Application of Abrasion Depending Life Cycle and Optimal Maintenance Strategies for Belt Conveyor Systems

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Abstract

In this paper, new signal and observer based methods are presented for stress depending maintenance of large-scale belt conveyor systems. In order to reduce maintenance costs and provide a high availability of such complex devices, it is necessary to achieve the optimal operating efficiency and simultaneously ensure a high level of safety. The proposed methods will provide more online information about system conditions and mechanical abrasion to optimize the current maintenance schemes.

1 Introduction

Belt conveyor systems are complex technical systems for transporting high mass flows over long distances, widely used in mining and on large-scale building-sites. Belt conveyors operate under the presence of many disturbances and strong parameter changes caused by the industrial surroundings and the operators are faced with increasing requirements on quality and productivity.

In recent years, maintenance is more and more integrated into the production process. Due to the increasingly critical view on maintenance costs, it is important to avoid expenditure for superfluous inspection and downtime caused by inspection defects. New operating strategies should on the one side provide an optimal availability and high level of safety and, on the other hand, reduce the maintenance costs. For that reason it becomes more important to get detailed information about the equipment conditions to determine the remaining life of system components.

For belt conveyor systems the research is focused on the mechanical components belt, gear, brake, driving and reversing wheel and idlers [5], [1]. The existing maintenance strategies are static calculation methods of life cycle based on predicted data without considering the real stress and system states of operation. The measurements available have not been integrated in the operation and strain depending maintenance scheme.

Attention of this paper is focused on the development of dynamic calculation methods, using real system data and estimated data provided by the robust observer-based. This approach includes the real mechanical and dynamical strain, e.g. the load, the torque and the velocity, to optimize the maintenance considering the abrasion depending and dynamic life cycle. The proposed approach can increase the life cycle of the mechanical parts in the case of a lower abrasion than predicted and enable an early substitution of components to avoid malfunction and downtime of the whole conveyor system.

2 Maintenance Strategies for Belt Conveyor Systems

The basic maintenance strategies can be classified into *preventive maintenance*, aiming at preventing consequential damage and loss of availability, and *corrective maintenance* (damage-elimination) in the case of partial or complete failure to restore the conveyor operability [3]. Today maintenance schemes for belt conveyor are based on human like exploitation of recorded system data and component information differing by the cause of service. This leads to the known basic methods of damage-based, time-based and condition-based maintenance, as displayed in figure 1, where the "damage prevention" strategy shows cost advantages comparing with other maintenance schemes [4],[3].

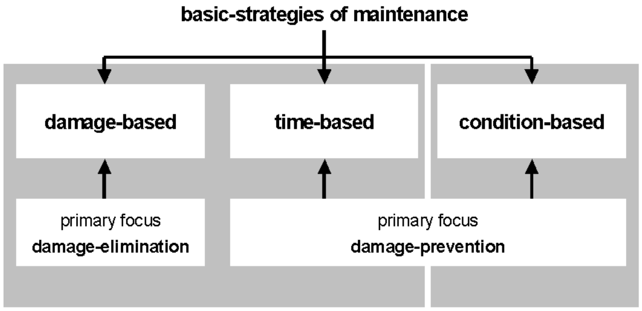

Figure 1: Maintenance strategies overview

The damage-based strategy is focused on damage-elimination by changing or repairing components after malfunction. This has the advantage that the machine modules life cycle is used. It will, however, lead to interruption of production with consequential damage of the whole open mining process. To avoid breakdown of the whole conveyor system, high cost is induced by storing spares and employing short call workforce.
The time-based strategy applies fixed cycles of maintenance with the benefit that the maintenance period is previously known. The storage costs will be reduced by using regular spare part delivery. But the life time of components do not achieve the optimal (maximum) value, which causes increasing costs for maintenance.
The advantages of both methods and their combination created the idea of the condition-based maintenance, aiming at reducing the storage costs and exploiting the whole life cycle. This approach yields as much maintenance activities as necessary to provide an optimal operational efficiency.
To investigate the equipments conditions the components to be considered have to be divided into subsystems related to abrasion approaches and described in terms of a function. High requirements for the application of the condition-based strategies are as follows:

- define the relationship between measuring and diagnosis results, abrasion condition,
- define measurement categories,
- online measurement and reliability of data,
- demounting of components for inspecting diagnosis.

2.1 Existing belt conveyor maintenance

The components and assemblies considered in this approach are gears, idlers, driving and reversing wheels. Today time-based methods to maintain the surface mining equipment are applied [1] using the static calculation of an expected life cycle L_p of a component loaded by a strain S_p predicted by the manufacturers. The value of S_p is a static determination considering the assumed, forecasted strain according to the operating company and the field of application of the belt conveyor. From there the maintenance cycles with consideration of L_p are fixed. Taking into account the manifold operating conditions and strong parameter changes between idling and maximum strain, changes of the load or the velocity during operations of the belt conveyor, it becomes clear that the time-based schemes are do not fit the desired optimal maintenance. Especially the unknown real load at each operating period causes difficulties in defining S_p, which will lead to an imprecise calculation of the expected life cycle L_p.

In view of that, the idlers are maintained according to damage-based methods, because most of the hundreds of idlers per belt conveyor are not heavily loaded as assumed. The consequence is the application until breakdown or damage of the belt too, with a high risk of consequential damage. Measurements available do not deliver the important data for the abrasion calculation as there are the load and it's distribution and the corresponding rotation rate of each idler, especially ball bearings.
The components gear and wheels are maintained time-based using the static calculation of the life time for a predicted strain to avoid malfunctions where the overall belt conveyor system has to be stopped for the repairing period with high costs. Considering the real operating states and strain will offer the condition-based maintenance for idlers, gears and wheels.

2.2 Condition-based maintenance approach

The direct measurement of stress defining values and its progression is not possible. The basic idea oft this project is a signal- and model-based approach to get information about the strain to reduce the maintenance cost by a high level of utilization of the life time. The spare costs are reduced and the downtime for maintenance cycles will be optimized. Figure 2 displays the structure of the condition-based maintenance approach where the calculation of the load-depending remaining life N of each component is described by a dynamic system. Based on the measurements of the process variables, velocity of the driving pulley v and the torque M, the necessary information about the system states is provided by the observer-based model [6],[7]. The "condition monitoring" provides measured and estimated data as well as the strain monitoring by

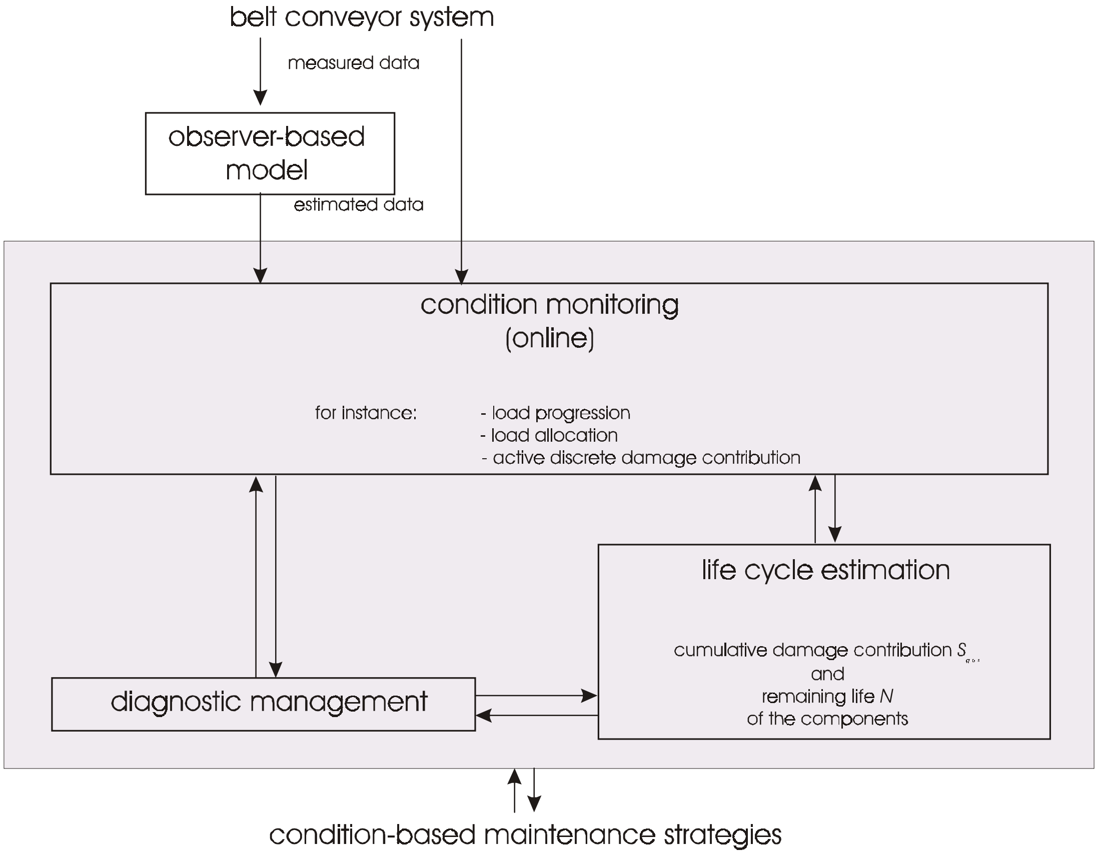

Figure 2: Structure of abrasion depending maintenance scheme for belt conveyor systems

calculating the load progression, load allocation and belt tension. Let's define the discrete damage contribution S_k which represents the abrasion of a mechanical component for a period T corresponding to an evaluation of the forecasted strain S_p

$$S_k = \frac{L_p}{L_k} \cdot S_p$$

where L_k is the life cycle of the real components strain for the period T. The evaluation period T has to be chosen according to sampling rate of system data and operating state.

The "life cycle estimation" (figure 2) determines the cumulative damage contribution S_{ges} and estimates the remaining life time N of the components. The cumulative damage contribution S_{ges} includes all results of the discrete damage contribution S_k from the installation time until presence:

$$S_{ges} = \sum_{k=1}^{k_{active}} S_k\left(P_k\right) + S_0$$

The remaining life time N depends on the life cycle L_p and the cumulative damage contribution S_{ges}, where a remaining life time of zero is equal to the calculated breakdown of the component.

$$N = L_p - S_{ges}$$

Obviously in practice, the point of change of the affected component is different from $N = 0$ according to the safety and reliability requirements. The "diagnostic management" contains visualization of the system states, display of relevant data and involves the input of the necessary characteristics of the components supports, such as historical data and component parameter supplied by the manufacturers. As a result, the load-depending estimation of life cycle and remaining life, considering the equipment's historical condition for belt conveyor systems will be demonstrated by an example.

3 Condition-based maintenance for Idler

In this section, the signal and model based abrasion calculation for providing the remaining life will be explained with the example of idlers. Idlers are carry the belt and the load and consist of two ball bearings and a steel mantle. Figure 3 shows the cross section of a belt conveyor system, with the load progression, the belt and an idler combination of three idlers. During operation the load of a belt conveyor is subject to strong changes between no-load running and maximum load (figure 5). The critical part of a 3-idler combination (figure 3) is the middle idler, which is bearing the main load. Due to the huge load range an exact forecast of the strain value S_p is difficult to determine. Application of a condition-based approach will optimize the calculation of the remaining life N.

The life cycle of an idler is defined by the ball bearings. The nominal life cycle L_{10} of a ball bearing is calculated by

$$L_{10} = \left(\frac{C_r}{P_r}\right)^3$$

where L_{10} is the life cycle that an idler reaches with a probability of 90 percent [2]. C_r is the dynamic radial load rating and is a characteristic value given by the manufacturer and depends on ball bearing material and grease. P_r is the dynamic equivalent radial load and is calculated by

$$P_r = X \cdot F_r + Y \cdot F_a$$

where the radial force F_r and the axial force F_a are caused by the weight of the belt and the load, X is the radial coefficient and Y is the axial coefficient. They are characteristic values defined by the ratio of F_r and F_a according to [2]. Figure 3 illustrates the resulting forces at the idlers combination.The radial force F_r and the axial force F_a for each idler n can be described by

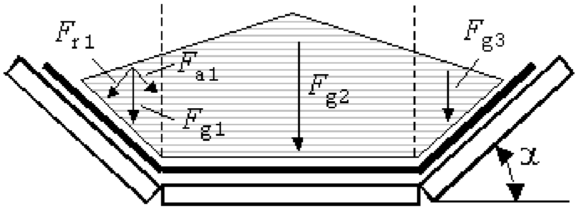

Figure 3: Cross section of a belt conveyor

$$\begin{aligned} F_{r\_n}(t) &= F_{g\_n}(t) \cdot \sin(\alpha_n) \\ &= m_n(t) \cdot g \cdot \sin(\alpha_n) \\ F_{a\_n}(t) &= F_{g\_n}(t) \cdot \cos(\alpha_n) \\ &= m_n(t) \cdot g \cdot \cos(\alpha_n) \end{aligned}$$

The mass $m_n(t)$ depends on the unknown load of the transported material $m_i(t)$ and the mass of the belt m_g. Indeed, the mass flow is subject to

$$\begin{aligned} \dot{m}_i(t) &= Q_{in,i-1}(m_{i-1}(t), v_{i-1}(t)) \\ &\quad -Q_{out,i}(m_i(t), v_i(t)) \end{aligned}$$

i.e. $m_i(t)$ is time-variant and also depends on the velocity of neighboring sections of the belt conveyor [6]. As a result the life cycle L_k for any period T is calculated considering the real strain as well as the calculation of the cumulative damage contribution S_{ges} and the remaining life N of each idler is possible.

4 Applications and Conclusion

We shall briefly present some results for the component idler of an open mining belt conveyor system. This belt conveyor system has a length of more than 1000 meter and the belt has a width of 2.5 meter. The mass of the belt is 160 kilogram per meter and the overall system consists of more than 800 idlers. For the transport of the overburden with the maximum load of 1300 kilogram per meter the driving unit of the conveyor system is equipped with three 2000 kilowatt motors.

The huge range of the dynamical progression of load and the velocity for the period of 1 day is displayed in figure 5. The remaining life N of the idlers calculated by a static time-based method considering the operation time is shown as dotted line in figure 4. The advantage of the dynamic condition based calculation method demonstrated in this example is that the remaining life of the component obviously increases, because of the lower real strain and load compared to the assumed value in the static method. With this method the operators get a more accurate knowledge about the conditions of equipments to optimize the preventive maintenance strategies. For industrial application the knowledge of historical data are necessary to verify and improve the dynamic calculated remaining life cycle. But there is almost a lack of this information and the application is limited to new or refreshed systems and components with big potentials reducing the long-term maintenance cost.

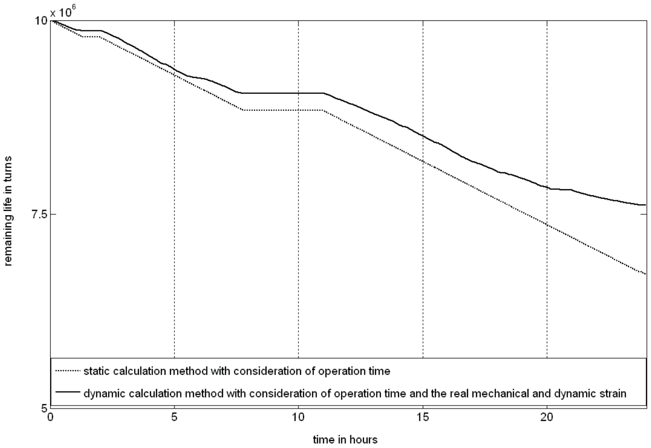

Figure 4: Remaining life time

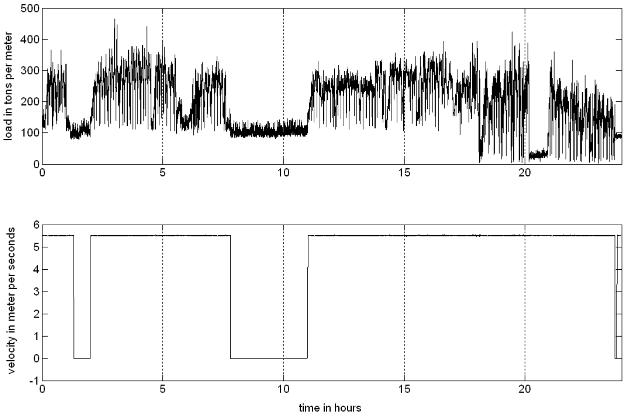

Figure 5: Measured data of load and velocity

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