Automated Adjustment of Rod Mill Grinding based on the Frequency Analysis of Acoustic Emission

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ABSTRACT

In the research, the automated adjustment of rod mill grinding based on the frequency analysis of acoustic emission was studied. The comminution process was monitored using acoustic emission surveying (AE) and further spectrum analysis. The aim was to clarify whether the acoustic emission could be used to determine the progress of the comminution process. The experimental campaign was carried out at a rod mill of a minipilot scale mineral beneficiation plant of University of Oulu. The experiments consisted of 8 tests, carried out with wet and dry material. Moreover, the mineral composition was varied by experimenting with gangue and valuable ore. As results, the attenuation of particularly over 1 kHz frequencies could be observed from the spectra. It was concluded that the AE spectrum analysis could be an applicable and useful method for the automated monitoring and control of the rod mill grinding process.

Keywords: rod mill grinding, acoustic emission, spectrum analysis, vibration analysis.

1 Introduction

1.1 Background

One of the main aims of the comminution is to release the valuable minerals from the associated gangue minerals at the coarsest possible particle size. There are various types of methods of comminution , for example a rod mill and a ball mill. The grinding can be carried out with both dry and wet material. By analysing the acoustic emission of the mill, the progress of the grinding can be possibly identified. This has been studied by measuring vibration of the supporting bearing for the pinion axis of a ball mill by Yigen Zeng and K.S.E Forssberg [1], [2]. The authors analysed the measurements with the PCR and PLS methods and found a the dependency between the operating of the mill and the vibration measurements. The studies were focused on low frequence (under 1 kHz) range.

The faculty of mining of the University of Oulu has built a full minipilot scale mineral processing plant on the campus of the university. The plant is built together with the industrial and research partners and it follows the ore beneficiation process of the Pyhäsalmi mine (scale of 1:5000). The plant contains both the grinding circuit and the flotation circuit. The minipilot has a maximum capacity of 30 kg/h, for Pyhäsalmi ore, when the grinding circuit and flotation circuit are used continuously. The plant can be configured for different types of ore as well. In the autumn of 2014 the joint researcher group of the Faculty of Technology and Oulu Mining School began a series of experiments to study the frequency analysis of AE signal of the rod mill grind.

Fig. 1. Minipilot mineral processing plant (Mining School, University of Oulu).

1.2 Objective

The objective of the study was to clarify whether the progress of the comminution at the rod mill can be measured based on acoustic emission method (AE) and analysed using spectrum analysis.

2 Method

The tests were carried at the rod mill of the minipilot beneficiation plant. The initial measurements were carried out at the outlet of the mill with the of the DR-40 data recorder using the device's built-in microphones (Fig. 2). The sampling frequency of the data recorder is 44.1 kHz and the resolution of the sample 16 bits. On the basis of the first test it was noticed due to the acoustic emission pressure from the mill the measurement distance must be increased. Additionally, the splashes from the mill contaminate the microphones if they have not been protected. In the second experiment, the measurement equipment consisted of TASCAM DR-40 data with Dayton EMM-6 measure microphones. The polar pattern of the microphones is a ball.

Fig. 2. Realisation of the first test recording.

The microphones were covered with protective tubes with which the microphones from splashes. The length of the tubes were 29 cm and 46 cm., The inner diameter of the tubes was 35 mm. Moreover, inside the protective tube, a cellular rubber tube (inner diameter 18 mm) was used. The microphones had been placed in the back part of shield tubes so that the distances of the microphone capsules from the front of the shield tube were 12 cm and 30 cm. Therefore, the acoustic emission to the microphone travels through the acoustically insulated pipe, 18 mm in diameter.

During the third experiment, in addition to the devices mentioned above, also XL2 Acoustic and Audio Analyzer of NTi Audio AG were used. The device contained a M2230 as a microphone. This microphone was mounted in the shorter protective tube. The measurements were performed during three different days using the equipment described above, respectively. The objective of the first day was to get a general idea about the acoustic emission produced by the rod mill. For it acoustic emission samples were saved with the data recorder (using built-in microphones). The recording took place from the outlet of the mill (Fig. 1). The spectrum of the first AE signal recorded from the mill was on the Figure 3.

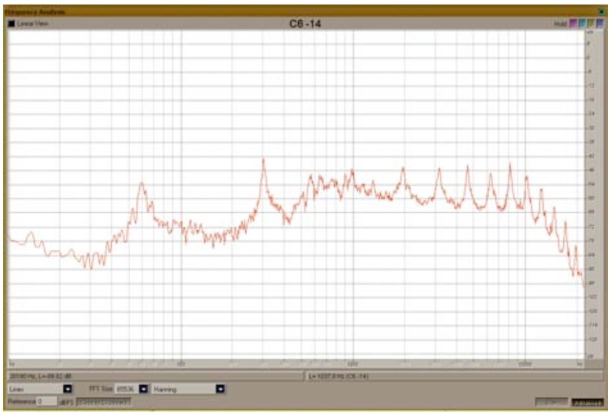

Fig. 3. Spectrum of the acoustic emission of the rod mill. Length of the sample is 2.5 s.

The test recording with a rod hanging freely from a thin thread was also carried out to study the effect of one rod to the vibration of the rod mill. The rod was hit with a hammer and the recorded AE signal was saved with the data recorder.. Figure 4 shows a spectrum from the 0.5 s sample measured 0.8 s after the impact.

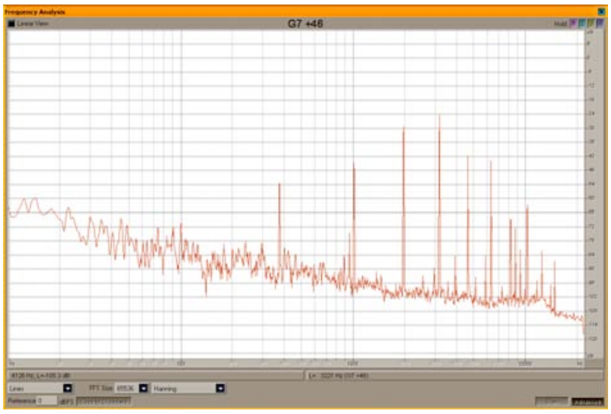

Fig. 4. Spectrum of one rod.

It is observed from the Figures (NROT) that the peaks in the spectrum are eigenfrequencies of the rods of the mill.

During the second measuring day the ore mineral from the Pyhäsalmi mine was comminuted with the rod mill. In the first the material was fed to the at 0,5 kg/min. The particle size range was 4-10 mm.The mill was stopped at one minute intervals and samples were taken for the particle size sieve analysis. The grinding continued altogether for five minutes. Next the particle size was reduced to 0-4 mm keeping the feed rate at 0,5 kg/min. Again, the sampling for sieve analysis and recording of AE signal were carried out as described above for five minutes.

Next water was added to the mill and particle size range was increased back to 4-10 mm maintaining the feed rate of 0,5 kg/min and the duration of experiment five minutes after which the particle size was decreased to 0-4 mm and the experiment was repeated. As described above, the grind periods were saved with the data recorder DR-40 with two EMM-6 microphones.

During the third measuring day the work was begun by operating the mill with rods only, without feeding the material to obtain an AE signal of an empty mill. The next experiment was carried out by feeding gangue (0-4mm) from Pyhäsalmi mine at 0,5 kg/min. The gangue is harder than the ore. The five-minute sampling sequence was carried out as described above.

The mill was emptied and vacuum-cleaned. The next five-minute experiment was carried out with gangue (0.5 kg/min). The water feed rate was 1 litre/min. The sampling interval was as defined above. The last experiment was also run with wet material. Water was added to the mill so much that its surface extended to the edge of the outlet. The gangue feed rate was the same as above. The sample for the definition of the particle size was taken after 5 minutes. Figure 5 shows microphone arrangement that was used in the second and third measurement times.

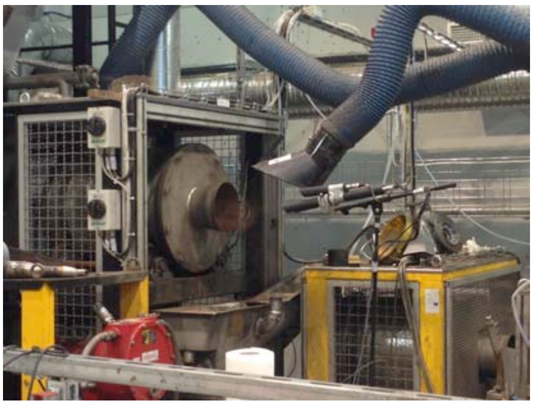

Fig. 5. Microphone arrangement in measuring of the acoustic emission of the mill.

From the samples (Figure 6) that were taken from the mill the particle size distribution was determined with the sieve analysis.

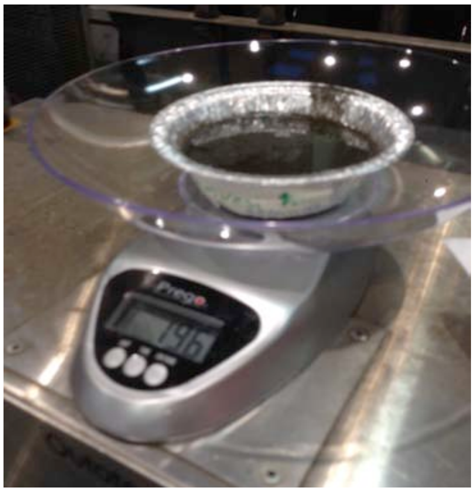

Fig. 6 Weighing of the sample.

The recorded acoustic emission signals were studied with the acoustic emission processing program, Cool Edit Pro, 2.1.

3 Results

The purpose of the initial measurements was to study if we could use AE in the automated control of the mill. For this, short acoustic emission samples were recorded from the rod mill. The spectrum analysis was then carried out for the first and last 2.6 s of each recording. In the Figure 7, the blue graph is from the beginning of the acoustic emission sample and the orange graph from the end.

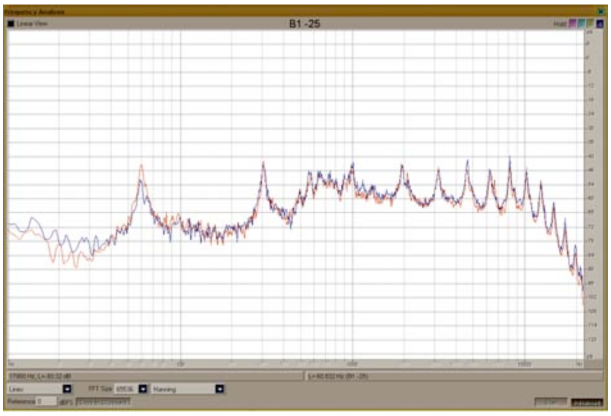

Fig. 7. Spectrum from sample of the first measurement time.

Figure 8 will show spectrum graph obtained with dry material after two (blue graph) and after five minutes (orange graph). The particle size range of the ore was 4-10 mm.

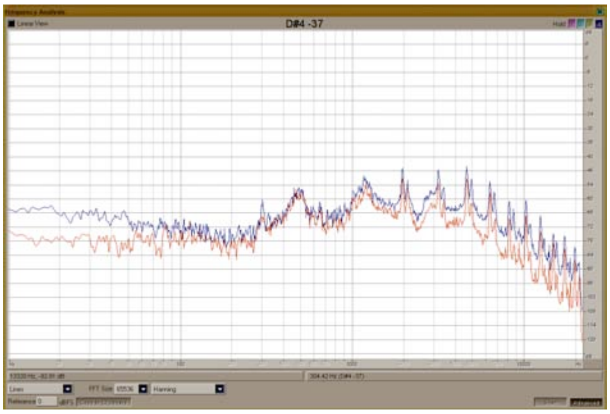

Fig. 8. Spectrum graphs from the beginning and end of the 5 min comminution with dry material.

Figure 9 shows spectrum graphs from the test with the particle size range 0-4 mm.. The blue graph will be since a first minute beginning and the orange graph since a fifth minute end. The mill was not emptied before the experiment and thus, it contained the ground material from the previous test.

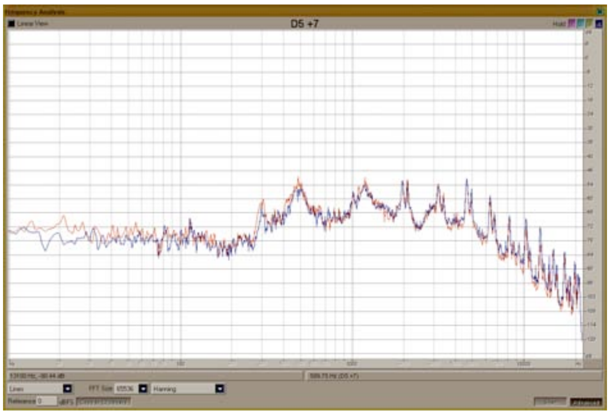

Fig. 9. Spectrum graph since the second stage of the test.

Next water was added to the mill and the next two tests took place with wet material. Figure 10 shows spectrums at one (blue) and five (orange) minutes.) In the experiment the particle size range the feed material was 4-10 mm.. Also in this case, the mill was not emptied before the experiment.

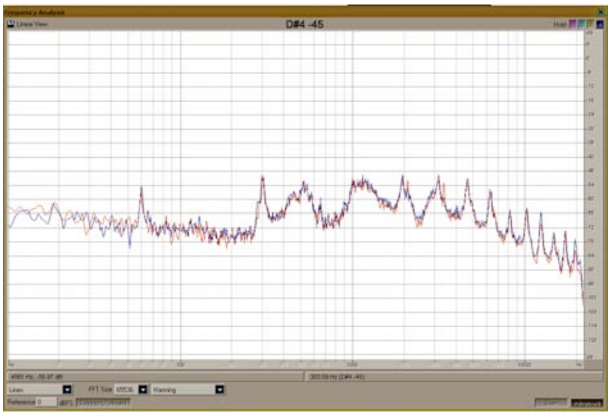

Fig. 10. Spectrum graph for wet material (feed particles size range 4-10 mm).

In the last experiment of the second day, the particle size range of the feed material was 0-4 mm. The samples for determining the grain size were taken after a minute and after 5 minutes at the end of the test. Figure 11 will show spectrum graph measured at one (blue) and five (orange) minutes. During the first grind minute the vibrating feeder was running. The effect of the feeder can be seen on spectrum on frequencies below 500 Hz.

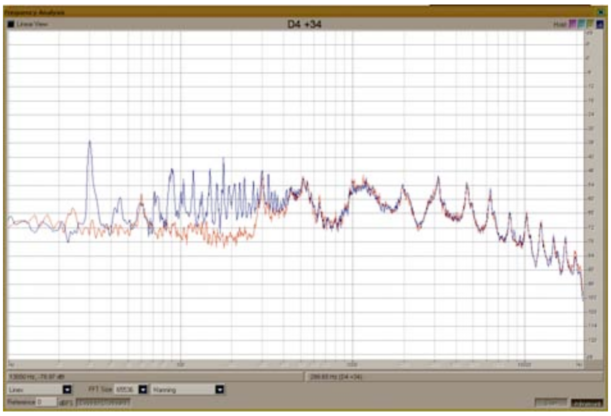

Fig. 11. Spectrum graph for wet material (feed particle size range 0-4 mm).

During the third measurement day the mill was fed with gangue from Pyhäsalmi mine. The gangue is harder than ore mineral. In the test a mineral was ground dry, wet (with a small amount of water) and with water 0-4 mm in particle size. After experimenting with the dry material the mill was emptied and was cleaned before the following test.

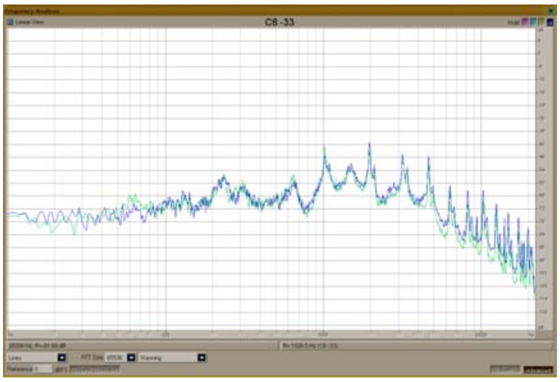

Fig. 12. Spectrum graph from the beginning and the end of the comminution of the dry material.

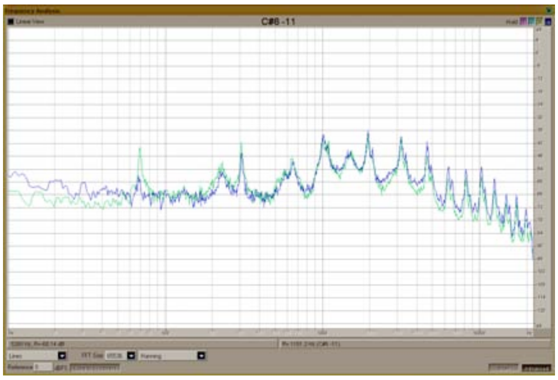

Figure 13. Spectrum graphs obtained with wet material at one (blue) and five (orange) minutes.

At the last stage of the third measurement time water was added to the mill in which case the grind was performed with water. The mill was not emptied after the previous period. Figure 14 will show spectrum graphs since the beginning and end of the taking place grind with water.

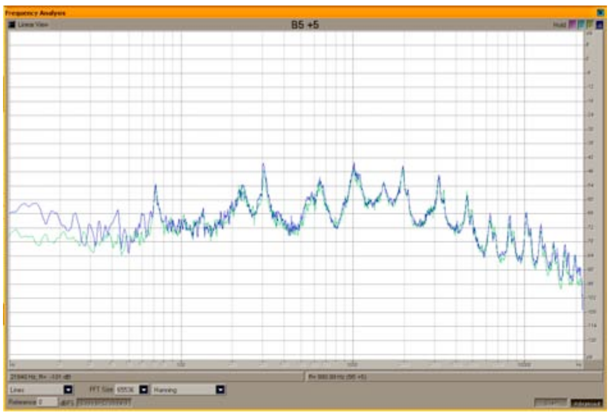

Fig. 14. Spectrum graph from the beginning and the end of the grind with water.

It can be seen from the results for the first measurement time that in the spectrum graph a change took place during the grind. In the graphs there were strong repeated peaks which continued up to the highest frequencies that were measured. On the basis of the spectrum of the impact test that has been done with one rod hanging freely, we can conclude that these peaks were on the eigenfrequencies of rods. For the handling of results the frequencies of the peaks were determined at a coarse level and correspondingly the areas between them. They are shown in figure 15.

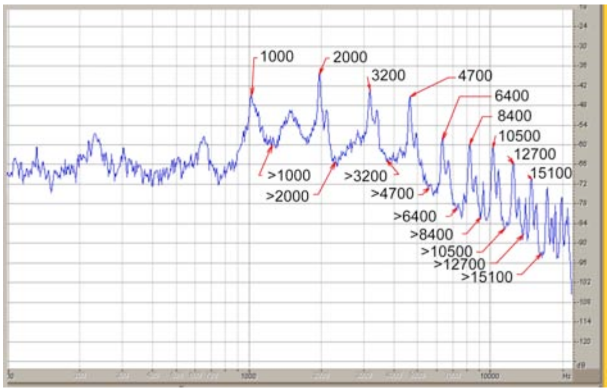

Fig. 15. Definition of frequency sections that have been used in the analysis.

The mineral which is ground in the second test series was an ore mineral of the mine of Pyhäsalmi. The particle size of the mineral was 4-10 mm and 0-4 mm. These were ground in different test series both dry and with water. Each test series lasted for five minutes. The samples for the particle size definition were taken at intervals of one minute.

The acoustic emission of the period which lasts for every minute was recorded and the changes in the magnitude of the spectrum which had taken place during the period were studied with frequencies which are in accordance with figure 15 for the analysis. These changes were collected in a table and of them the bar graphs were made. During the grind period which lasts for a minute to be examined, the bar graphs will represent by different examination frequencies the attenuating which has taken place.

In figure 16 can be seen the attenuating which has taken place during the 4-10 mm ore mineral grind dry.

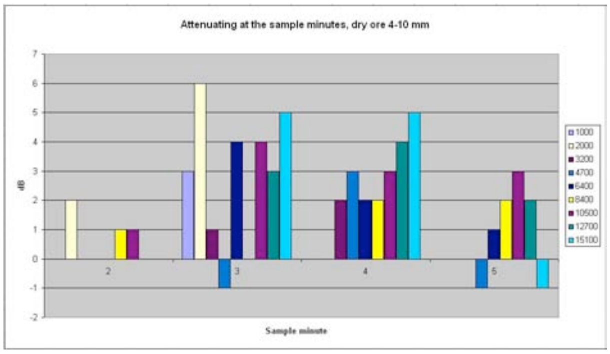

Fig. 16. Ore mineral 4-10 mm, dry grind.

The measurement data exists from the time of four minutes. It is noticed that during the second grind minute a significant change will not take place with different examination frequencies. Instead considerable attenuating will take place during the third and fourth minute. During the fifth minute the attenuating will still take place with higher frequencies.

Next the test was continued by feeding ore mineral 0-4 mm to the mill. The results of its test can be seen in figure 17.

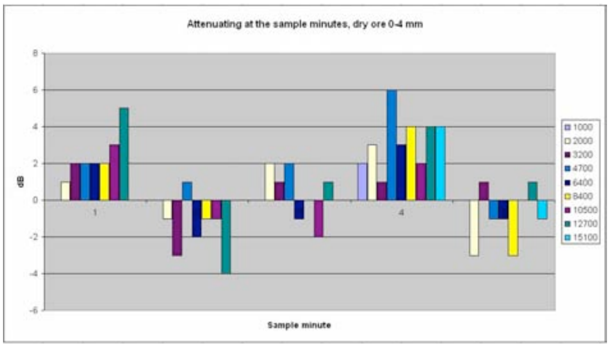

Fig. 17. Ore mineral 0-4 mm, dry grind.

So this test series was an extension to the previous test series that has been presented in figure 16. It is noticed that during the first minute attenuating has taken place. Instead the changes have been occasional during the second and third and fifth minute. During the fourth minute considerable attenuating has taken place.

At this stage of the test water was added to the mill and so the following grind tests took place with water. First an ore mineral the particle size of which was 4-10 mm was fed. The results of the test are in figure 18.

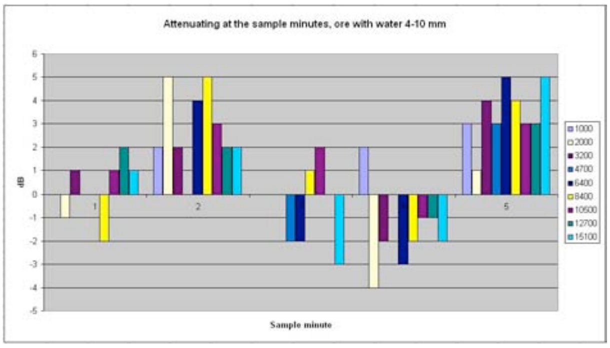

Fig. 18. Ore mineral 4-10 mm, with water grind.

A test the attenuating has taken place during the second minute and during the fifth minute likewise. During the first, third and fourth minute the changes have been small and occasional.

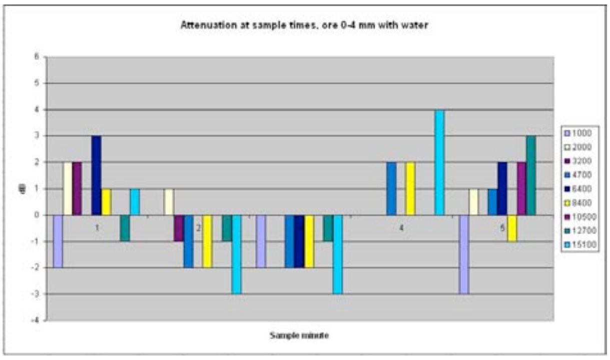

Fig. 19. Ore mineral 0-4 mm, with water grind.

Figure 19 shows visible in the last part of the test of the magnitudes of examination sections changes which have taken place. The particle size of the ore mineral that has been fed to the mill was 0-4 mm. This test was an extension to the previous, in other words the mill contained a ready at the end of the previous test ground mineral. This test has contained attenuating at the initial stage on some frequencies, then, intensification, during the second and third minute and finally, attenuating, particularly in a fifth minute.

The mineral which is ground in the third test series was a waste rock of the mine of Pyhäsalmi. The particle size of the mineral was 0-4 mm which was ground in different test series dry, wet and with water. Each test series lasted for five minutes. The samples for the sieve analysis were taken at intervals of one minute only at except the last end of the test.

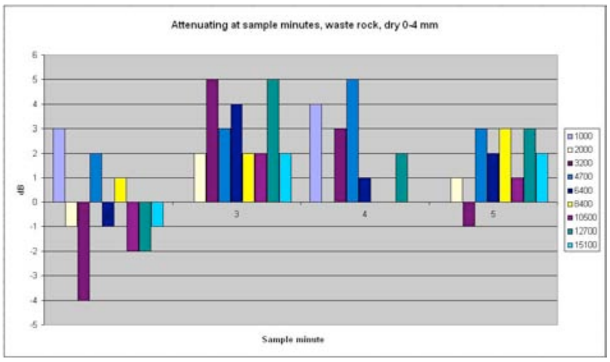

Fig. 20. Waste rock mineral 0-4 mm, dry grind.

Figure 20 will show the attenuations in the examination points when a waste rock the particle size of which is 0-4 mm is ground dry. At the beginning of the grind both attenuating and intensification in the separate frequency sections can be perceived. At this stage the mill will contain only little mineral to be ground, 1 kg at the end of the second minute. During the third minute strong attenuating has taken place, in fourth minute also, but not on all the frequencies. In a fifth minute the attenuating has taken place except for the lowest frequencies.

At the second stage of the test the mill was emptied and was cleaned.

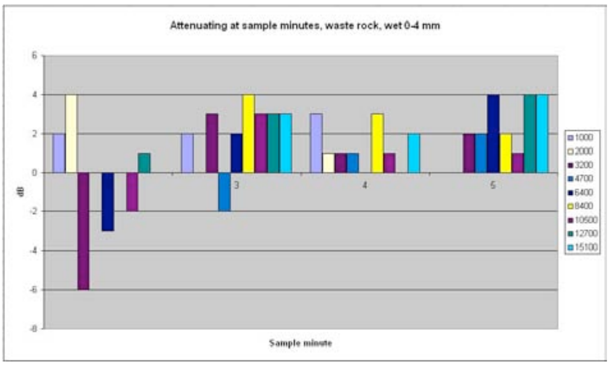

Fig. 21. Waste rock mineral 0-4 mm, wet grind.

Water was added to the mill so much that the material to be ground was wet but the grinding did not take place in fact in water. A waste rock, the particle size of which was 0-4 mm, was fed to the mill. Figure 21 shows the attenuating during different test minutes on the observation frequencies. During the second minute (in which case the mill contained a little material) the attenuating was occasional. Intensification also took place with some frequencies. Since the third test minute the attenuating took place with nearly all the frequencies to be examined.

At the third stage of the test, water was added to the mill so much that the grinding took place with water. The material already in the mill was not removed. Figure 22 shows the attenuating which has taken place during five minutes.

During the first test minute the a little intensification has taken place with most test frequencies. During the second and third minute both the intensification and the attenuating have taken place. During the fourth test minute attenuating took place the clearest. During the fifth minute the intensification took place with some lower frequencies and the attenuating with some higher frequencies.

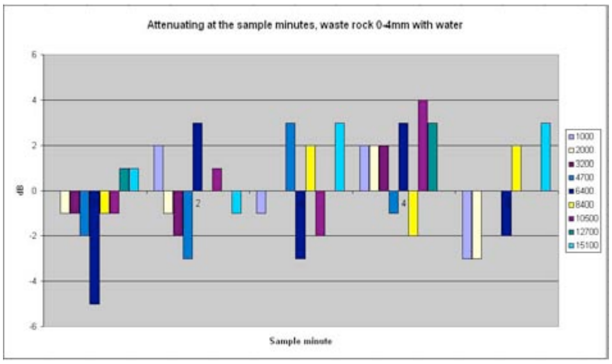

Fig. 22. Waste rock 0-4 mm, with water grind.

4 Conclusion

On the basis of preliminary tests it is noticed that the most significant attenuating in the frequency spectrum took place with higher than 1 kilohertz frequencies. The eigenfrequencies of the rods of the rod mill were chosen as examination frequencies up to a 15,1 kHz frequency. It was the easiest to read the amplitude of the spectrum in these points. Also between the peaks a similar change as by the peaks took place but the evaluation of the level of the spectrum was more difficult.

When a grind progressed, in the frequency spectrum attenuating took place. This was the most obvious with dry ground. When a waste rock mineral was ground with water, the attenuation was more occasional than with dry ground. It would be a possible solution to use the acceleration sensor fastened directly to the shell of the mill for the elimination of the effect which attenuates the acoustic emission in water. In that case the vibration would come as a structure-borne noise directly to the sensor. The measuring area of the sensor should extend to 20 kHz.

For the control of the grind process the interesting sections should be chosen from the frequency spectrum. Based on the changes a connection between changes and state of the grind process should be designed. Possibly the differentiating of the acoustic emission signal could give a better sensitivity to the monitoring of the state of the process. Anyway, the attenuation of particularly over 1 kHz frequencies could be observed from the spectra. Finally, it was concluded that the AE spectrum analysis could be an applicable and useful method for the automated monitoring and control of the rod mill grinding process.

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