symmetrical loading of power line phases at asymmetrical loading of the electrodes;
- stabilization of the arc current and automatic maintenance of the voltage under electrodes of electric furnace.

As compared with the furnaces of direct current, the reconstruction of the furnace using 3-phase ultra-low frequency rectifier required substantially lower capital cost (more than 2 times less).

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