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METHOD FOR CONDITION-BASED MAINTENANCE BASED ON SOUND MEASUREMENTS USING THE EXAMPLE OF SELECTED BELT CONVEYOR SYSTEMS

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A B S T R A C T

The article describes a method for condition-based maintenance, which is based on the evaluation of acoustic characteristics of a plant. Starting from the general requirements and objectives for maintenance, the measurement procedure is explained. Subsequently, the feasibility of the method is demonstrated and its limitations are shown by means of two test sections. A brief economic consideration shows the economic advantage in addition to the increased reliability of the plants.

K E Y W O R D S

Condition-based maintenance;
Acoustic model;
Belt conveyor;
Open cast mining.

The recording of the properties of idlers and conveyor systems is not only necessary within the scope of production and quality assurance, but also in particular after commissioning and during the entire service life of the conveyor system. As a rule, the acceptance inspection is carried out by the manufacturer or system operator shortly after the initial commissioning by checking the parameters listed in the specifications.

At commissioning:

• Basic function checks with and without conveyed material

• Start-up behavior

• Checking for belt misalignment

• Alignment of the scaffolding and idler garlands

• Acoustic acceptance for immission-relevant installations

• Additionally, belt tension, control of gearboxes, drives and belt drums with regard to electrical parameters, slip, etc.

In the course of operation, continuous wear occurs, especially in the area of the idlers. In order to avoid unplanned shutdowns and malfunctions, various checks and maintenance measures are carried out [1]:

• Regular inspection trips by e.g. mobile fire-fighting team, checking for rough visual and acoustic conspicuities;

• Automatic thermal imaging cameras for the detection of hot spots, especially in plants at risk of fire (coal);

• Annual noise measurements for immission-relevant installations.

1. Condition-based maintenance

According to the definition, maintenance is the «Combination of all technical, administrative and management measures during the life cycle of an object that serves to maintain or restore it to its functional state so that it can perform the required function» [2]. Condition-based maintenance is a method of preventive maintenance strategies. When replacing wear components or system parts, it is not based on fixed times, usage intervals or defects that have occurred, but on the actual prevailing system condition using technical diagnostics. In principle, the general objectives are pursued:

• Increasing the operational safety and availability of a plant;

• Reduction of maintenance costs through targeted operation of components up to the wear limit and avoidance of unplanned failures with consequential damage;

• Ensuring optimal operation and utilization of power reserves;

• Reduction of environmental impact by lowering pollutant emissions and minimizing noise and vibration emissions.

It comprises the following basic procedure, which must be tailored to the respective systems and operating conditions:

• The selection of suitable parameters for assessing the condition of the plant;

• Carry out regular and permanent measurement of the parameters to diagnose developing damage;

• Determination of adapted maintenance intervals or measures to ensure plant operation.

If possible, the recording of the plant condition should be carried out without dismantling machine parts and during ongoing operation in order to avoid additional production interruptions [3].

Insofar as sufficient knowledge is available about the operating conditions, the failure behaviour and the prevailing parameter properties, it is possible to make forecasts about the probable remaining service life of the respective plant components. The objective of utilising the longest possible service life of individual components without premature replacement or failure is optimally fulfilled with this approach.

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http://dx.doi.org/10.5510/OGP2022SI100698

The above-mentioned procedure for the maintenance of belt conveyor systems in the area of the pure conveyor section (excluding drives, return stations, etc.) deviates in certain points from those of condition-based maintenance.

Essentially, the assessment of the condition of the installation is carried out without the use of diagnostic procedures through a mostly subjective assessment by experienced installation operators during regular inspections. The comparison of limit values, for example with regard to noise immission, by means of sound pressure level measurements is only carried out in exceptional cases, especially if the installations are relevant to immission. As a rule, defective or overheated idlers are detected during regular inspection runs and, depending on the acute situation, immediately removed from service on site by means of quick-lowering lugs, or continue to operate until the next scheduled maintenance date and then replaced.

The disadvantages of this approach lie mainly in the subjective assessment of the plant condition by the staff. It is possible that not all defects are detected promptly and reliably, which can lead to unscheduled shutdowns. Furthermore, optimum plant utilisation is not given with regard to the remaining running time of the idlers and the noise emission of the plant. Exceeding noise specifications can result in far-reaching measures, especially with regard to environmental protection, which can lead to premature component replacement or, in the worst case, to restrictions in the operating permit, mostly at night.

1.1. Development trends in condition monitoring of construction elements and their application to idlers and belt conveyors

In the past, numerous approaches and methods have been developed for monitoring production facilities and belt conveyor systems in particular, which are suitable for performing condition-based maintenance. Based on the approach, a distinction is to be made between systems in which corresponding technical diagnostic sensors are integrated in the components and those in which the data is recorded externally and usually without contact. The advantages and disadvantages of both systems are also discussed below, from which a corresponding need for action can be derived.

1.1.1. Integrated monitoring systems

In the case of integrated monitoring systems, the sensors are permanently installed in the components of a system to be monitored. In the special case of the belt conveyor system, there is a great deal of interest in the condition assessment of the idlers and in the roller bearings that are particularly relevant for failures. Analogous to roller bearing diagnostics, the evaluation of vibration and temperature data can be used to draw conclusions about the degree and course of damage and, in the best case, the remaining service life.

In a publication from 2019, a method is described for diagnosing hot-running idlers and rolling bearing damage with the aid of temperature sensors in the axle journals of idlers in the area of the rolling bearings and corresponding data transmission. The basic prerequisite for complete monitoring of all idlers is the presence of temperature sensors for each roller bearing and reliable, long-range data transmission. The temperature data of an idler roller chair are transmitted via a data line to a radio module and from there forwarded by radio to a central evaluation point [4]. The disadvantages of this method lie in the large number of sensors required, whereby the use of temperature sensors still represents the more cost-effective variant compared to vibration sensors. Belt conveyor systems usually extend over several kilometres of conveying distance, with several thousand idlers being installed, which would require a correspondingly high number of sensors (comparisons tabele 1). Another problem is the connection of the individual sensors to the radio module via a data line, which must be designed to be robust enough for the harsh operating conditions. The assembly of the comparatively filigree plug connections during installation and possible idler changes must also be taken into account. Furthermore, the detection of rolling bearing damage via a temperature rise is only a very late method of reliably detecting a defect, as the author correctly points out. The remaining reaction time for changing the affected idler is correspondingly short.

In addition to this application, which is specifically tailored to idlers, there are numerous other systems that are used in practice for stationary rolling bearing diagnosis and condition monitoring. These are mostly all based on the installation of a temperature or acceleration sensor near the bearing and a wired or radio-supported data transmission to a central evaluation system. The systems follow the development trend under the keyword Industry 4.0 or the Internet of Things [5,6].

Analogous to the integration of temperature sensors in idlers described above, the numerically high use of sensors and the data transmission, which is susceptible to opencast mining conditions, also have a disadvantage here.

1.1.2. External systems

Using technical diagnostics that rely on sensors that are not permanently installed on or in the idler machine element,

Table 1

Equipment of the K66 coal conveyor in the Nochten open-cast mine, source [1]

Belt width:	2000 mm
Conveying speed:	6.7 m/s
Conveying capacity:	7500 t/h
Drive power:	4 × 900 kW
Centre distance:	2.525 m
Number of scaffolding bays:	406
Garland count Obertrum:	5 or 6 per scaffold bay
Garland count lower run:	1 per scaffold bay
Garland distance Obertrum:	1.2 m (5) resp. 1.0 m (6)
Equipment Obertrum:	3-piece garland - A159x750/600/750-6310-5-18

there are currently a variety of systems that are used to monitor and maintain conveyor systems.

There are methods in which measuring sensors are inserted into the conveyor belt itself. With the help of shear stress sensors inside the conveyor belt, defective idlers can be detected when they are passed over, insofar as a change in the resistance to movement occurs. Two patent specifications are based on this approach:

• Method for continuous measurement of the wear of all idlers in belt conveyors [7];

• Method for monitoring the belt alignment and/or the belt run of a belt conveyor device as well as belt conveyors [8].

However, since a change in the resistance to movement also depends on other factors such as temperature, loading condition and belt speed, it is difficult to draw a definite conclusion about idler damage. Furthermore, a significant increase in the rotational resistance of roller bearings only sets in at a far advanced degree of damage, which also greatly reduces the reaction time for any maintenance measures here. Temperature sensors installed in the conveyor belt can be used to detect hot-running idlers and rolling bearing damage that is accompanied by a temperature increase [9]. Here, too, the short reaction time for carrying out maintenance measures has a disadvantage. In the maintenance of belt conveyor systems with idlers in garland suspension, the practice of replacing and scrapping the complete idler garland – usually consisting of three or five idlers – has become established, even if only one idler is defective. For this reason, RWE has developed an idler test stand where the complete idler garlands can be diagnostically examined. Defective idlers are specifically sorted out and the intact ones are reassembled into new idlers and used again in the conveyor systems. This test stand makes it possibly to objectively determine the reusability of idlers and thus reduce maintenance costs [10]. This idler test stand is only a downstream diagnostic device for the evaluation of the idler condition. It cannot replace the localisation of defective idlers in the belt conveyor system. For the detection and localisation of idler damage in belt conveyors, systems exist in which, for example, cameras or microphones installed at specific points monitor the condition of idlers and other machine elements. Defective idlers can be detected at an early stage via sensor modules at different points on the conveyor and failures can be avoided. Furthermore, increased energy consumption caused by this is minimised and the costs for electricity and maintenance are reduced [5]. However, due to the fixed installation of the sensor modules at selected locations, only certain local points can be monitored and a reliable detection of defects becomes more difficult with increasing distance to the sensor system. In order to compensate for this disadvantage, a method was developed which, in addition to permanently installed microphones, uses an automated drone equipped with an infrared and RGB camera. The data evaluation of this successfully used prototype is carried out automatically, which makes it possible to plan service periods according to demand and to better estimate the expected service life of the components [11].

ABB has also developed an automated system in which the sensors travel along a rail-guided vehicle next to the conveyor system. Thermal imaging and ultrasound data are recorded, which can be assigned to the respective idlers depending on the position of the vehicle. Depending on the environmental and operating conditions, however, other or adapted sensors can also be used. The system can create a detailed condition map of the conveyor and estimate the probability of failure of individual components as well as plan the replacement of defective idlers [12]. For the assessment of the condition of belt conveyor systems and in particular of the installed idlers, the collection of vibration data by measuring structure-borne or airborne sound is suitable to provide reliable information for condition-based maintenance. Automated methods using vehicles of any kind (drones, rail-bound vehicles, etc.) appear to be the most suitable for precisely assigning the collected data to the respective machine elements. However, the installation of these systems and their adaptation to the respective application are associated with a high initiation effort. In addition, the harsh operating conditions of belt conveyor systems also place high demands on the robustness of the automated measurement technology. The basic prerequisite for the functioning of automated monitoring of belt conveyor systems and idlers in the course of condition-based maintenance is always that the systems work more reliably than the machine elements to be monitored themselves.

1.1.3. Maintenance of belt conveyor systems-open question

Based on the current state of the art and the existing procedures for the maintenance of belt conveyor systems, there is a need for action at some points, which will be investigated in the following work. This is essentially based on the following points:

• Use of methods of technical diagnostics for objective assessment of the condition of the plant;

• Centrally controlled evaluation of the collected data;

• Use of few sensors to reduce initiation costs;

• No stationary installation of sensors in order to cope with the harsh operating conditions and not to increase the maintenance and servicing effort with additional components;

• Evaluation of acoustic data for condition assessment of the idlers and rolling bearings;

• Development of a simple system that is characterized by low initiation effort and highly flexible use on technical equipment.

On the basis of these points, a method is to be developed which is characterized by the use of one or more sound microphones which are moved along belt conveyors in a hand-guided or automated manner in order to record data relevant to the condition.

2. Presentation of the test series on the test sections of the belt conveyor system 66

The basics for the acoustic measurement of belt conveyor systems are described in detail by Täschner (Täschner, 2014) in the course of his dissertation on the «Investigation of the acoustic effect of idlers for targeted noise reduction on belt conveyor systems». The procedure is taken up here and applied to the condition-based maintenance of a belt conveyor system.

2.1. Technical parameters of the conveyor systems examined

The plant under consideration is located in the Nochten opencast mine and is operated by LEAG to transport the extracted lignite from the mine in Nochten to the Boxberg power plant (table 1). Within the belt conveyor system, two test section have been investigated since 2008, which differ in terms of the idlers installed.

Since 2018, the measurements at the plants have been carried out and supervised by BTU employees, before that by LEAG employees. However, the data for evaluation has been available since the beginning of the respective investigation periods.

2.2. Objektives of the studies

The objectives of the investigations are derived from the general objectives of the maintenance of technical installations and include the following points in particular:

- Reduction of operating costs, repair, through targeted operation of the idlers to the wear limit before unplanned failures and consequential damage occur;
- Reduction of environmental pollution due to increased noise emissions;
- Selection of suitable idlers to increase service life;
- Testing of the measurement concept and optimization with regard to effort and intervals of use;
- Determination of the early warning characteristics of the concept by determining the residual operating time from the time of the first detectable wear until total failure;
- Determination of the possible total service life of the system until general refurbishment.

The use of additional acoustic measurement technology and the regular monitoring measurements initially increase the running costs for maintenance compared to the conventional approach. However, the aim is to reduce the total costs over the entire service life of the system by enabling the system to be operated for a significantly longer period of time through the targeted replacement of defective idlers before a complete replacement has to be carried out.

2.3. Measurement setup and implementation

In order to be able to guarantee comparability of the individual measurements, it is necessary that the operating conditions of the plant are approximately constant at the respective measurement dates. This means that the conveyor speed must be 6.7 to 6.8 m/s and the load must be over 2/3 of the maximum load. Furthermore, regular monitoring measurements are important in order to be able to replace conspicuous idlers promptly. The spacing of the inspection intervals depends on the remaining service life to be expected from the first detectability of damage to an idler until failure. The interval should be correspondingly shorter - on the test sections examined, the nominal inspection interval was set at three months. The actual interval between measurements is usually longer, which can be attributed to unfavourable weather and operating conditions and the associated delays. Depending on the system and the installed idlers, the remaining service life from the detection of the first signs of rolling bearing wear to the replacement of the idlers is over six months, which means that longer intervals between measurements are also possible. The prerequisite for this, however, is that not too many idlers become acoustically conspicuous due to wear in the intervening period, as otherwise the localisation of the garlands to be changed is no longer possible on the basis of sound measurements. A structure-borne sound analysis would make it possible to locate the defective idlers, but would be correspondingly more time-consuming.

The diagram in figure 1 shows the influence of damaged and noisier idlers on the average sound power of a belt conveyor system. The system conditions marked in colour are system-specific and depend on the idlers used and the general system specifications. Depending on the maintenance concept, the limits can therefore shift during the operating time of the belt conveyor system. In condition-based maintenance with regard to noise, it is advantageous, for example, to adjust the maintenance level – i.e. the sound power level of the system parts from which maintenance measures are triggered – to the general system condition. For the examined test sections of the belt conveyor system 66, it was determined that the maintenance level is 9 dB above the median of the sound power levels of all segments. This dynamic adjustment has the advantage that external influences during the measurement or systematic errors are compensated for insofar as they affect the complete system. Different delivery rates as well as temperature and weather influences are also compensated for in this way. In addition, this approach may require a maximum limit value for the entire plant, which may also depend on immission specifications. Since the maintenance level also increases continuously due to the constant difference to the median, a continuous deterioration of the plant condition can occur,

Table 2

List of the examined belt conveyor sections and assignment of the installed idler types with the technical specifications according to table 1

Test section 1	Belt conveyor 66, segments no. 340 to 359: • Study period from February 2008 to September 2017 • Abandonment of the investigations due to failure of all original idlers and replacement with another design • Idler manufacturer A • Type «Ü», outer casing with low concentricity tolerance ≤ 0.5 mm
Test section 2	Belt conveyor 66, segments no. 320 to 339: • Investigation period since February 2008 • Idler manufacturer B • Type «Ü», outer casing with low concentricity tolerance ≤ 0.5 mm

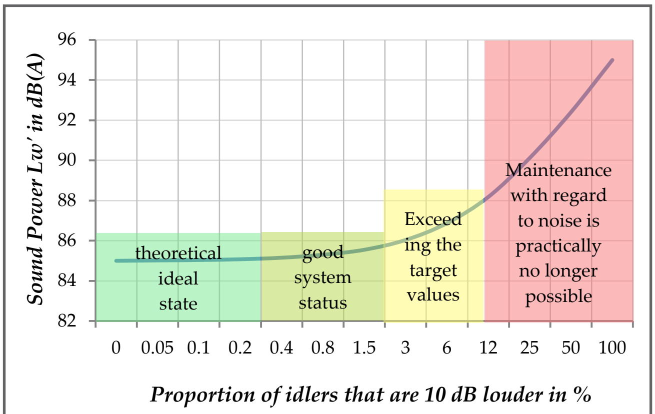

Fig.1. Model calculation for the influence of damaged idlers on the average length-related sound power of a belt conveyor system with $L_{w'}$ = 85 $dB(A)$ for undamaged idlers and $L_{w'}$ = 95 $dB(A)$ for idlers with damaged idler bearings [13]

since no or insufficient maintenance measures are triggered. This can occur in particular if all plant components wear out at the same time or if there are frequent failures as the plant's service life progresses. The data required for plant assessment are regularly recorded by intensity measurements according to figure 2 and then the length-related sound power level is calculated for the assessment.

In order to ensure that the method used provides meaningful data that is representative of the system, it must be coordinated in advance using the acoustic model that has been set up. The measuring surface is of great importance, as it ensures that it reflects the system-specific sound intensities. The sound sources themselves (carrying idlers) and any reflections (conveyor belt, covers, etc.) must be taken into account. Quantitative statements on the representativeness of the measuring area are provided by comparative sound pressure level measurements at different distances from the conveyor system. The sound power level determined according to DIN ISO 9613-2 using DIN 45635-1 (sound pressure measurements) must be within the permissible error tolerance, analogous to the sound power level according to DIN EN ISO 9614-2 (continuous scanning sound intensity measurement) [13]. To speed up the measurements and reduce the results to the relevant data, only the sound power levels of the segments (5 to 6 festoons) are initially determined. Only when a segment exceeds the mean sound power level of the test section by 9 dB are the individual festoons selectively measured in order to identify the responsible and damaged idlers. A garland determined to be defective in this way is then reported and replaced with a new garland of the same model and manufacturer during the next regular maintenance.

2.4. Results and evaluation of the examined test section on the belt conveyor systems in the Nochten opencast mine

For the two test sections examined according to table 2, the test results are presented in the following diagrams.

Test section 1

At the end of 2007, test section 1 was newly equipped with idlers from manufacturer A and measured for the first time in February 2008. With an average length-related sound power level Lw’ of around 87 dB(A)/m, the new system has a slightly below-average value for non-noise-reduced idlers.

However, the median of the length-related sound power level begins to increase significantly and steadily after only two years of operation and exceeds 90 dB(A)/m. In the following, the condition-related maintenance measures take effect and by May 2011 nine idler garlands are removed and replaced by new ones. The measures are effective and the median of the length-related sound power level fluctuates around 90 dB(A)/m until then. By the following measurement in August 2011, however, there is a sudden increase to 95 dB(A)/m, which results in another extensive garland replacement of six pieces. However, this does not succeed in lowering the median of the length-related sound power level again, but it continues to rise until it reaches its maximum of about 100 dB(A)/m between January and October 2014. Between May 2011 and October 2014, another 24 idler garlands were replaced. While only one garland had to be replaced in the first two years of operation, the replacement ratio increases to 4% in the third year and to about 10 % of the garlands in the test section in the following years. With such a high replacement frequency, condition-based maintenance does not represent an economic improvement in this case either, without wanting to go into this in more detail. Until August 2011, replacement was carried out exclusively by idlers from the same manufacturer A. However, since these idlers had design defects in the area of roller bearing sealing, which is also the reason for the accelerated and premature failure, garlands that had to be changed were subsequently replaced by idlers from another manufacturer.

Due to constructional defects in the area of the roller bearing seals of the idlers of manufacturer A, these idlers failed abruptly and in large numbers after a period of use of about four to five years. At this point, it was no longer possible to maintain the belt conveyor system in a safe and operational condition through the applied condition-based maintenance method. For this reason, almost all remaining garlands from manufacturer A in this section were replaced by other garlands in November 2015 and the test section was abandoned. However, the subsequent measurements from the beginning of 2016 clearly show that the selection of suitable idlers as replacements again leads to a lowering of the average length-related sound power level to the original value. This test section also shows the limits of the

Fig.2. Schematic measurement path with an intensity probe at the segments of the test sections

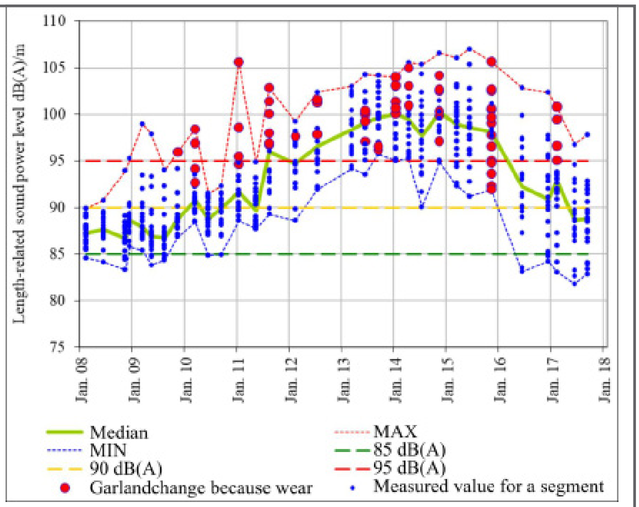

Fig.3. Test results for test section 1, garland type A3G-2000-A159×750/600/750-10-5-18-Ü, maximum runout 0.5 mm, idler manufacturer A, test section with 20 segments and approx. 100 garlands

considered condition-based maintenance method. In the case of systematic faults in the installed components - such as the roller bearing seals in this case – it is not possible to implement the method successfully over a longer period of time. Furthermore, the selection of high-quality idlers for use in high-performance belt conveyor systems is a decisive factor in terms of system safety and overall service life. The surface and running properties of the idler roller shell, such as circularity and eccentricity, are particularly decisive for the noise emissions of the conveyor line, as are the shell thickness and shape. For the service life of the roller bearings, the design and reliability of the sealing system play a decisive role, in addition to a design adapted to the operating conditions, correct mounting, and the type and quantity of lubricant. As a consequence of these test results, the idlers of manufacturer A considered here are no longer used in any of LEAG's conveyors.

Test Section 2

The investigations on test section 2 were also started in February 2008, after the plant had been re-equipped at the end of 2007. The idlers installed here have the same specifications as in test section 1 (maximum concentricity deviation 0.5 mm) but are from manufacturer B.

The median of the length-related sound power level of the newly equipped unit is about 90 dB(A)/m and thus at an average level for this idler design. The diagram from Abbildung 6 shows that the median also fluctuates around 90 dB(A)/m over the entire study period up to the last measurement taken into account in August 2021. Increases are noticeable due to individual defective idlers, which were, however, replaced by the triggered measures. Over the 14-year period under consideration, it can thus be guaranteed that the system is acoustically at the level of the new condition. However, the replacement of festoons due to defective ones is not evenly distributed over this time. For example, in the third, fourth and seventh years of operation, there is an increased replacement ratio of about 4 to 6 % of the total idler garlands included. Within the 14-year period under consideration, a total of 19 garlands were replaced due to wear and tear. This corresponds to a replacement ratio of about 1.5% per year in relation to the total number of garlands and thus significantly below the level of test section 1, where the ratio averaged almost 8% per year. The results of test section 2 prove the applicability of the described method for condition-based maintenance and the objectives set:

Maintaining the plant condition in a safe and operational state at the level of a newly equipped plant

Increasing the total service life up to the total overhaul by utilising the service life reserves of the individual components

With the type of system under consideration and the operating requirements, this belt conveyor has a service life of about seven to eight years, until the system and especially the installed idlers need to be completely overhauled. The investigation period of 14 years so far this represents a significant increase in service life. Furthermore, the measurement results do not allow the conclusion that a significant deterioration of the system condition is to be expected in the near future, which would require a complete overhaul.

Economic consideration of the presented method of condition method-based maintenance

The economic aspects of the test series will only be considered here on a rough basis, as a complete breakdown of the costs would exceed the scope of this paper. The following boundary conditions are used as a basis [1]:

Fig.4. Defective bearing seal on a support roller of manufacturer A, which subsequently leads to the penetration of contaminants into the rolling bearing, source: LEAG

Fig.5. Consequential damage to a support roller from manufacturer A in the form of a completely destroyed rolling bearing, the inner ring has already worked its way several millimetres into the support roller axle [1]

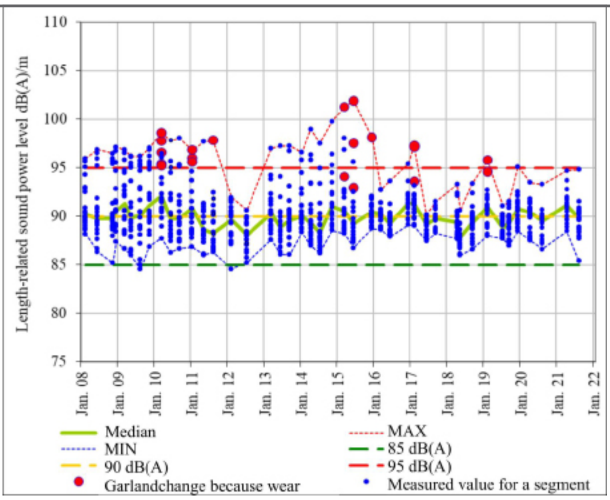

Fig.6. Test results for test section 2, garland type A3G-2000-A159×750/600/750-10-5-18-Ü, maximum runout 0.5 mm, idler manufacturer B, test section with 20 segments and 100 approx. garlands

- Scheduled service life for idlers in ground-level conveyor sections (with noise relevance): 7 years
- Cost of material idler garland: € 307
- Cost change idler garland: € 24

Added to this are the personnel costs for measurement and evaluation at the test sections. Travel times are not taken into account, as they are not in proportion to the comparatively short plant sections. For each section, the pure effort for measurement and evaluation, including the derivation of recommendations for action for maintenance, amounts to roughly one hour per quarter. An hourly rate of 100 € including all ancillary costs is assumed for the measurement engineer. Under these conditions, this means for test section 2 in the examined period of about 14 years that the installation would have had to be equipped with new idlers twice without condition-based maintenance. If no garland has to be replaced within the regular operating time of 7 years – which does not correspond to reality-the following total costs result:

$$Costs\,(14\ years)^{convertional}_{test\ section\ 2} = 2\cdot 100\ garlands\cdot\frac{(307.00€ + 24.000€)}{garland} = \\ = 66200.00€$$

66220 within 14 years corresponds to running costs for the maintenance of the idlers of the plant of about 4729 € per year.

This contrasts with the ongoing costs for condition-based maintenance and the 19 garlands replaced over the 14-year period under review:

$$19\,garlands\cdot\frac{(307.00€ + 24.000€)}{garland} + 100.00\frac{€}{h}\cdot 1h\cdot 4\left[\frac{measurements}{year}\right]\times \\ \times 14\left[years\right] = 66.28900€ + 5.60000€ = 11889.00€$$

Per year the costs for the maintenance of the system with regard to the idlers thus only amount to about 850 €. In the calculations, a complete replacement of all garlands in condition-based maintenance was not taken into account, as the evaluation of the test sections has so far not provided any indication of a possible maximum service life. Nevertheless, it can be demonstrated on the basis of this rough observation that the presented method of condition-based maintenance on belt conveyors brings a cost advantage compared to the conventional method. The costs could be reduced even further if the regular measurements and associated evaluation could be partially or completely automated. Furthermore, no consideration was given to the follow-up costs in the event of an unplanned standstill, which can be considerable in practical operation.

Conclusion

The investigations on the four test sections of the belt conveyor systems in the Nochten opencast mine prove that the presented method of condition-based maintenance based on noise measurements is suitable for

- to keep the plant in a safe and operational condition and to avoid unscheduled shutdowns,
- the overall acoustic and mechanical condition can be maintained at the level of a newly equipped system,
- the total operating time of the plant can be increased many times over until the general overhaul and,
- a prognosis on the damage behaviour can be given with sufficient lead time for the implementation of maintenance measures.

The prerequisite for this is the recording of acoustic measurement data of the system at regular inspection intervals in order to be able to detect damage at an early stage. Furthermore, the selection of high-quality idlers has a great influence on the applicability of the method, the ongoing maintenance costs and the overall service life of the system. This quality is largely determined by the surface finish of the idler shell, the effectiveness of the sealing system and the manufacturing and assembly accuracy. A rough profitability analysis points to the clear cost advantage of the presented method of condition-based maintenance on belt conveyor systems compared to the conventional approach.

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Метод технического обслуживания по состоянию на основе звуковых измерений на примере отдельных систем ленточных конвейеров

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Реферат

В статье описывается метод технического обслуживания по состоянию, основанный на оценке акустических характеристик установки. Начиная с общих требований и целей технического обслуживания, объясняется процедура измерения. Затем продемонстрирована осуществимость метода и показаны его ограничения на примере двух тестовых участков. Краткое экономическое рассмотрение показывает экономическую выгоду в дополнение к повышению надежности установок.

Ключевые слова: техническое обслуживание по состоянию; акустическая модель; ленточный конвейер; открытая добыча.

Seçilmiş lentli konveyor sistemləri nümunəsindən istifadə edərək səsin ölçülməsinə əsaslanan texniki xidmət metodu

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Xülasə

Məqalədə qurğunun akustik xüsusiyyətlərinin qiymətləndirilməsinə əsaslanan şəraitə uyğun qulluq metodu təsvir edilmişdir. Baxım üçün ümumi tələblərdən və məqsədlərdən başlayaraq ölçmə proseduru izah edilir. Sonra iki sınaq bölməsi vasitəsilə metodun məqsədəuyğunluğu nümayiş etdirilir və onun məhdudiyyətləri göstərilir. Qısa iqtisadi mülahizə qurğuların artan etibarlılığına əlavə olaraq iqtisadi üstünlüyü göstərir.

Açar sözlər: vəziyyətə əsaslanan texniki xidmət; akustik model; lentli konveyer; açıq mədənçilik.