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Vibration characteristics and dynamic control of vacuum treatment

Abstract

Vibration characteristics of vacuum treatment at industrial steel vacuumisation units are studied. The amplitude-frequency spectrum and the main sources of vibration of vacuum treatment units are analysed. It is shown that the vibration spectrum is dominated by low and high frequency ranges. In the low-frequency range the vibration of vacuum treatment units is connected with bath oscillations and wave formation on the surface, as well as with decarburisation of metal during oxygen blowing and vacuum-carbon deoxidation and degassing processes. In the high-frequency region the sources of vibration are pulsations of vented gases. Correlation relations between vibration and technological parameters of vacuum treatment are established. Possibilities of vibration method for dynamic control of vacuum treatment are shown. The character of vibration signal level change at the frequency of 8 Hz reflects the dynamics of decarburisation during oxygen blowing of metal at reduced pressure. In the established frequency ranges the vibration characteristics allow to control the processes of vacuum-carbon deoxidation and degassing.

Keywords: *vacuum treatment, vibration characteristics, dynamic control, vacuum carbon deoxidation, vacuum degassing. Introduction*

Acoustic and vibration control methods have been widely used in the oxygen-converter process to assess decarburization in the converter bath, to determine the level of slag during the blowdown and to predict slag-metal emulsion emissions [1–3].

At the same time, the wide possibilities and potential of vibration and acoustic controlling systems open prospects for their use, for example, in the vacuum treatment of steel [4–5].

This paper presents the results of research on vibration characteristics of steel vacuum degassing in circulating vacuum degasser (RH) and DETEM units.

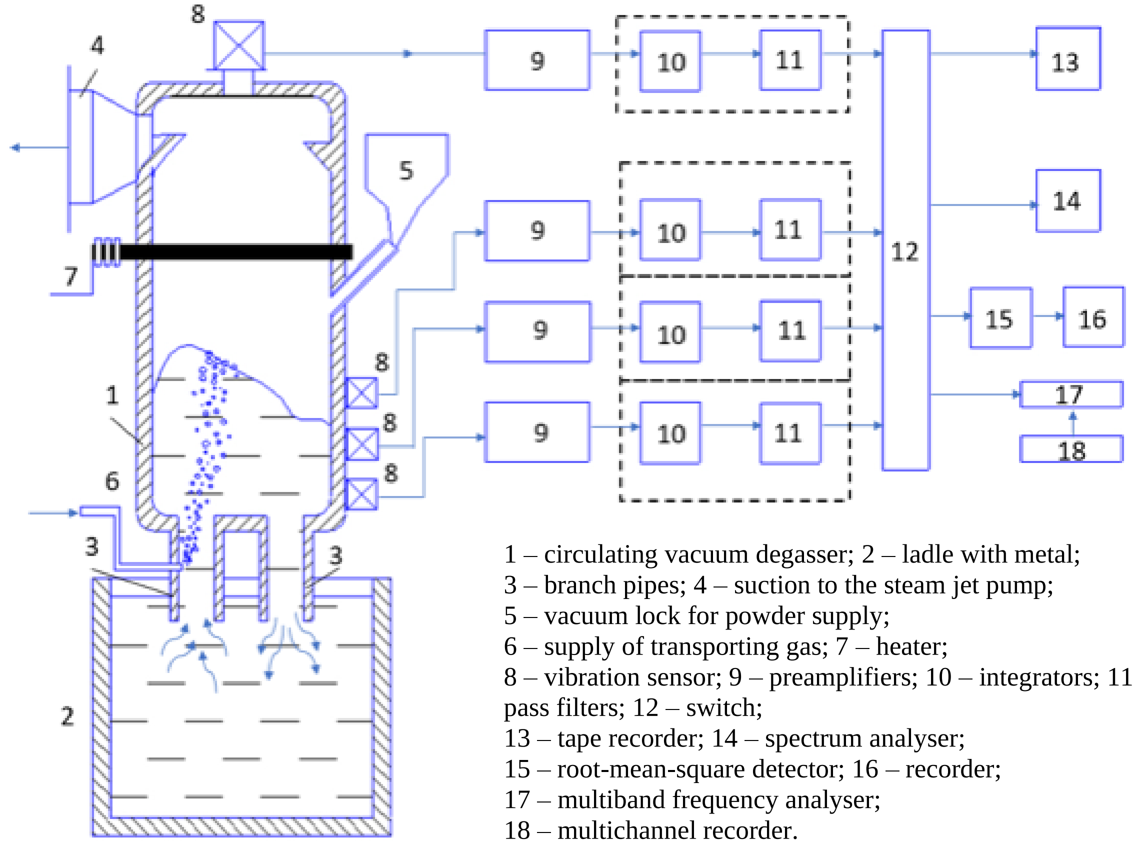
At 100 and 160 t circulating vacuum degassing units (Fig. 1) vibration sensors were installed at different levels of the vacuum chamber body and on the lid. As experiments have shown, the vibration signal taken from the vacuum chamber body turned out to be the most representative. At the same time, the level of vibration signal and its changes during the processing practically did not depend on the place of installation of the vibration sensor on the body. Therefore, in further experiments the measurement of vibration characteristics was carried out with the help of one sensor installed on the body at the level of the graphite heating element.

Experimental

Both deoxidized, and crude metal were subjected to vacuum treatment in the RH circulation unit. The vacuum level in the vacuum chamber was monitored in the process. During the treatment of crude metal, a gas analyser allowed to monitor the composition of the exhaust gases (CO, CO2).

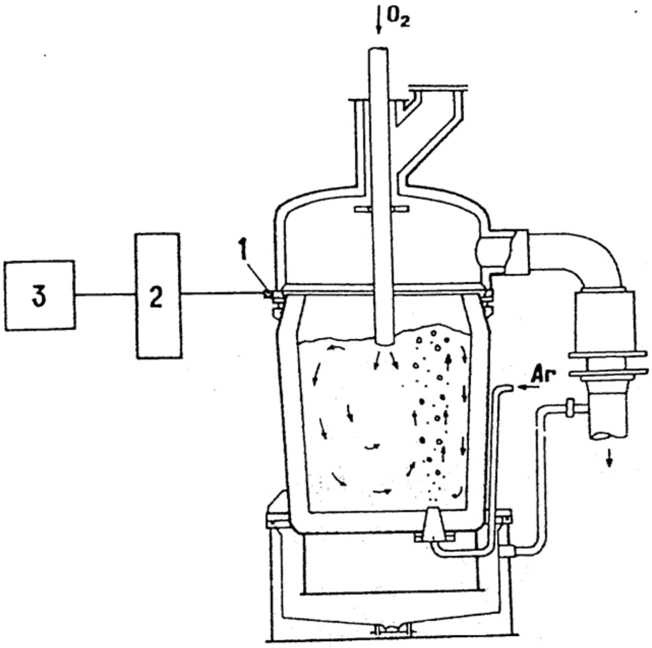
The DETEM method, developed by Dorrenberg Edelstahl and Technometal (Germany), is designed for vacuum treatment of small weight melts (from 5 to 40t) without additional heating. The unit is a steel ladle, which is vacuum-tightly covered with a lid from above (Fig.2).

The vibration sensor was installed on the flange of the ladle lid (Fig. 2), which is vacuum-tightly mounted on the ladle and forms a single vacuum chamber with it. Thus, the vibration signal was taken directly from the element of the unit structure that perceives and transmits the vibrational processes in the ladle during blowing and processing.



1 – circulating vacuum degasser; 2 – ladle with metal;
3 – branch pipes; 4 – suction to the steam jet pump;
5 – vacuum lock for powder supply;
6 – supply of transporting gas; 7 – heater;
8 – vibration sensor; 9 – preamplifiers; 10 – integrators; 11 – band pass filters; 12 – switch;
13 – tape recorder; 14 – spectrum analyser;
15 – root-mean-square detector; 16 – recorder;
17 – multiband frequency analyser;
18 – multichannel recorder.

Fig. 1 The scheme of vibration measurements on a circulating vacuum degassing unit.



1 – vibration sensor,
2 – signal amplification and processing unit,
3 – recording device

Fig. 2 The scheme of vibration measurements at the DETEM unit.

Results and Discussion

The research was carried out in two stages. At the first stage, amplitude-frequency spectrums of vibration characteristics were studied, and vibration sources were analysed. At the second stage, correlations between vibration and technological parameters of treatment were considered.

Fig.3 shows the amplitude-frequency spectrum of the vibration velocity of the circulating vacuum degassing unit during the treatment of rimmed and deoxidized metal.

The amplitude-frequency spectrum of the vibration velocity of the DETEM unit was considered during the period of oxygen blowing and afterward during the period of vacuum-carbon deoxidation and degassing of steel (Fig.4).

Considering the comparability of vibration velocity values measured at particular frequencies, the amplitude-frequency spectrums in Figs. 3 and 4 show the vibration velocity values in absolute units (mm/s).

As can be seen from Fig. 3, the vibration spectrum of the steel vacuum treatment in the circulating vacuum degasser is represented in a wide frequency range of 1-8000 Hz. Both for vacuum treatment of rimmed and deoxidized steels, low-frequency (4–16 Hz) and high-frequency (2 000–8 000 Hz) ranges are distinguished. At the same time, the vibration level during vacuum treatment of rimmed steel in the whole frequency range due to the intensive processes of vacuum-carbon deoxidation is much higher than that measured during treatment of deoxidized metal.

The presented in Fig. 4 amplitude-frequency spectrum of vibration velocity of vacuum metal treatment at the DETEM unit complements the amplitude-frequency characteristics obtained at the circulating vacuum degasser due to the oxidative decarburization at oxygen blowing in the DETEM process. In this case, the amplitude-frequency spectrum is characterized mainly by a low-frequency range with a maximum level of vibration velocity at 4-6 Hz. The relatively high level of vibration at frequencies 31.5 and 63 Hz is obviously related to the influence of the electric field of close frequency on the measured signal.

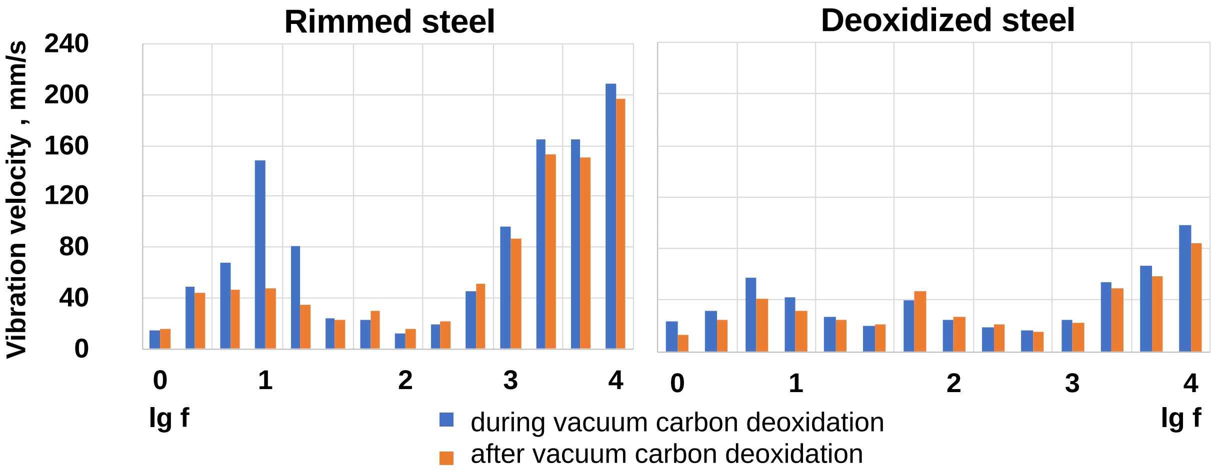


Fig. 3 Amplitude-frequency spectrum of vibration velocity of circulating vacuum degasser during treatment of rimmed and deoxidized steel.

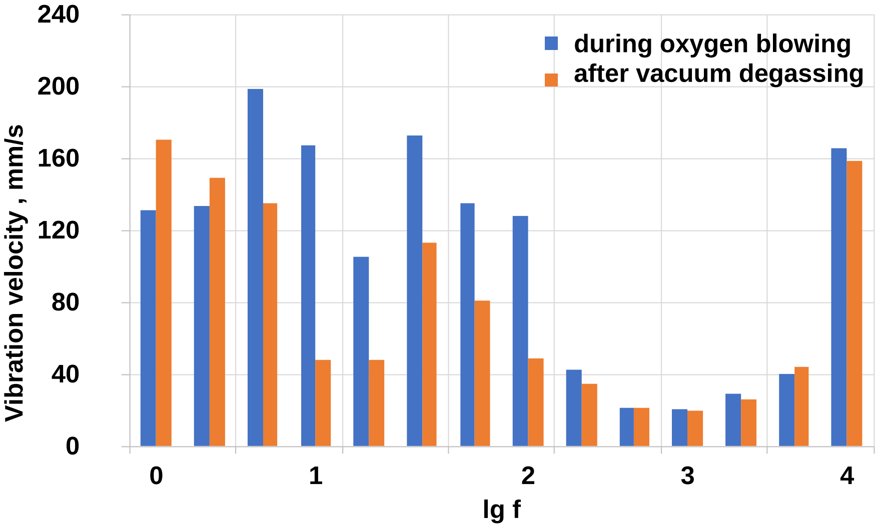


Fig. 4 Amplitude-frequency spectrum of vibration rate at the DETEM unit.

During vacuum treatment of steel without oxygen blowing, the amplitude-frequency spectrum of the DETEM unit is also mainly characterized by the low-frequency region. At the same time, the vibration level at frequencies 4-16 Hz is significantly lower than during oxygen blowing periods. It is noted that the difference in vibration levels during oxygen blowing and without oxygen blowing is most significant at 8 Hz.

A relatively high level of vibration was noted at the frequency of 8000 Hz. In general, the wide frequency range of vibration during vacuum treatment of steel confirms its connection with rather complex physical and chemical processes occurring during the treatment. Changes in their dynamics explain the differences in vibration levels in separate periods of vacuum treatment.

Fig. 5 shows the comparison of amplitude-frequency spectrums of vibration displacement and vibration velocity of 160 t oxygen converter, and DETEM unit during oxygen blowing and RH unit during vacuum-carbon deoxidation and degassing.

Vibration of the vacuuming units and oxygen converter is characterized by the low-frequency region of 1–16 Hz. At the same time, vibration displacement and vibration velocity levels for the oxygen converter are much higher than those recorded at DETEM and RH units.

Vibration velocity at frequencies of 2–16 Hz for oxygen converter is 300–370 mm/s, on DETEM units during oxygen blowing - 180 mm/s and on RH units during vacuum-carbon deoxidation and degassing - 50–150 mm/s.

The latter is due to different intensity of metal decarburization. During blowing in an oxygen converter with intensive blow supply, the vibration level is high. The DETEM unit is much less vibrating because the blowing intensity is lower, and the decarburization rate is not as rapid. In the RH unit, which realizes volumetric decarburization by vacuum-carbon deoxidation, the vibration displacement intensity and vibration velocity are much lower.

Based on the analysis of physical and chemical processes during the vacuum treatment of steel, the oscillatory effects causing the vibration of the vacuum treatment units have been identified. Considering possible oxygen blowing, the sources of vibration during vacuum treatment are:

- pulsations of oxygen jet when flowing through lance nozzles;
- vibrational processes during interaction of oxygen jet with melt;
- vibrational phenomena at interaction of argon jets with a metal bath and release of argon bubbles;
- pulsations during the formation and release of argon bubbles during blowing through a porous insert;
- wave processes on the surface of circulating metal;
- self mechanical vibrations of the vacuum chamber;
- acoustic resonances of oscillations in the free volume of the vacuum chamber;
- vibrational phenomena in case of the volumetric type of vacuum-carbon deoxidation process;
- vibrational processes during decarburization in the secondary reaction zone;
- pulsations of exhaust gases.

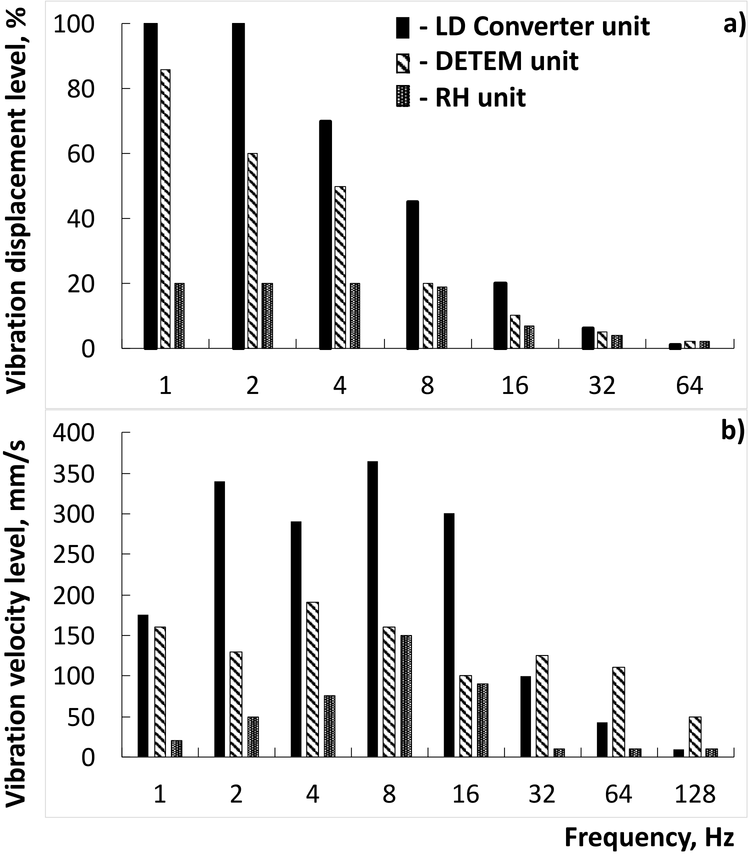


Fig. 5 6

The performed experiments of vibration characteristics measurement during treatment of deoxidized steels have shown that the processes of vacuum-carbon deoxidation and degassing taking place in the vacuum chamber of RH are manifested in the vibration of the unit body. These frequencies are 4–8 kHz.

In the specified frequency range, the vibration signal was recorded to the secondary registration device directly from the body of the vacuum chamber. As an example, Fig. 6 shows changes in the vibration signal level at the frequency of 8 kHz during treatment. Considering that the vacuum in the chamber (less than 1 mbar) was reached practically by the 4th minute of treatment, the duration of vibration level decreasing for 7 minutes is considered as one that characterizes the dynamics of vacuum-carbon deoxidation and degassing processes. The type of the given curve, as well as at other melts, is close to the known dependencies of oxygen and hydrogen content change in the process of treatment [6].

At the beginning of the treatment, at relatively high concentrations of oxygen and hydrogen in the metal, the vibration signal level is maximum. In the process of vacuum-carbon deoxidation and degassing, as the concentration of oxygen and hydrogen in the melt decreases, and the corresponding slowing down of the rate of oxygen binding and hydrogen removal, the level of vibration signal decreases. At the 8th minute of processing, the vibration level reaches the minimum values and does not change further, which indicates the completion of the vacuum-carbon deoxidation and degassing processes.

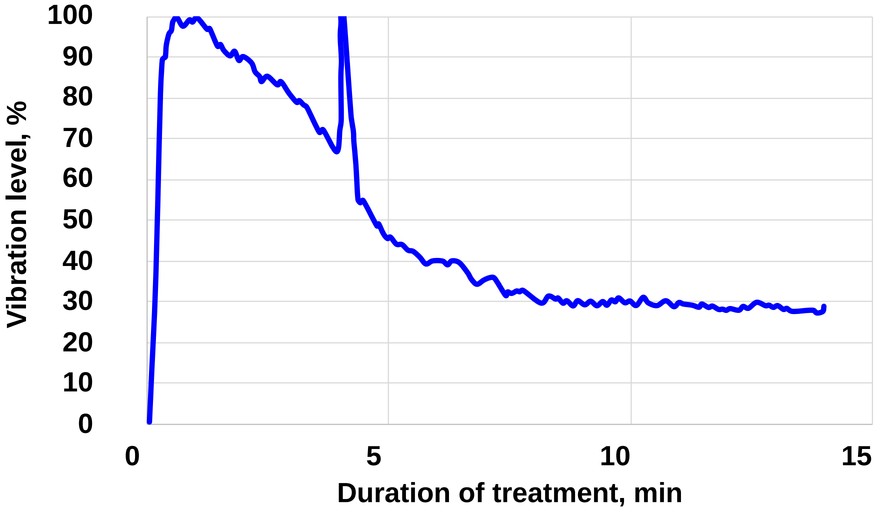


Fig. 6 The changing of the RH unit vibration level at frequency 8 kHz.

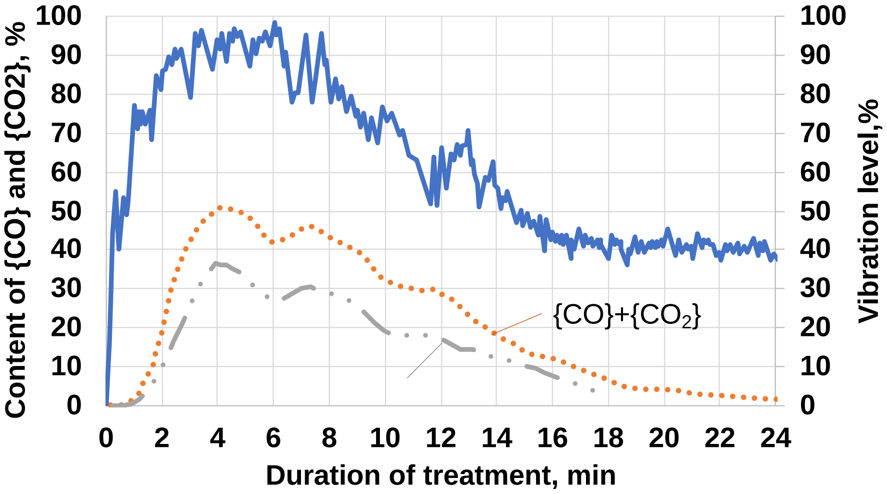


Fig. 7 The changing of the vibration level and the content of carbon oxides in exhaust gases during the treatment of rimmed steel in the RH unit.

During treatment of crude metal, along with the level of vibration signal, the content of CO and CO_2 in the exhaust gases was monitored. Fig.7 shows changes in the vibration signal level and the content of carbon monoxide and the value of {CO} + {CO_2} during the treatment. Close character of change of the monitored values in the main period of treatment is established. After the third minute of processing, the air from the chamber is practically withdrawn, and the amount of gases is determined by CO and CO2 emitted because of vacuum-carbon deoxidation. Changes in the level of the monitored vibration signal correspond to changes in the amount of withdrawn gases, consisting mainly of CO and CO2. After 19 minutes of treatment, practically zero and not changing values of {CO} + {CO_2} in the exhaust gases correspond to a constant (background) level of the vibration signal, which, in this case, was determined by the flow rate of the injected and exhausted argon.

Thus, the variation of the vibration signal in the high-frequency range is related through the amount of the exhausted gases to the vacuum-carbon deoxidation processes.

According to changes of vibration signal level, it is possible to control the dynamic of vacuum-carbon deoxidation processes during the treatment and to determine the completion of these processes by reaching the minimum and constant values of vibration level. In the case of deoxidized metal treatment, when the composition of waste gases is not controlled, vibration control is the only indirect dynamic characteristic of the vacuum-carbon deoxidation process flow.

The character of vibration signal level changes in the low-frequency range during the treatment was studied at the frequency of 8 Hz. At this frequency, changes of vibration signal are most likely related to the processes of boiling and barbotage of the bath because of argon blowing, gas release during vacuum-carbon deoxidation and metal degassing.

Fig. 8 shows the character of changes in the vibration signal level at a frequency of 8 Hz during deoxidized steel treatment. During the first 2 minutes and 40 seconds of treatment, the vibration signal level is relatively low (about 30% on the scale of the secondary registration device) and is determined by the intensity of argon blowing of the metal. At the end of the 3rd minute of treatment, there is a sharp increase in the level of vibration signal from 30% to 66%. The increase in vibration level is associated with metal boiling, because of the development of vacuum-carbon deoxidation and metal degassing processes. At this point, low pressures in the vacuum chamber are reached at relatively high oxygen content in the metal. Further, as the metal is deoxidized at constant vacuum chamber pressure, the boiling intensity decreases, which is accompanied by a continuous decrease in the vibration signal value. At the 7th minute of treatment, the level of vibration signal decreases to 32% and stabilizes. The latter indicates the completion of the vacuum-carbon deoxidation and degassing processes at the selected treatment mode. At the end of treatment, as well as in the first two minutes of the process, the vibration level is determined by the bath barbotage because of argon blowdown.

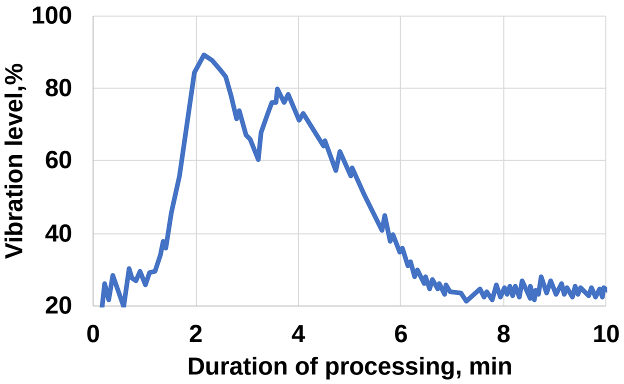


Fig. 8 The changing of the vibration signal level at frequency 8 Hz.

At sharper reduction of pressure in the vacuum chamber (during the first two minutes, the pressure in the chamber was reached less than 3 mbar), earlier boiling of metal was recorded because of intensive processes of vacuum-carbon deoxidation and degassing. Fig. 9 shows that the maximum vibration levels, indicating the intensive processes of vacuum-carbon deoxidation and degassing, were reached already by the end of the 2nd minute of treatment. Subsequently, a decrease in the vibration signal level was observed, which by the 7th minute of processing decreased to minimum values (about 30% on the scale of the secondary registration device).

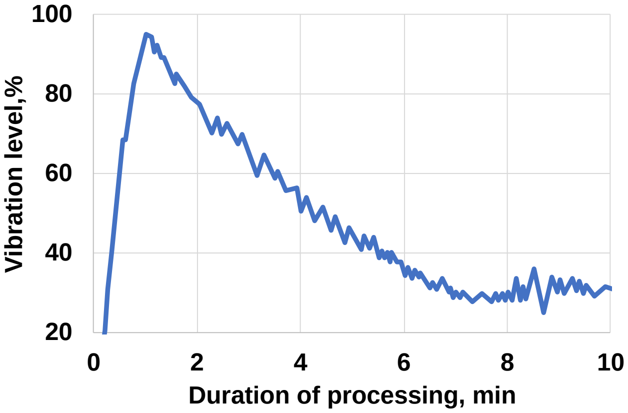


Fig. 9 The changing of the vibration signal level at high-frequency range.

In general, as industrial studies have shown, the information about changes of vibration signal level in the low-frequency range allows controlling directly the intensity of vacuum-carbon deoxidation and degassing processes. It also allows determining the moments of their beginning and ending.

The above dependencies were used as a basis for the developed vibration control of vacuum-carbon deoxidation and degassing processes during steel treatment at the RH circulation-type unit. To improve the accuracy, reliability, and validity of control, it was proposed to measure the vibration level simultaneously in the low- and high-frequency ranges.

On DETEM units, vibration control was carried out at a frequency of 8 Hz. Fig. 10, as an example, shows the change in the vibration level at a frequency of 8 Hz at one of the melts. It was found that the character of changes in the vibration signal level reflect the dynamic of carbon oxidation during the blowdown. [7]. Up to the 2nd minute of treatment, the level of vibration signal increased from 20% of the background value up to 70% (on the scale of the secondary registering device). During the first 4 minutes of oxygen blowing, due to the intensive decarburization process, the vibration signal level is high and fluctuated in the range of 50-78%. After the 6th minute of blowing, the vibration decrease was indicating the slowing down of carbon oxidation. At the same time, the vibration signal level was decreasing from 64% to 22%. The decrease (almost three times) of carbon oxidation rate relates to a decrease in its concentration in metal, a decrease in oxygen assimilation degree due to the lance heightening and decreasing of the depth of its immersion into the bath. At the 9th minute of blowing, the zone of oxygen jet injection on the surface of the bath was visually observed. At that moment, the lance was immersed to the working depth of 200 mm. Consequently, the decarburization rate increased and, accordingly, the vibration level increased from 23% to 44%. However, due to the lower carbon content in the bath, the carbon oxidation rate and signal level recorded at 2–6 minutes of blowing were not achieved. After the 12th minute, the typical decrease in decarburization rate and vibration signal level occurs again, indicating the reasonability of stopping oxygen blowing. When the level of vibration signal decreased almost to background values, the lance was lifted, and blowing was stopped. In the process of further treatment of metal under vacuum (without oxygen blowing) from 13 to 21 minutes, the level of vibration signal remained constant (about 20%).

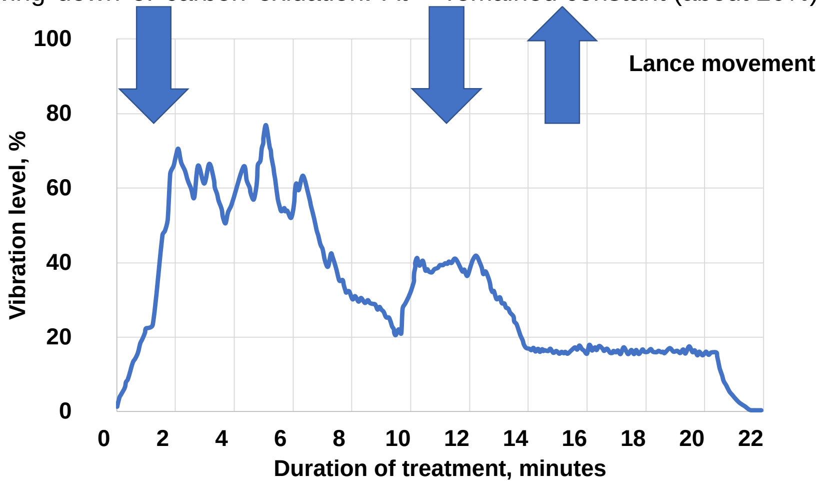


Fig. 10 The changing of the vibration signal level in the low-frequency range (8 Hz).

The obtained results formed the basis of the developed system of vibration monitoring and controlling of the oxygen blowing process. In accordance with the chosen algorithm, to intensify the treatment process, the vibration level at a frequency of 8 Hz and the decarburization rate are kept as high as possible within the operating conditions of this DETEM unit.

Considering the results of the application of vibration control at the circular vacuuming unit, at the DETEM unit of the metallurgical plant “Dorrenberg Edelstahl” vibration control was applied to evaluate the processes of vacuum-carbon oxidation and degassing. In general, the character of the obtained dependencies was close to those obtained by vibration measurements in the circular vacuum degasser.

The similarity of the results in both cases is due to identical sources of oscillations generating vibration of vacuuming units and testifies to the universality of the established patterns.

Conclusions

1. Vacuum processing vibration has been studied and the amplitude-frequency characteristics of circulating vacuum (RH) and DETEM units have been analysed.

2. The main sources of vibration during vacuum treatment of steel are highlighted. It is shown that in the low-frequency region, the vibration of vacuum treatment plants connected with decarburization of metal during oxygen blowing and processes of vacuum-carbon deoxidation and degassing. In the high-frequency region, the sources of vibration are pulsations of exhaust gases.

3. Correlations between vibration and technological parameters of vacuum treatment have been established.

4. The conclusion is made about the universality of the patterns obtained at RH and DETEM installations and the possibility of application of the developed approaches for control of vacuum treatment processes at different types of units.

5. The principal possibility of application of the vibration method for control of decarburization and degassing during the vacuum treatment of steel is shown. The reasonability of vibration control of vacuum treatment in low- and high-frequency ranges is established.

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