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Accusteel – Acoustic Computer Control System for EAF and BOF Steelmaking Process - Technology of XXI Century

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The Accusteel acoustic computer system is proposed as an alternative to existing certified computer complexes and systems. It is proved that the Accusteel computer system uses the method of determining of mass-average temperature, chemical composition of the melt in real time and has confidence which determined the correlation coefficient 0.97-0.99.

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Strictly as per the compliance and regulations of:

Accusteel – Acoustic Computer Control System for EAF and BOF Steelmaking Process - Technology of XXI Century

O. Shlik [α] & A. Shlik [σ]

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I. Introduction

Acoustic systems for the slag control and management by the noise of BOF melting process were widely used in the 1960s [1-2].

Accusteel - acoustic computer system - provides control of the BOF or EAF process in real time by the noise of smelting. The algorithm's simplicity [3] and reliability of acoustic computer system allows us control of the mass-average temperature, chemical composition and slag formation in the melt by noise of the process. Testing and improvement of the system's algorithm was held since 1992 to 2014 on BOF and EAF furnaces with a charge of 15 – 350 tons on steelmaking plants in Israel, Italy, Spain, Japan, China, Ukraine, Russia, USA, Brazil. More than one hundred thousand heats were made, the data of which was used in the comparative evidence-based analysis.

It was recognized that certified computerized process control and management systems can control the process only at the end of smelting. The correlation of these temperatures and chemical composition is determined by a correlation coefficient of 0.2–0.5.

Consider the experience of using the Accusteel system at one of the US companies, the company Nucor. It was DC electric arc furnace with charge 150 tons. The smelting process was controlled by the robotic complex. Where the temperature was measured out by a thermocouple and carbon percentage %C was calculated using temperature data.

The results of statistical analysis of 151 heats (the main technological parameters of smelting: temperature T°F and carbon percentage %C) in 150t. DC electric arc furnace are presented in table 1.

Table 1: Statistics of technological parameters of EAF heats

	T1°F	Ta1°F	T2°F	Ta2°F	%C1	%Ca1	%C2	%Ca2
Count	148	151	99	113	142	146	99	119
Average	2990	2973	2953	2969	0.036	0.035	0.036	0.035
St. Dev.	±41	±27	±59	±30	±0.003	±0.004	±0.003	±0.005

There is a statistical data analysis of 151 heats, main technological parameters: T1°F and T2°F - temperatures measured by thermocouple, Ta1°F and Ta2°F - temperatures determined by the computer system Accusteel in the moment of thermocouple measurement. The chemistry: the concentration of carbon in the melt %C1 and %C2 was determined by the plant's computer system that allows to determine the carbon percentage by the temperature mesured by thermocouple. The carbon percentage %Ca1 and %Ca2 which determined by the Accusteel system in the moment of the carbon percentage determination %C1 and %C2 are the same in absolute value to %C1 and %C2. The average mathematically expected temperatures are slightly varied within 5-17°F. Standard deviation of the temperatures of the melt determined by the thermocouple is twice the standard deviation of the temperatures determined by the Accusteel system.

The result of the correlation data analysis of determined temperatures and melt chemistry is presented in Table 2.

Table 2: Correlation analysis of technological parameters of heats

Function	T1°F (T2°F)	Ta1°F (Ta2°F)	%C1%(C2)	%Ca1%(Ca2)
Coefficient	0.72	0.98	0.22	0.99

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From Table 2 it can be seen that the correlation coefficient of temperatures measured by thermocouple and carbon percentage determined by the local method is low compared with the data of the Accusteel system, requires graphic confirmation.

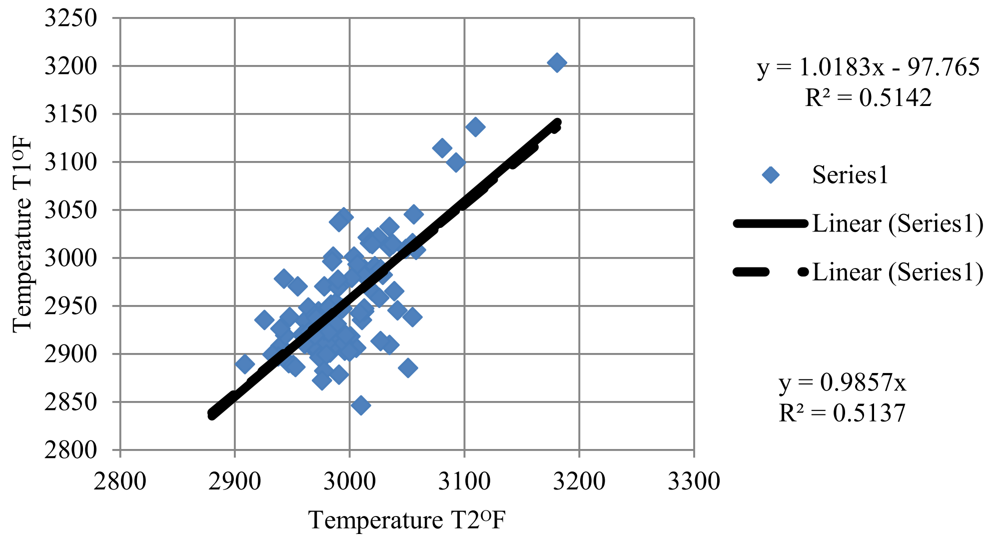

Fig. 1: Correlation function T1ºF (T2ºF) of temperatures determined by the local method of the thermocouple measurement

Fig.1 shows that the temperature data determined by the local method of the thermocouple measurement have a data spread with square deviations $R^2 = 0.51$. The temperature data determined by the computer control system was showed high reliability for local random variables, the information obtained confirmed by a correlation coefficient of 0.72.

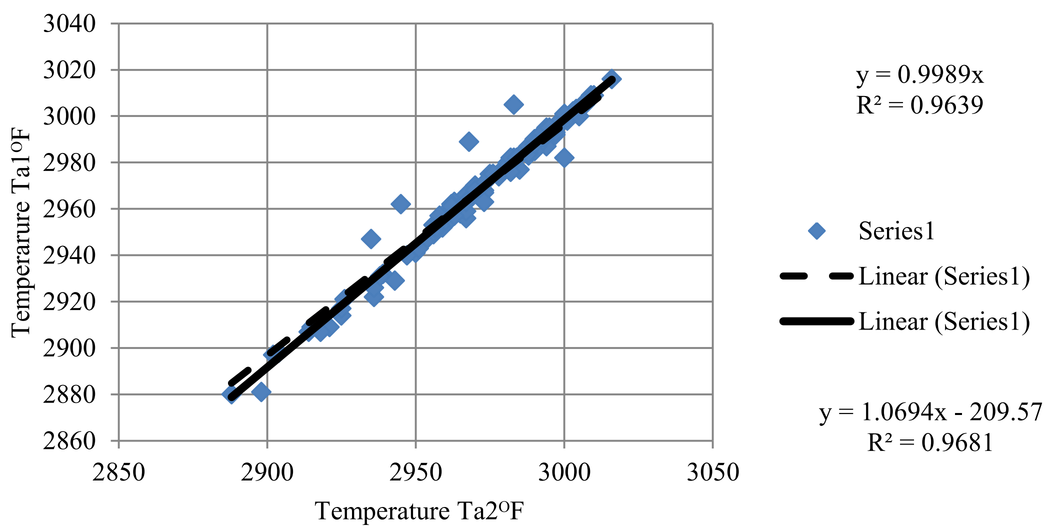

Fig. 2: Correlation function Ta1ºF (Ta2ºF) of mass average temperature determined by the Accusteel system

Fig. 2 shows that the data with great reliability describe straight lines, as evidenced by $R^2 = 0.96$ of quadratic deviations of the function describes of the data distribution. Mass-average temperatures of the melt determined by the Accusteel system have a correlation coefficient of 0.98.

One of the main technological parameters is the percentage of %C carbon in the melt. The control of carbon concentration in the melt on the furnace was made by a computer system on the basis of measured local random temperatures by the thermocouple system.

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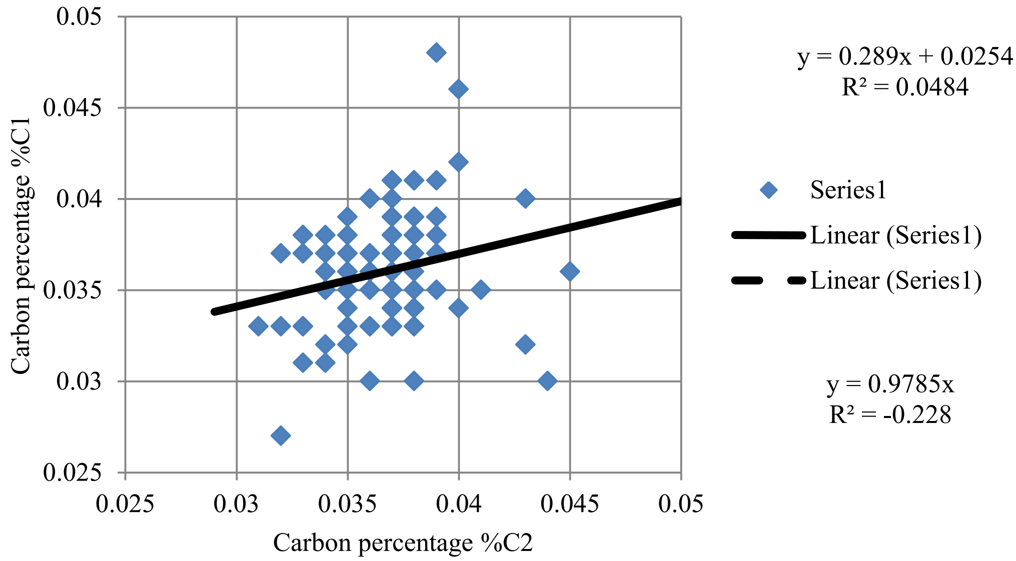

Fig. 3: Correlation function %C1(%C2) of the carbon percentage determined on the temperature measured by the thermocouple system

Fig. 3 shows that the data have a large spreading as evidenced by the low correlation coefficient of 0.22. The low reliability of data about the carbon percentage %C is result of using by computer system in the calculation algorithm locally randomly determined physical temperatures by the thermocouple system.

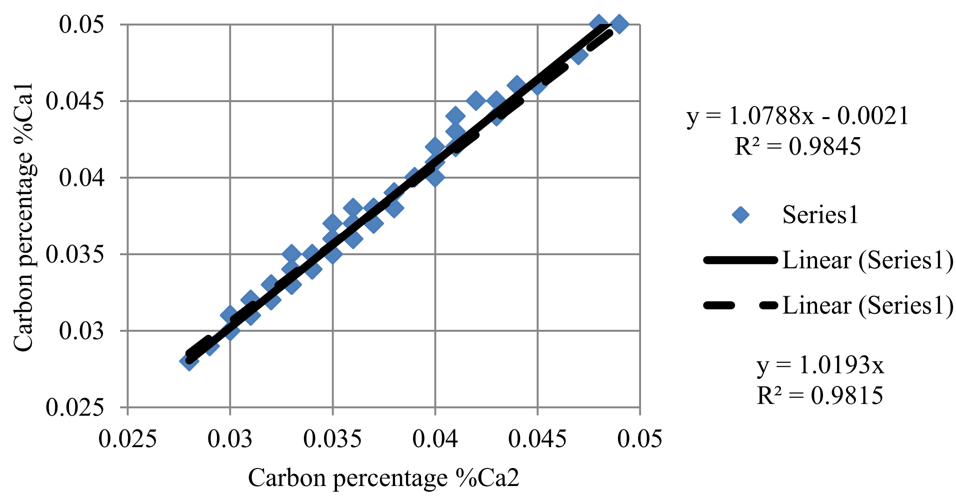

Fig. 4: Correlation function %Ca1(%Ca2) of the carbon percentage determined by the Accusteel computer system on the basis of temperatures Accusteel

Fig. 4 shows high reliability of determining the carbon percentage in the melt based on the temperature data determined by the Accusteel system. The high reliability of the mass-average temperatures determination by the Accusteel system allows us to determine with high confidence the data on the percentage of chemical elements in the melt. What indicates the correlation coefficient 0.99.

Improving the technological process. Figure 5 shows the diagram of visualization of technological parameters of the smelting process in EAF furnace with a charge of 150 tons.

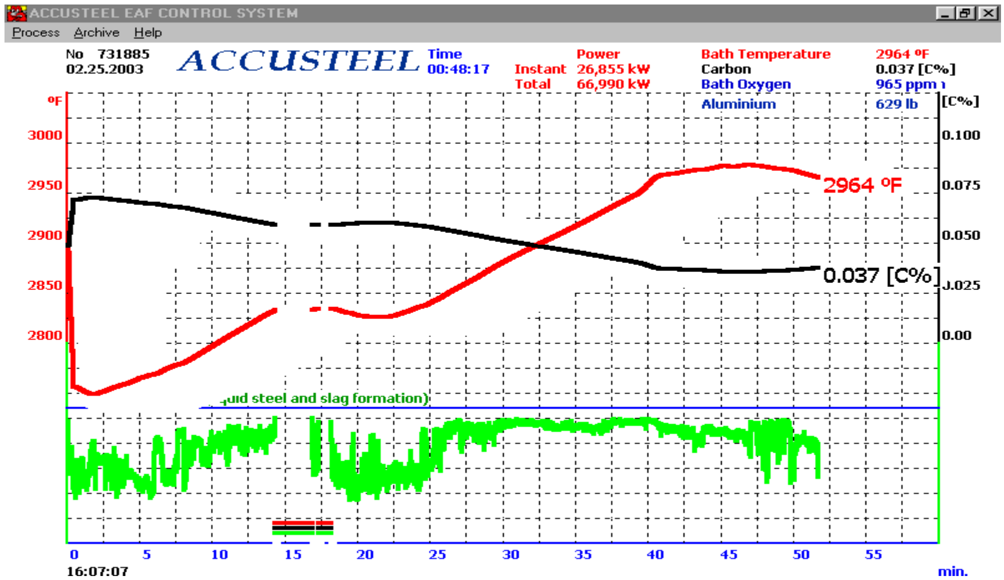

Fig. 5: Heat diagram № 731885 from 02.25.2003

This is heat diagram of one the first heats in the start of Accusteel system test on DC EAF furnace. We can see that from 27-th minute of the process the melt bath was formed and the period of melt refining was started in the closed arc mode. The period of melt refining is characterized by the maximum consumption of the energy supplied to the melt. From 40-th minute within 12 minutes the process is made with an open electric arc because intensive tapping of the slag phase. This process control mode causes poor absorption of energy entering the melt.

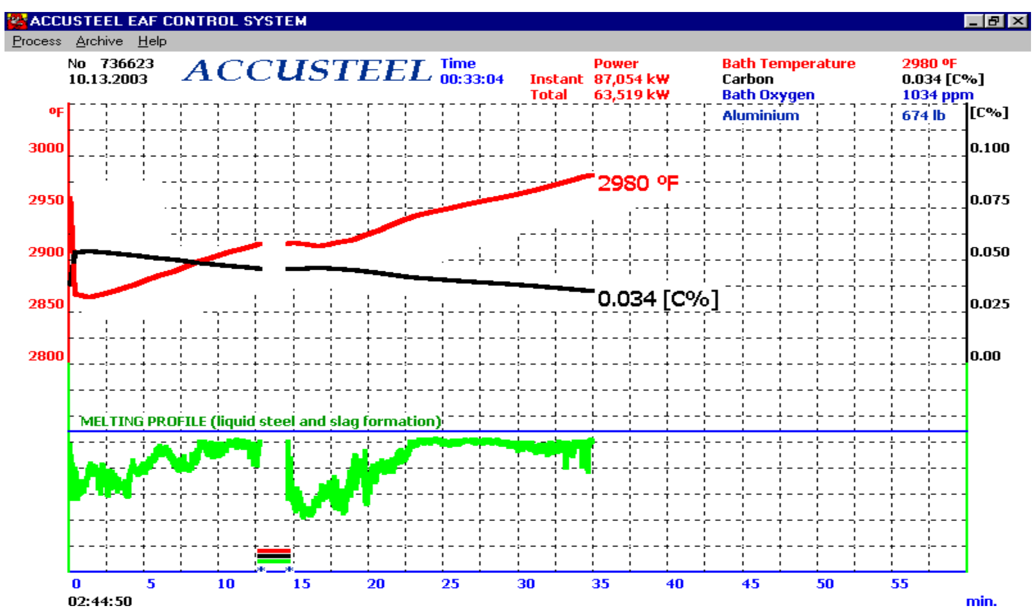

Fig. 6: Heat diagram № 736623 from 10.13.2003

Fig.6 shows that after 9 months of the Accusteel system's work the smelting process was optimized. The melting cycle has been reduced from 72 minutes to 48 minutes with a saving of 6 megawatts of electrical energy and also amount of the oxygen blast to melt.

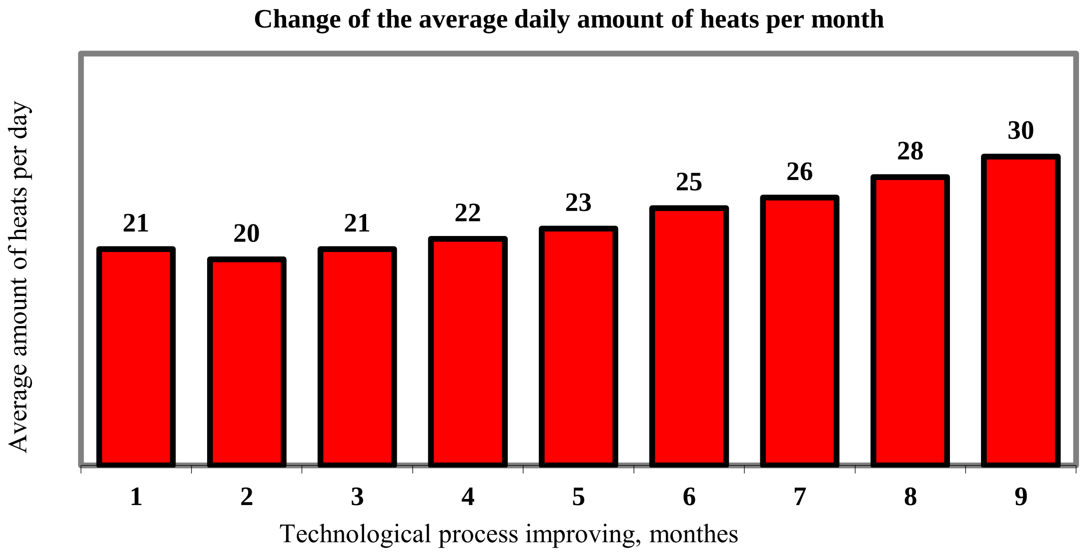

Fig. 7: Diagram of the average-daily performance per month on EAF furnace of 150t as a result of the technological process optimization using the Accusteel system's information

Fig. 7 shows that using information of the Accusteel system for nine months production was increased from an average of 21-22 to 30 heats per day for DC EAF with a charge 150 tons.

Lets consider the possibility of using the Accusteel system on the BOF where the “drop-bomb” thermocouples computer temperature control system is used. The tests were made using the Accusteel system on the 80t charge blast oxygen furnace (BOF), company Mannesmann, Brazil. It is known that the BOF process is controlled visually by a torch on the neck of the furnace using the experience of the BOF operator. Temperature control during the melting is made for 3-4 minutes or 15-20% oxygen blow before the end of the process without stopping the process by the thermocouple computer system by immersion in the melt "drop-bomb" thermocouple. The chemistry of the melt is determined by the local method by taking a sample of the melt for express analysis after stopping the process.

The results of statistical data analyses of temperature by “drop-bomb” thermocouple and chemistry of the melt are presented in table 3.

Table 3: Statistics of technological parameters of BOF heats

	T1ºC	Ta1ºC	T2ºC	Ta2ºC	%C1	%Ca1	%C2	%Ca2	%P1	%Pa1	%P2	%Pa2
Count	100	100	100	100	100	100	100	100	100	100	100	100
Average	1617	1616	1560	1618	0.038	0.042	0.19	0.041	0.01	0.01	0.012	0.013
StDev	±27	±16	±24	±17	±0.0111	±0.004	±0.21	±0.004	±0.0037	±0.0035	±0.0035	±0.0036

Where: T1ºC is the temperature determined by the “drop-bomb” thermocouple, the second temperature for performing statistical and correlation analysis is the temperature T2ºC determined by the thermocouple in the ladle. For statistical and correlation analysis of the chemistry of the melt were used data of the carbon percentage %C in the furnace %C1 and in the ladle %C2 and for the phosphorus percentage in the furnace %P1 and in the ladle %P2. Data of temperature and chemistry determined by the Accusteel system: Ta1ºC - temperature, chemical element concentrations %Ca1 and %Pa1 taken in time of measurements made by the “drop-bomb” and in the end of heat (100% blast) temperature Ta2ºC, carbon and phosphorus percentage %Ca2 and %Pa2.

The table 3 shows that the average temperatures T1ºC and Ta1ºC corresponded. The difference in StDev - standard deviations, errors in determining the temperature and chemical composition of the melt, can be explained by the local definition of data for the thermocouple, heterogeneity of the melt where there are intense heat exchange processes accompanied by convective currents due to the temperature gradient presence. For the Accusteel system data the mass-average temperature of the gas in the furnace cavity characterizes the thermophysical properties of the melt. For evaluation of the reliability of the information received the correlation analysis of data determined by computer systems was performed.

The correlation analysis results of the temperature and chemistry of the melt are presented in table 4.

Table 4: Correlation analysis of technological parameters

Function	T1(T2)	Ta1(Ta2)	C1(C2)	Ca1(Ca2)	P1(P2)	Pa1(Pa2)
Coefficient	0.03	0.97	-0.022	0.97	0.6	0.97

The results of the correlation analysis in Table 4 confirm the low reliability of the information obtained for the temperatures determined by the "drop-bomb" thermocouple system and the chemistry of the melt. Indicates low reliability of the information received. The correlation of the temperature and chemistry data of 0.97 indicates the reliability of the data determined by the Accusteel system.

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