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Self-engineering: possibilities for maintenance operations in the mining machines industry

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Abstract

Self-engineering is a relatively new branch of knowledge that aims to understand how systems could "autonomously" re-configure or repair themselves without the intervention of the operators. A direct field of application is within the maintenance spectrum. Having systems or machines capable of self-detecting or even self-repairing could represent a game-changer, in capital asset fields such as the mining industry in particular.
This paper aims to investigate the possible benefits and challenges of self-engineering / self-maintenance concerning mining machines, specifically bucket-wheel excavators (BWEs).
Firstly, describing the state of the art and the main principles of self-engineering (and, particularly, the applications of self-maintenance) and the complexity of the mining industry in terms of machines and capital assets. Secondly, using as a real case example, the revitalization process of a 50,000 kg bucket-wheel excavator gearbox for an open-cast lignite mine in Serbia, pinpoints how self-engineering / self-maintenance could make the difference in managing the equipment.
Finally, it discusses the results sketching the pros and cons of self-engineering in mining machines and similar capital assets.

Keywords: self-engineering; self-maintenance; maintenance operations; mining industry; bucket-wheel excavator; gearbox revitalization.

1. Introduction

To deal with the increasing complexity of systems and uncertainty of their environments, engineers are exploring the self-adaptivity concept. Self-adaptive systems are capable of dealing with a continuously changing environment and emerging requirements that may be unknown at design time. Building self-adaptive systems cost-effectively and predictably is a major engineering challenge [1].

One of the most important aspects is that in designing self-adaptive systems, the feedback loops that control self-adaptation must become first-class entities. Therefore, identifying the critical challenges systems and products must address to enable systematic and well-organized engineering of self-adaptive is of paramount importance.

Self-engineering is therefore a powerful and interesting solution that could find applications in several industrial domains and research fields.

Within self-engineering, self-maintenance refers to the ability to carry out regular quality and safety checking by the machine itself, to detect anomalies, and to make immediate repairs when needed by using stocked spare parts to avoid potential catastrophic loss [2]. These characteristics represent a possible game-changer in the field of maintenance due to their ability to automatically repair (to a certain extent) failing components, or at least to re-adjust the system to ensure working operations.

It is commonplace in various industrial sectors, to spend a multitude of the investment cost or replacement cost on cyclic maintenance and overhaul lifespan extension during the service life, especially in the capital asset industry.

The current approaches of cyclic maintenance and overhauls are unable to manage unexpected future events physiologically embedded in a complex system [3]. State of the art for static analysis and testing in the industry has also not yet proved to be able to provide those capabilities [4].

Using a complex maintenance operation in the coal mining industry as a case study, the paper tries to investigate if self-engineering and self-maintenance could be adopted in the future to provide the capabilities required and increase both availabilities of large equipment and decrease the number of maintenance operations.

2. The case study: gearbox revitalization of a bucket-wheel excavator (BWE)

Electricity in Serbia is provided by Elektroprivreda Srbije (EPS), a 100% state-owned company. EPS is responsible for virtually all

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electricity production in Serbia. To realize the electricity production it operates some liquid fuel power plants but mostly hydropower plants and coal mines and power plants.

The total electricity production of EPS is around 36 GWh of which 25 GWh are produced using lignite as a fuel [5]. The lignite is mined in several areas of Serbia; one of them is the Kolubara region which produces around 30 million tons of lignite annually. The lignite at the Kolubara fields is extracted in open cast mines with continuous mining processes. To be able to extract the coal, the soil that covers it, called overburden, has to be removed. The overburden is excavated using bucket wheel excavators (BWEs), transported using conveyor belts and deposited at the opposite side of the minefield where the coal has already been mined, using a spreader. The combination of these three operations is called, BTO, and it forms a whole production line.

The coal itself is also mined by BWEs and transported using conveyors to either a storage facility or directly onto a train going to the power station.

The BWE functioning is straightforward: the bucket wheel rotates, scooping up the soil or coal, and deposits it on the conveyor present on the bucket-wheel boom. At the centre of the machine, the material falls through a chute onto the next conveyor running through the discharge boom. This conveyor dumps it on either a mobile conveyor or directly on the fixed conveyor system transporting it through the mine.

Fig. 1. BWE at Tamnava West field.

The bucket-wheel boom can move upwards and downwards due to a hoisting mechanism and can move sideways thanks to the superstructure that rotates on a massive axial bearing located above the crawlers. The crawlers allow the machine to move and steer.

The case study uses the revitalization process of the gearbox driving the bucket wheel of a BWE (Fig. 1) working at Tamnava West field (part of the Kolubara mine) in operation since 1995 as a starting point for the reflection on the adoption of the self-engineering paradigm.

2.1 Selection of maintenance operation

The selection of the gearbox maintenance operation is motivated by the impact of its downtime both from a technical perspective and from a financial perspective. Figure 2 shows a Pareto analysis of the BWE systems ranked by failure frequency/cost ratio. The first group of systems are the bearings in the gearbox. In theory, designed for infinite life without displaying an increasing failure rate; in reality, they accumulate damage over time and should thus be replaced following a preventive approach instead of corrective maintenance.

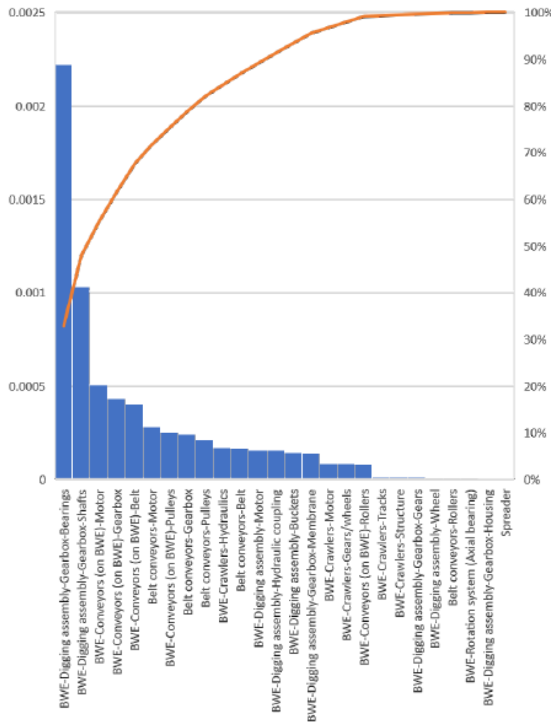


Fig. 2. BWE systems ranked by failure frequency/cost ratio

The second group of systems are the shafts of the digging gearbox. In general, the shafts are designed in such a way that they will not fail due to a degradation process and are thus not suitable for preventive replacement. Large electric motors benefit from preventive maintenance according to [6] and should thus be included in the program, the ones for the belt conveyors with the highest priority because of their high score.

2.2 Gearbox revitalization process in a nutshell

As said and despite a design-out for maintenance approach, the health condition of a gearbox constantly deteriorates during the lifetime, manifesting itself in the form of noise and vibration. During a revitalization process of a gearbox, housing, gears, bearings and, if necessary, the membrane, are repaired or replaced (Fig.3-4). The gearbox is connected to two 670 kW electric motors, each one with its input shaft and set of gears.

Fig. 3. Gears in the housing.

Fig. 4. Largest gear with damage.

The two drive-trains both power the final gear that activates the main shaft that supports the bucket wheel. To support the described setup, the housing is made of three main sections, lower, middle and top.

The bearings allow for small movement of the gearbox in an axial direction allowing for some misalignments with the main shaft. The bearing is considered to be a major design flaw due to its recurrent failures. The exact failure mechanism is unknown but it deforms permanently. This deformation causes misalignments in the system and hinders the movement of the gear along the shaft.

3. Maintenance improvements and self-maintenance

The analysis of the gearbox overhaul project led to the identification of technical and organizational challenges.

Future coal demand depends on politics and environmental choices of countries and thus it could either increase or decrease in the next twenty years. The ultimate goal of a mining operation is to match the demand for coal at the lowest possible cost. Not matching demand will probably result in either a high cost for importing electricity or power outages for the communities. With these serious possible consequences improving maintenance cannot be done with the only aim of reducing cost, resulting in higher risks for production. On the contrary, a proper approach will focus on increasing the availability of the overall equipment.

3.1 Increasing BWE availability

After an analysis of the maintenance logs, it seems feasible to aim for a higher availability which currently stands around 40-50% of the overall time. Increasing the availability of newer equipment would remove the necessity of using old equipment dating back to the 1960s. Modern equipment utilizes improved designs resulting in lower maintenance costs. Modern equipment however requires considerable investments.

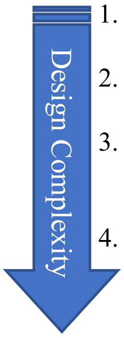
Increasing the availability of existing equipment from a technical perspective can be done in two ways:

- Upgrading the design
- Advanced maintenance tools

The first solution is a strategy already extensively applied at Kolubara mines, resulting in more reliable equipment indeed. The latter, advanced maintenance, is less deployed within the discussed equipment fleet (but also in general in the mining sector), relying still on corrective maintenance as a general approach.

3.2 Advanced maintenance tools

As well as discussed by [2] a self-maintaining machine does not belong in the conventional physical maintenance concept, but rather in the functional maintenance concept instead. Functional maintenance aims to recover the required function of a machine by trading off functions, whereas traditional repair (physical maintenance) aims to recover the initial physical state by replacing faulty components, cleaning, etc. The way to fulfil the self-maintenance function is by adding intelligence to the machine, making it clever enough for functional maintenance. This characteristic can be achieved either:



1. designing a machine to operate in different regimes;
2. designing the machine to a self-trigger service request;
3. designing the machine to reconfigure capabilities to apply to different operations;
4. designing the machine to be adaptive to new scenarios retaining memory of previous events. [3,7].

Taking into account the complexity of the system analysed, it becomes clear that not all of the listed advanced solutions can be easily applied to a BWE due to several limitations. In particular, (3) designing the machine to reconfigure capabilities and (4) designing the machine to be adaptive seem still quite difficult to implement taking into account the technical characteristics of the BWE. Introducing the feature to operate in different regimes (1) using a system able to dynamically select prognostics models to ensure prediction accuracy, is also less relevant because the BWE needs to operate with a constant regime for ensuring productivity. A machine able to self-trigger service request (2) is an achievable implementation.

The next step will be a detailed understanding of the technical feasibility of this solution: where and how could a self-trigger service system be implemented on a BWE? In essence, a machine equipped with a self-trigger service gathers data through a self-monitor, it runs a self-diagnose and self-triggers the service request with detailed and clear maintenance requirements. The machine is set up for anticipating a failure and improving the operational availability [8,9,10]. The maintenance task is still conducted by a maintenance crew, but integration of machine, maintenance schedule, dispatch system and inventory management system will minimize maintenance costs to the greatest extent and raise customer satisfaction to the highest level [2]. With specific reference to the case study previously mentioned, a BWE equipped with a self-trigger service request should then be able to:

- monitor the two drive-trains
- monitor the bearings
- create a request for inspections

4. Discussion

Self-maintenance offers an interesting approach for improving the reliability of assets. The case study proposed shows how the application of self-maintenance on such a peculiar machine, the BWE could be approached. Self-maintenance, as also pointed out by several authors in previous studies, strives for achieving results that could include high-automation solutions, from real-time condition monitoring system to continuous repairing routine actions.

These considerations lead to agree that there is, at the moment, a consistent need of thinking on different approaches to maintenance in the mining industry.

According to the presented reflections, continuous improvement and special re-design actions should be taken into account by BWE asset managers and operators for:

- Having better overall availability of the different parts of the BWE
- Offering the opportunity to make sub-systems of the BWE more adaptive to disturbance, becoming more resilient and less prone to failures

5. Conclusions

The paper acts as a “reflection” paper in the application of self-maintenance in a complex context (mining sector). Due to the intrinsic properties of the reflective nature of the paper, further and more extensive research is required to explore more in details the benefits of such a novel approach.

Given the potential of self-engineering solutions for designing new systems that achieve better reliability performances, there is still a surprising lack of application of this philosophy in current industries, especially in managing complex assets. Taking into account the power of self-maintenance solutions in improving reliability and uptime, this paper highlights possible future research fields.

Although the case has been studied to inspire researchers and professionals in the mining industry, the self-engineering and maintenance approaches should be more widely used in different industrial sectors and assets for fostering the real potential of this combination. The authors are deeply committed to the proposed approach for inducing organizations to change their maintenance practices. Further research will focus on the development of pilot use cases based on self-engineering principles for introducing self-maintenance in companies' programmes ensuring higher reliability standards.

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