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THE PREDICTION OF METAL SLOPPING IN LD CONVERTER ON BASE AN ACOUSTIC SIGNAL

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The negative influences of slopping in a BOF are pollution to the environment. They give lower yield and cause equipment damage. The prediction of these phenomena is based on information processing from the measuring microphone. The change of frequency in certain range is done by a signal for the prediction of slopping. In this paper two methods for prediction of slopping are described. The first method is based on measuring and processing of sound emitted from the vessel during the blow. The second method utilizes Fourier's transformation for processing of acoustic signal from sonic meter. The success rate of prediction has been evaluated by help of five criterions. It is possible to forecast the slopping on selected frequency (band). It is the essence of the second method, because this method has high success (criterion K1). Note, that criterion K5 defines acknowledgment of duration slopping. This criterion has the highest value.

Key words: *LD converter, slopping, acoustic pressure, Fourier transformation, prediction, evaluation*

Utvrđivanje izboja materijala u LD konvertorima na temelju zvučnog signala. Negativni utjecaji izboja materijala zbog prskanja iz BOF su: zagađivanje okoliša manja proizvodnja i oštećenja na opremi. Utvrđivanje ovih fenomena zasniva se na obradi podataka koji dolaze s mjernog mikrofona. Napravljena je promjena frekvencije u određenom rasponu i to je signal za utvrđivanje izboja. U radu se opisuju dvije metode za utvrđivanje izboja. Prva metoda se zasniva na mjerenju i obradi zvuka koji nastaje u posudi tijekom upuhavanja. Druga metoda koristi Fourijerovu transformaciju za obradu akustičnog signala koji dolazi iz sonometra. Pomoću 5 kriterija procijenjen je stupanj uspješnosti utvrđivanja. Izbacivanje se može predvidjeti na odabranoj frekvenciji. To je suština te druge metode i ta metoda je uspješna (kriterij K1). Pazi, kriterij K5 definira potvrdu trajanja izbacivanja. Taj kriterij ima najveću vrijednost.

Ključne riječi: *LD konvertor, izboj, akustički tlak, Fourijerova transformacija, utvrđivanje, procjenjivanje*

INTRODUCTION

The losses caused by slopping from a BOF vessel are well-known. All existing methods to control slopping require measurement devices, and these methods are reactionary in nature [1].

The measured acoustic manifestation of the environment in the converter process is recorded and archived in a personal computer. The source of the sound is created in the converter during converter process in view of space acoustics in the enclosed space, i.e. a diffuse space and is an accompanying phenomenon to this process. It may include a piece of information that can contain in this signal undesirable manifestations (sloppings ....) associated with this process. The measurement chain is assembled according to the requirements from technological limitations of the process and from financial limitations resulting from the demanding environment for the service life of the entire measurement chain. The requirements for its application are as follows: recording and sampling the sound with frequency 20000 Hz. For the above measurement, the microphone of type MiniSPL was used, which meets the required conditions for regular reading of acoustic signal.

Those are related to its capability to sample the sound in the required frequency band from 20 Hz to 20 kHz.

DESCRIPTION AND ANALYSIS OF NEGATIVE PHENOMENA (SLOPPING, OUTFLOW)

The steel making is generally known therefore we'll deal with only that part of problem, which brings a new view on negative occurrences (outflow, slopping) that relate with the steel making process.

The slopping means a irregular flowing of small or big elements of metal and slag during a blowing process through throat of converter.

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The slopping can be caused by several factors:

- explosive course of melting,
- as consequence of wrong shape of converter's working space,
- weak or unsteady circulation of melting,
- resonation of moving of melting and gas,
- resonation of cross waving in converter,
- shape of converter's working space, when deep of melting and height of working space are not in satisfactory.

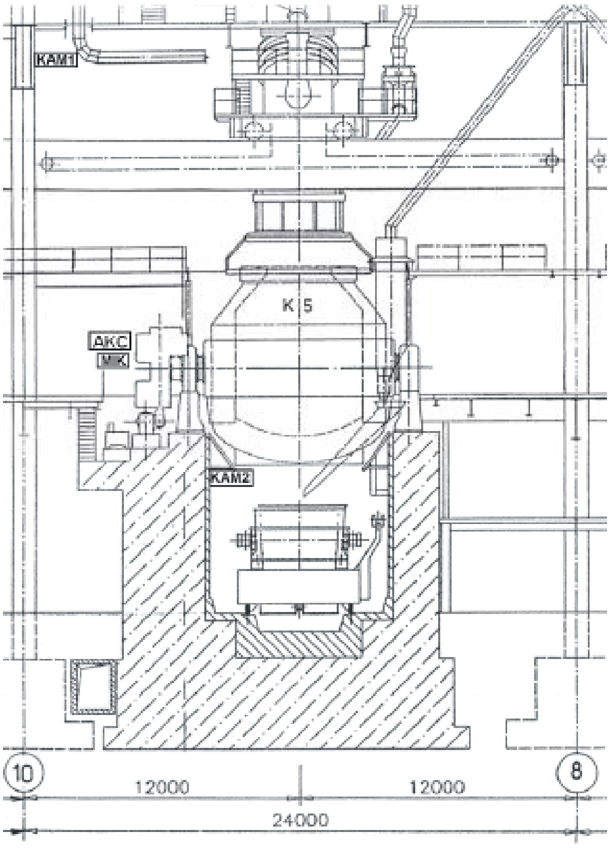

Figure 1. **Schematic settings of probes**
Slika 1. **Shema podešenosti pokusa**

In the consequence of slopping the extraction is decreased, heating balance and final temperature of steel are changed, the buckles on end of converter's throat are made. The slopping is visually identified at occurrence by which from the flaming converter the piece of melt and slag are thrown.

In the process of steel making the oxygen is added into a melt iron through throat as stream of gas for decarbonization. The recent authors write that the top of blowing stream of oxygen cause a quick decarbonization of slag in final step of process. The gas stream takes a liquid into the surrounding of converter. This occurrence is generally known as outflow. It was examined by many researchers, because it's a cause of operation problems and it leads to decreasing of productivity and benefit. It is desired to eliminate this occurrence.

The outflow visually shows flames from throat of converter. The both mentioned occurrences have negative impact on efficiency of process.

THE RECORDING OF VIDEO AND ACOUSTIC SIGNAL

For analyzing of acquired data we consider an assumption, which express that a given occurrences are the failures and result of some unregulated variables, which have influence on steel making process. These negative occurrences

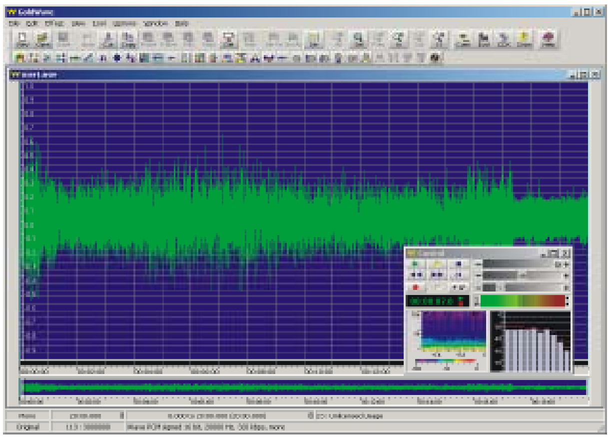

Figure 2. **The time behavior of acoustic signal and Fourier analysis**
Slika 2. **Vrijeme ponašanja akustičkog signala i Fourierova analiza**

- failures are observed by digital cameras KAM1 and KAM2. Such an information was evaluated in order to obtain some time for failure to occur and time of failure itself. The camera KAM1 observes slopping and KAM2 observes outflows.

The starting point for next evaluations was the measurements during February and May 2004. In this period 66 melts

Figure 3. **The starting of slopping (CAM1)**
Slika 3. **Početak izbacivanja (prskanja) (CAM1)**

were taken. In consideration of amount of data, which are obtained in measurements, we can regard them as sufficient in number, so they can be evaluated by a statistic method.

The acoustic signal was monitored by measuring string which contained the microphone Mini SPL (MIK), sound card (SoundBlaster Audigy 2), and recorded by computer program Goldwave (Figure 2.), and this is an example of measured acoustic signal with Fourier analysis.

From the analysis (see Figure 2. right down corner) of Fourieris transformation we can say that relevant frequencies for defining negative phenomena have a low value.

The visual forms of acoustic signal are displayed on Figures 3., 4. (slopping) and Figures 5., 6. (outflow).

Figure 4. **The end of slopping (CAM1)**
Slika 4. **Završeno izbacivanje (CAM1)**

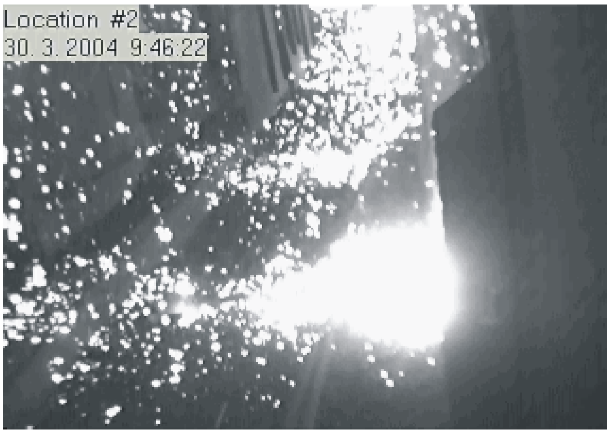

Figure 5. **The beginning of outflow (CAM2)**
Slika 5. **Početak istjecanja (CAM2)**

THE PREDICTION OF SLOPPING IN LDCONVERTER ON THE BASIS OF AN ACOUSTIC SIGNAL

The beginning of the reading process is identical with the beginning of oxygen blowing in a given smelting process.

Figure 6. **The end of outflow (CAM2). The visual forms of acoustic signal are displayed on Figure 3., 4. (slopping) and Figure 5., 6. (outflow)**
Slika 6. **Kraj istjecanja (CAM2). Vizualni oblik akustičnog signala su prikazani na slici 3., 4. (izbacivanje) i slikama 5., 6. (istjecanje)**

For the recording of sloppings and intensive gas stream two industrial cameras were used, which were located in the space underneath the converter (for slopping observation) and in the space above the converter (for gas stream observation). This video technology makes it possible to observe the beginning and the end of these phenomena in time. We can see on Figures 3. - 4. the beginning and the end of slopping.

We developed two methods. The first method is based on measured and processing of sound emitted from the vessel during the blow. The second method utilizes Fourier's transformation for processing of acoustic signal from sonic meter [2].

The sound as predictor of slopping

The calculation of acoustic level pressure was made according relationship:

$$L = 10 \log \frac{p^2}{p_0^2} = 20 \log \frac{p}{p_0} \quad / \mathrm{dB} \qquad (1)$$

where:

p - effective value of acoustic pressure / Pa,
p_0 - normalized acoustic pressure $2 \cdot 10^{-5}$ Pa.

The algorithm of prediction negative phenomena was following:

The passive optimization method [3] determined upper (UB) and down (DB) boundary of sound (acoustic level pressure). If immediate value of sound is between upper and down boundary then this model will predict the negative phenomena.

This calculation of this algorithm was made as an average for each 5 s.

The using of Fourier's transformation

Acoustic signal processing was made according the following relationships:

$$F(f)=\int_{-\infty}^{+\infty} f(t)\cdot e^{-j2\pi f}\mathrm{dt} \tag{2}$$

where:

$f(t)$ - time signal,
f - frequency,
$F(f)$ - Fourier transform.

For the calculation FFT the following formula has been used Fourieris transformation:

$$F_k=\sum_{i=0}^{N-1} x_i\cdot e^{-i\frac{2kj\pi}{N}} \tag{3}$$

where:

$x(i)$ - acoustic samples for FFT,
N - the number of samples,
F_k - samples of FFT.

In Figure 7. is shown spectrogram, which expresses dependence magnitude, frequency index on time. From these dependencies it is very difficult to determine the beginning and the end of negative phenomena. Therefore samples of FFT in chosen bands were evaluated.

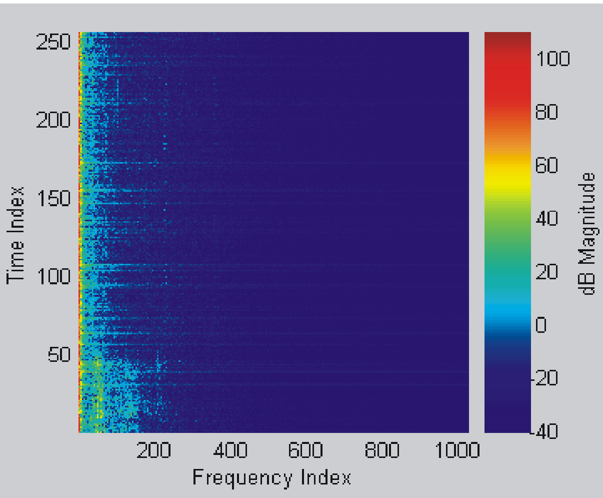

Figure 7. **Fourier transform of acoustic signal**
Slika 7. **Fourierova transformacija akustičnog signala**

For the prediction of sloppings, a comparison of the values in 16 frequency bands was used, which were taken from the values of the spectrogram with a step of 625 Hz. (1. band included frequencies 0 - 625 Hz, 2. band: 625 - 1250 Hz, ...). At prediction optimization (i.e. which 2 bands are to be compared) we evaluated as best band 1 and 16. The success rate, however, was comparatively small. Therefore, we decided to divide the spectrogram into 32 bands.

The calculation for 32 frequency bands has been made according (4) to:

$$F_{pi+1}=\frac{1}{32}\sum_{k=i\cdot 32}^{i\cdot 32+31} F_k,\quad i=0\ \dots\ 31 \tag{4}$$

where:

F_k - samples FFT.
F_{pi+1} - sample in $i+1$ band.

The ratio F_{pi}/F_{pj} has been used for prediction according to the following algorithm:

1. If the value of ratio has been above upper boundary (UB) then the prediction of slopping is.
2. If the value of ratio fell below lower boundary (DB) then the return on point 1.

THE EVALUATION

The success rate of prediction has been evaluated by following criterions:

$$K1=\frac{n_p}{n_v}\times 100 \tag{5.1}$$

$$K2=\frac{n_Z}{n_v}\times 100 \tag{5.2}$$

$$K3=\frac{n_n}{n_v}\times 100 \tag{5.3}$$

$$K5=\frac{n_1}{n_v}\times 100 \tag{5.4}$$

where:

n_p - the number of predicted sloppings,
n_v - the total number of sloppings in melts,
n_z - the number of unsuccessful predictions,
n_n - the number of unpredicted sloppings,
n_1 - the number predictions after start slopping.

The given criterions K have following meaning. $K1$ expresses the success of prediction, $K2$ expresses unsuccessful prediction model (model has predicted, but phenomena has not occurred), $K3$ - number of unpredicted sloppings, *K*5 - number of confirmed negative phenomena during his existence, if phenomena were predicted by criterion *K*1. The success of model we can evaluate by difference *K*1 – *K*2. If this different is big then we can say that model is suitable for prediction.

Table 1. **Evaluation of sound as predictor of slopping**
Tablica 1. **Vrednovanje zvuka kao signalizatora izbacivanja**

DB / dB	UB / dB	K1 / %	K2 / %	K3 / %	K5 / %	K1–K2 / %
60	60	15	10	85	0	5
60	62	15	10	85	0	5
60	64	15	10	85	0	5
60	66	15	10	85	0	5
62	60	15	10	85	0	5
62	62	15	10	85	0	5
62	64	15	10	85	0	5
62	66	15	10	85	0	5
64	60	15	10	85	0	5
64	62	15	10	85	0	5
64	64	15	10	85	0	5
64	66	15	10	85	0	5
66	60	15	10	85	0	5
66	62	15	10	85	0	5
66	64	15	10	85	0	5
66	66	15	10	85	0	5
68	60	15	10	85	0	5
68	62	15	10	85	0	5
68	64	15	10	85	0	5
68	66	15	10	85	0	5
70	60	15	10	85	0	5
70	62	15	10	85	0	5
70	64	15	10	85	0	5
70	66	15	10	85	0	5
72	60	15	10	85	0	5
72	62	15	10	85	0	5
72	64	15	10	85	0	5
72	66	15	10	85	0	5
74	60	15	10	85	0	5
74	62	15	10	85	0	5
74	64	15	10	85	0	5
74	66	15	10	85	0	5
76	60	15	10	85	0	5
76	62	15	10	85	0	5
76	64	15	10	85	0	5
76	66	15	10	85	0	5
78	60	15	10	85	0	5
78	62	15	10	85	0	5
78	64	15	10	85	0	5
78	66	15	10	85	0	5

The results of evaluation of sound as predictor of slopping are showed in Table 1. DB, UB are down and up boundary of sound range. In the following table the best combinations of up and down boundary in term of success of prediction are chosen. We can see from this table that this method is not successful.

In Table 2. the results of evaluation of the ability to forecast slopping are showed. *P*1 and *P*2 are bands. We can see from Table 2. that first three ratios of FFT samples are suitable for prediction of slopping.

Table 2. **Evaluation of using of Fourier's transformation as predictor of slopping**
Tablica 2. **Vrednovanje uporabe Fourierove transformacije kao signalizatora izbacivanja**

P1 / -	P2 / -	DB / -	UB / -	K1 / %	K2 / %	K3 / %	K5 / %
9	10	0,903	1,150	91	18	9	545
10	9	0,871	1,110	91	18	9	560
14	15	1,080	1,410	91	18	9	413
8	7	0,873	1,130	90	18	10	514
15	16	1,100	1,400	90	18	10	579
14	16	1,360	1,730	90	16	10	551
15	14	0,718	0,935	89	17	11	434
9	10	0,882	1,130	89	42	11	532
8	32	1,210	3,270	89	56	11	478

CONCLUSION

Both methods for slopping prediction are based on processing acoustic signal. The first method is not suitable. The possible reason of this method to be unsuccessful is the fact that sound is on integral value. The slopping is possible to forecast on selected frequency (band). It is the essence of the second method, because this method has high success (criterion *K*1). Note, that criterion *K*5 defines acknowledgment of duration slopping. This criterion has the highest value.

Both methods were developed in steel plant U.S. Steel Košice.

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