FEATURES OF THE AE TESTING OF EQUIPMENT ON OPERATING MODE

Sergey ELIZAROV ¹, Vera BARAT ¹, Vladimir BARDAKOV ¹, Dmitry CHERNOV ¹, Denis TERENTYEV ¹

¹INTERUNIS-IT LLC, Moscow, Russia; Phone: +7 495 3617673; e-mail: terentyevda@interunis-it.ru

Abstract
The possibility of AE testing of roller supports of the rotary kiln in operating mode was investigated in the alumina refinery in the sintering and calcining shops. Each roller support consists of a shaft, roller and bearing blocks. Each element is entitled to be tested. Research task was to assess the possible locations of damage, filtering of in-plant noises, and identification of the damage type. By simulating AE signals it was discovered that the ratio of amplitudes at different AE sensors allows to determine the location of damage within the accuracy of the structural node. Linear location of AE sources is possible only within the shaft. It was revealed that the only significant source of the high amplitude impulsive noise in operating mode are scuffs and roughness on the roller surface or kiln tyre. Impulses corresponded to noise are recorded with the period which is equal to the rotation interval of the support, or the kiln, so such impulses can be easily filtered. Detected defects of shaft can be divided into 2 types. Defects of the first type correspond to fatigue cracks and are located as a rule in places with the highest concentration of stresses such as fillet transitions. The second type presumably corresponds to the shaft surface deterioration at friction contact. The amplitude distribution parameters of impulses that characterize this process correlate with the working lifespan of the roller supports. Bearing defects are more diverse. Such defects as inner bearing race cracks, brinelling, and violation of lubrication rate were identified in the AE data on the basis of information about known defects.

Keywords: AE, operating mode, shaft, roller, bearing block

1. Introduction

Acoustic emission (AE) testing is traditionally carried out on non-operating objects. Such requirement is associated both with the Kaiser effect, leading to the necessity for exceeding the test load above the working one, and with a high level of acoustic and electromagnetic noises during object operation. This requirement is one of the main factors that reduce the AE method competitiveness in regard to other methods of non-destructive testing (NDT).

However, AE testing could be performed under operation conditions, if the AE data acquisition period is increased and a specialized method is developed, which should take account of the effect of various technological and external acoustic noises, features of the object loading under operating conditions, the effect of damaging factors and possible destruction mechanisms.

Fig. 1. The kiln resting on paired support rollers
In this paper the possibility has been investigated to carry out AE testing of support rollers of rotary kilns in operating mode. Experimental work was carried out in October 2015 in the territory of JSC “RUSAL – Achinsk Alumina Refinery” (Russia) in the sintering and calcination shops.

The object under test was the support roller of the rotary kiln (Fig. 1). The rotary kiln is a cylindrical vessel having a diameter of up to 5 m and a length of up to 185 m, which is installed with tilt. It is designed for sintering ore to form solid aluminates. The kiln rests on 7 or 8 paired support rollers. The support rollers mounted at a discharge end are most loaded.

Each paired support roller consists of two units, right and left, which are installed on a common foundation. Each unit comprises a shaft, a support roller pressed on it and 3 bearing assemblies mounted within 2 enclosures (Fig. 2). The kiln turnaround time is 50 s, while the rotation period of the support roller is 12.5 s. The working lifespan of the support rollers under test was 1 year to 13 years.

The support roller is a complicated and crucial element of the rotary kiln structure. Under its damage the equipment is urgently shut down, and faulty components are replaced. Such shutdown results in rotary kiln downtime, and thus in high cash expenditures. Every year at the refinery about 5 support rollers out of 200 ones fail during the year due to breakage of bearings and about 1 support roller – due to shaft destruction. Therefore, when performing AE testing, it is necessary to provide detection of defects in all the elements – not only in the shaft, but also in the roller and in the bearings.

The roller is a part of the support roller, which is in direct contact with the kiln, so its major defects are scores and metal flaking.

The shaft is a solid-metal cast structure. When the kiln rotates, the cyclic loading of the shaft occurs in radial and axial directions. The shaft damage can occur at all stages of its operation. At first, the defects reveal themselves which appeared during shaft manufacturing, such as pores, sinks, and thermal cracks. On long-term servicing, fatigue cracks occur, and fatigue and abrasion wear of the shaft takes place. Since the support rollers operate in adverse temperature conditions, at high levels of vibration and in conditions of cyclic loading, the most likely defect in the shaft is the formation of fatigue cracks.

The main bearing elements include an outer ring, an inner ring, cylindrical rolling elements and a cage. The bearing destruction is caused by 3 main reasons. The first reason is an incorrect mounting of the bearing, wherein stress raisers may occur associated both with the cage damage and with the shaft and bearing misalignment or with the bearing unbalance. The second reason is insufficient quantity or poor quality of lubricants. If dust and dirt
penetrate into the lubricant, an abrasive layer is formed, which abrades metal and leads to the formation of stress raisers. With lubricants dried out or lack, rubbings appear which also lead to the formation of stress raisers and the object destruction. The third reason is a fatigue failure of the bearing. As is known, the object under study sustains the cyclic loading. By lapse of time, the level of accumulated damages reaches a deadline that produces plastic deformation and cracking in the bearing elements. The fatigue flaking and brinelling can be assigned to the bearing defects based on plastic deformation.

Since the shaft is a monolithic structure with numerous raised portions and variations of thickness, performance of NDT of the shaft by means of traditional scanning methods is difficult even for the non-operating support rollers.

Because of the low angular velocity (one revolution per 12.5 s), the well-known vibrometry method is not quite suited for testing the bearings of support rollers of rotary kilns.

At the same time, a variety of laboratory studies with artificial defects [1-4] and cases of successful AE monitoring of the support rollers of rotary kilns [5] have demonstrated that the AE method as applied to testing the integrity of support rollers can be used under operation conditions, and this method is highly sensitive and permits to detect defects irrespective of the type and shape of defects, as well as the rotation velocity [5].

To summarize, it may be concluded that the testing of support rollers of rotary kilns in operating mode is a problem which can be solved with a high confidence by the AE method.

2. Preliminary procedures

Acoustic emission sensors GT200 (“GlobalTest” company, Russia) with a working frequency range of 130-200 kHz and a sensitivity up to 1000 V/(m/s) were used. The signal from sensors preliminary arrived to a preamplifier manufactured by "INTERUNIS-IT" company (Russia) having a gain of 26 dB and a frequency filter with 30-500 kHz pass band. A 4-channel external input-output module “E20-10” (“L-Card” company, Russia) was used as a data acquisition system. The output of “E20-10” module is a digital signal waveform having any length and a sampling frequency of 2.5 MHz.

![Fig. 3. Noise signals with period 12.5 s and 50 s, caused by scores and roughness on the surface of kiln roller or kiln tyre](image)

During NDT of support rollers of rotary kiln under its operation conditions, the noise level in audible sound frequency range is quite high. Its sources are processes taking place inside the kiln (movement of charging material), and also there are noises of drive motor, noises of loose parts during kiln rotation, and noises arising when the kiln tyre rotates. However, in the range above 30 kHz because of a point dry contact between the kiln tyre and
the roller, the acoustic noises generally are no more than 32 dB\textsubscript{AE} in the most unfavorable point, i.e. at the place of charging material feeding. Scores and roughness on the surface of kiln tyre or kiln roller are the only significant external source of acoustic noises. On coming in contact with the site of score, an AE signal with amplitude of up to 100 dB\textsubscript{AE} appears. However, these interfering signals can be easily eliminated from further analysis since they are recorded with the definite period equal to the period of support roller or kiln rotation (Fig. 3).

It has been also found that level of electromagnetic noises do not exceed 40 dB\textsubscript{AE} and thus has no significant influence on the results of AE testing.

In the repair shop, the measurements of attenuation and propagation velocity of acoustic signal were carried out on the non-operating support roller and with protective caps removed. An electronic imitator was used to imitate AE sources. Imitations were produced on the shaft in the area of fillet and at the ends, as well as on the inner and outer rings of bearings (Fig. 4).

![Fig. 4. Scheme of support roller with the protective caps opened. Places of emitting by imitator and recommended sites for mounting AE sensors](image)

Within the shaft the attenuation coefficient was 5 dB/m, and the propagation velocity of acoustic waves was 3776 m/s. The high attenuation value was detected (30-35 dB) at the interface “bearing enclosure – shaft”. Thus, when the imitator radiates on one of the bearings, the amplitude of received signals on the bearing located near the opposite end does not exceed the noise level.
It follows from these results that the AE testing should be carried out as follows (Fig. 4). For full testing of all 3 bearings, including a zone location with accuracy to an element of particular bearing, it is necessary to mount AE sensors at all available access points, namely 3 AE sensors on each of 2 bearing enclosures (Fig. 5). Since the shaft length is not too large (4050 mm), to perform its full AE testing, which includes the linear location, it is sufficient to provide access to the shaft by removing protective caps and to mount 2 AE sensors: 1 on the side of thrust bearing and 1 on the opposite side (Fig. 6). Slow rotation of AE sensors installed at the shaft ends does not cause significant technical difficulties if AE testing continues about 1 h.
3. AE testing

AE testing of the operating support roller was the next working stage. The AE data were taken at the normal rotation of kiln and support roller for 1 or 2 h. 5 support rollers were investigated with the protective caps opened, where a direct access both to the bearings and to the shaft was afforded. 10 support rollers were also investigated with the protective caps closed, where an access for testing was afforded to the bearings only.

3.1. AE testing of bearings

In 1 of the bearings lubricant dried out, that resulted in an intensive friction and a gnash within the audible sound frequency range. AE sensors also fixed signals with amplitude of about 100 dB$_{AE}$ and duration of more than 100 000 µs (Fig. 7). Thus, by identifying such signals the lubrication intervals can be estimated.

The AE diagnostics can detect not only defects in the bearing, but the pre-destruction states characterized by the formation and accumulation of microdamages in the various parts of bearing structure. The source of AE signals at this stage may be plastic deformation or small abrasion of the surface that occurs when dust or dirt penetrates into the lubricant. Such processes are characterized by the stream of low-amplitude AE signals.

On the support roller, put into operation 1 year ago, the signals with amplitude up to 60 dB$_{AE}$, duration of about 100 µs and event rate about 3-4 s$^{-1}$ were recorded (Fig. 8). Based on similarity with the pulses from of an indentation [6], they were assigned to the process of material plastic deformation (brinelling).

![Fig. 7. AE signal registered on bearing enclosure. Abnormality of lubrication intervals](image)

![Fig. 8. AE signal registered on bearing enclosure. Plastic deformation (brinelling)](image)
On the support roller, put into operation 3 years ago, the higher event rate (up to 10-12 s\(^{-1}\)) and higher amplitudes (up to 76 dB\(_{AE}\)) of AE signals were observed (Fig. 9), indicating that the accumulation of microdamages passes into a more intensive phase, i.e. the damage accumulation.

The final stage of damage accumulation is the defect formation, for example, fatigue flaking or cracking. In this case, the significant change in nature of AE signals stream occurs: the event rate rises, the amplitude trends appear, and most importantly, always the periodicity of occurrence is present, caused by the fact that the acoustic signals at this stage arise under periodic collisions of the bearing roller with the site of damage.

On the bearing of one of the support rollers, a moderately active periodical AE source was detected (Fig. 10), which, as a result of the low characteristic level of amplitudes, did not pass the confirmation process.

A more powerful periodical source (about 100 dB\(_{AE}\)) which was detected on the other roller support (Fig. 11), turned out to be a crack in the bearing outer ring.
Fig. 11. Periodical AE signal registered on bearing enclosure. A crack in the bearing outer ring

Thus, using the AE signal stream parameters as the base, it is possible to identify both catastrophic sources and moderately active sources. The regular AE diagnostics of the support roller with the potentially possible defect in the bearing permits to estimate and forecast the intensity of damage accumulation.

3.2. AE testing of shaft

An AE signal, typical for friction, is a continuous random process characterized by distribution of the pulse amplitudes close to normal that is not typical for cracks. It was found that the higher values of acoustic signal root mean square (RMS) are observed on the support rollers with long lifetime, and this allows us to conclude that the AE signal RMS characterizes the integrated value of wear of the shaft surface. Fig. 12 shows the signals obtained during diagnostics of the shaft of support rollers being in operation for 2 years and 9 years.

Fig. 12. The signals obtained during diagnostics of the shaft of support rollers being in operation for 2 years and 9 years

The appearance of individual pulses with large amplitude (up to 81 dB$_{AE}$) on the background of the continuous signal (Fig. 13) may evidence that the surface of the shaft begins to ruin at frictional contact.
The acoustic emission corresponding to formation and growth of cracks has a fundamentally discrete and aperiodic nature. When the crack rises, as a rule, high-amplitude pulses are generated with the specific distribution of the AE data stream parameters. While testing the support rollers, on 2 shafts being in operation for 11 and 13 years the AE sources was registered with amplitudes up to 78 dB$_{AE}$ and event rate about 10-20 s$^{-1}$ (Fig. 14). Judging from the AE waveforms and the distribution of AE parameters, presumably, this activity corresponds to active fatigue cracks. The analysis of results of linear location has shown that the AE sources are in the area of fillet, i.e. at the sites with the greatest stress concentrations. According to the Russian standard «Safety rules № PB 03-593-03», the detected AE sources turned out to be non-critical and for this reason did not undergo the confirmation process.
4. Conclusions

1. The possibility has been investigated to carry out AE testing of support rollers of rotary kilns in operating mode.
2. In the range above 30 kHz the acoustic noises generally are no more than 32 dB$_{AE}$. Scores and roughness on the surface of kiln tyre or kiln roller are the only significant external source of acoustic noises. They are recorded with the definite period equal to the period of support roller or kiln rotation.
3. For full testing of all 3 bearings, including a zone location with accuracy to an element of particular bearing, it is necessary to mount 3 AE sensors on each of 2 bearing enclosures. To perform full AE testing of shaft, which includes the linear location, it is sufficient to provide access to the shaft by removing protective caps and to mount 2 AE sensors: 1 on the side of thrust bearing and 1 on the opposite side.
4. The signals with amplitude of about 100 dB$_{AE}$, duration of more than 100 000 µs allows to estimate the lubrication intervals.
5. In the final stage of damage accumulation in bearings, the significant change in nature of AE signals stream occurs: the event rate rises, the amplitude trends appear, and most importantly, always the periodicity of occurrence is present.
6. The higher values of acoustic signal RMS are observed on the support rollers with long lifetime. The appearance of individual pulses with large amplitude on the background of the continuous signal may evidence that the surface of the shaft begins to ruin at frictional contact.
7. While testing the support rollers, the AE sources activity was registered on 2 shafts in the area of fillet. They presumably correspond to active fatigue cracks. The detected AE sources turned out to be non-critical.

References