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Prototype of an energy harvesting sensor with wireless data transmission

Andreas Bürger[1], M.Eng., Prof. Dr.-Ing. habil. Sylvio Simon[2],
Dipl.-Wirt.-Ing (FH) Stephan Hernschier[3], M.Eng.,
BTU Cottbus-Senftenberg, Universitätsplatz 1, Senftenberg, Germany[123]
andreas.buerger@b-tu.de

Summary:
Rotating parts such as shafts, gear wheels, ball bearings or idlers are subject to wear that limits their service life. Damage causes production downtime and consequential damage to the entire production plant. Based on the application in an idler roller, a system design is presented with which it is possible to record and wirelessly transmit relevant measured values in or on rotating machines without an additional voltage source. The system is largely maintenance-free and can be realised with components that are currently freely available on the market.

Keywords: Energy harvesting, sensors, rotating machinery, monitoring, maintenance

Motivation

As passive support and guide elements for the conveyor belt, idlers are an essential component of belt conveyor systems. The cost of a single idler roller used in open-cast mining is approx. 100 €. However, their damage can cause consequential damage amounting to several million euros plus production downtime costs.

A system was to be designed and realised as a prototype, which records the essential measured values of an idler roller with a self-sufficient energy supply and as maintenance-free as possible and transmits them wirelessly to a receiver module.

The load on the idler roller is essentially determined by the following factors:

- Vertical to the axis by the mass of the conveyor belt and the conveyed goods themselves
- the speed of the idler roller, which is determined by the belt speed
- horizontally to the axis by tensile forces, which are determined by the mass of the conveyor belt, the conveyed goods and the other idlers belonging to the idler garland
- weather conditions
- the operating mode (continuous, constant or variable speed) and the operating time

Failure of the idler roller is noticeable in two borderline cases if no action is taken beforehand:

- Wear of the idler cover to the point of destruction and thus destruction of the conveyor belt
- Wear of the idler roller bearings, which can lead to heating and increased rolling resistance up to ignition of the conveyor belt

Regular visual and acoustic inspections with and without measuring devices (e.g. visual inspection, thermal imaging cameras, sound level measuring devices) are currently standard practice.

Direct monitoring of one or more parameters of each individual idler is technically possible, but requires a high material cost.

Concept for a prototype

A system is designed which is characterised by the following properties:

- Measured value acquisition and (pre-) processing in a measuring module on or in the idler, i.e. cable connections for power supply or data transmission are not possible
- Maintenance-free and, in principle, not lifetime-limited and maintenance-free energy supply, preferably through energy harvesting

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- In principle, all relevant measured variables can be measured and analysed
- Utilisation of technology currently freely available on the market
- Possibility of visual status display directly on the idler roller
- Wireless data transmission to one or more mobile and/or stationary receiver modules

The system is to be constructed from components freely available on the market. It consists of at least two main components whose functional modules are shown in Fig. 1. The designed system consists of the main components measuring module and receiver module. The measuring module measures the vibration acceleration and the bearing temperature and realises data pre-processing in the form of spectral analysis and limit value recognition.

Data is transmitted wirelessly between the measuring module and receiver module using BLE.

The energy supply of the measuring module is ensured by energy harvesting from the inductively utilised kinetic energy of the idler roller to be monitored.

The measuring module is activated when there is sufficient stored supply energy, records current measured values and transmits them to the receiver module ready to receive. After data transmission, the measuring module goes into sleep mode and restarts the measuring and transmission cycle when electrical energy is available. The receiver module is located outside the component to be monitored.

It can be mobile, e.g. on the user, or stationary, e.g. permanently installed in the system. The prototype of the receiver module contains the functions data transmission and measured value display.

Further functions, e.g. data processing and data storage as well as network functions, can be added as required.

Economic considerations

The following minimum conditions must be met for the economical use of a measuring system, i.e. hardware including analysis software and personnel costs for monitoring the condition of the monitored system:

- The maintenance cycle of the measuring system must be greater than or equal to the maintenance cycle of the monitored system.
- The costs of the measuring system must be lower than the costs of the monitored system, including downtime and labour costs for system replacement or repair.
- The costs of the measuring system must be lower than the possible damage to the system caused by a defective system without the use of the measuring system, including downtimes, production losses and labour costs.
- The reliability of the measuring system must be higher than the reliability of the monitored system.

The costs for the measuring module were calculated based on the time and material required and estimates for the costs of series production. If only one prototype is produced, the costs for development including software, programming and hardware total approx. 3,700 €.

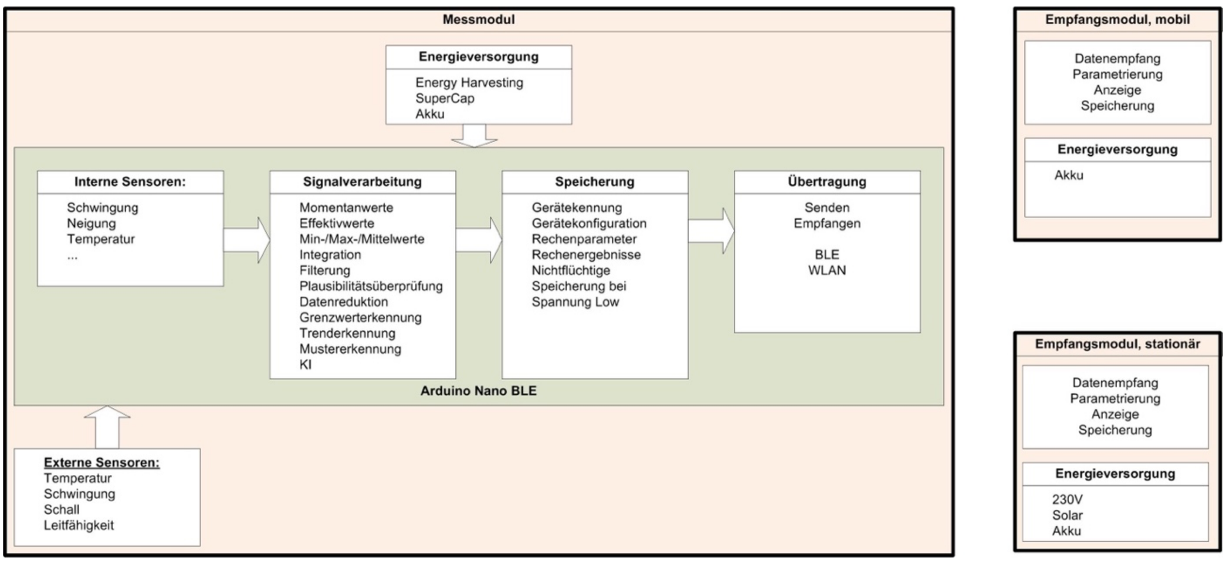

Fig. 1: Main components and function modules

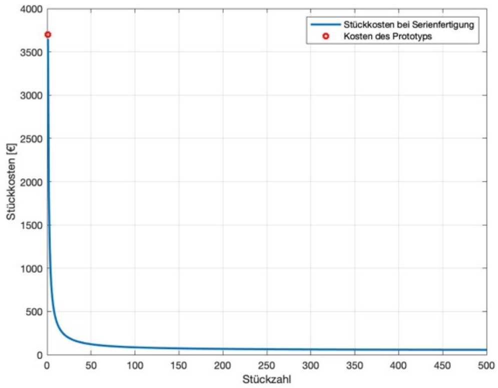

Fig.2: Comparison of unit costs of the prototype compared to series production

If the measuring module is manufactured in series, the costs of a single measuring module quickly fall to slightly more than the hardware costs, depending on the number of units (Fig. 2). The costs for the receiver module depend on the application scenario. In principle, a separate receiver module can be used for each measuring module. The costs for the receiver module are then comparable to those of the measuring module. If only one receiver module is used to serially interrogate all receiver modules, the total cost of this receiver module (development including software, programming and hardware) is approx. 3,700 €. Technically, it is also possible to use a smartphone as a receiver module. Assuming that every employee is equipped with a smartphone, only programming costs are incurred. According to an initial estimate, the cost of programming an app that has a similar functionality to the receiver module presented here costs approx. 4,200 €, but offers great potential for expansion due to the large hardware resources of a smartphone. In addition to the costs, the expected service life of the measuring module is the other main factor influencing cost-effectiveness. The service life of the measuring module should be longer than the service life of the monitored system and should ideally be able to be used in another system after the failure of the monitored system without great effort.

According to [1], the end of the service life of a SuperCap is reached when the capacity has fallen to 70 % of its original value or the internal resistance has doubled. The service life of a SuperCap is usually specified as 10 years and depends on the ambient temperature, the cell voltage, the charging currents and the number of charging cycles. The defined service life of the SuperCap therefore does not necessarily limit the operational capability of the measuring module. The operating capability of the measuring module can be increased by overdimensioning the SuperCap with regard to the factors limiting the service life. The cost of an idler roller of a type frequently used in open-cast mines is approx. 100 €. The service life of the idler can be expected to be 7 to 8 years without condition-based maintenance and up to 14 years with condition-based maintenance. The monitoring of an idler can be regarded as an element of condition-based maintenance.

According to this data, it is to be expected that the measuring module may also have reached the end of its service life when the idler reaches the end of its service life.

The cost of a measuring module was estimated at around 50 € for series production. This would increase the total costs of an idler roller equipped with a measuring module by approx. 50 % without resulting in a longer service life compared to the current measures. The labour and material costs for integrating the measuring module and the energy harvesting system into the idler roller, which have not yet been considered, would further increase the costs. The practical application of the system designed here therefore appears uneconomical, but is well suited for measuring and monitoring tasks in test and trial systems.

Summary an outlook

The prototype of a measuring system for the measurement and wireless transmission of acceleration and temperature was designed and a functional sample consisting of a measuring module and receiver module was constructed. The measuring module is powered by electrical energy generated by means of energy harvesting. The measured values are received and displayed with the receiver module or with an app on a standard smartphone.

The cost estimate showed that this system does not have any positive economic effects when used in idlers due to the long service life of the idlers. However, due to its simplicity and the use of freely available components, this system offers interesting application possibilities for test purposes. It should be noted that real-time data transmission is not possible with this system.

References

[1] CAPCOMP GmbH,“Welche Faktoren bestimmen die Lebensdauer der Ultracaps?“ 23.05.2022

URL: https://www.capcomp.de/kondensatoren/ultracap-lebensdauer.html (visited: 23.05.2022).