Detection of Overheated Rollers in Belt Conveyor Systems

Simon Trippler
GTE Industrieelektronik GmbH, Viersen, Germany

Andreas Czylwik
University Duisburg-Essen, Duisburg, Germany

Abstract

Belt conveyors are used in many different industrial applications like power plants, mines or smelting works where they are essential for a continuous and economical flow of material. Unplanned downtimes often lead to the stop of complete production lines. Therefore, early detection of failures becomes more and more important. Current statistics [1] show that overheated rollers are the most common reason for fires at belt conveyors. Caused by bearing failures, rollers heat up and become an ignition source for the belt when the conveyance stops. Available roller condition monitoring systems are expensive and interfere with maintenance activities, and are not used for that reason.

GTE and NTS have developed a roller condition monitoring system [2] that meets economical and technical requirements. Locally vulcanized into a belt, this system allows to monitor all rollers of a belt conveyor system detecting temperature increase. It consists of several temperature sensors directly below the belt´s surface and a control unit for data storage and wireless transmission to an external base station. For testing this system, a belt conveyor system mockup was developed. The mockup provides different conveying velocities, a heated roller and a thermal imaging camera for monitoring the roller.

Keywords: belt conveyor systems, hot roller detection

Introduction

For detection of overheated rollers a concept is presented, which allows to monitor all rollers in a belt conveyor system with a single sensor system. It consists of multiple discrete sensors implemented into the belt (Fig. 1). With units for data processing and transmission, the discrete temperature sensors form a sensor system that moves over all rollers of a belt conveyor system.

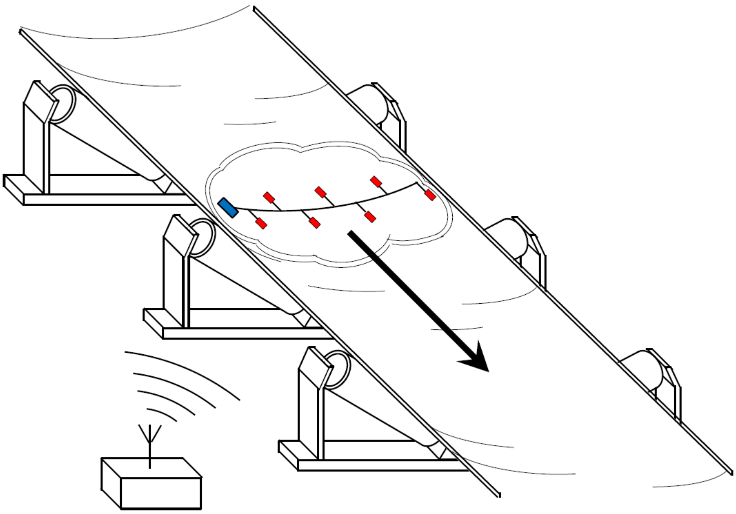

Fig. 1. Roller temperature monitoring system.

For energy supply, batteries are located in the belt's rim due to lack of space, because there are no tensioning ropes. For that reason, electronic components are also located in the rim. For data transmission a mobile Bluetooth Low Energy unit is used that automatically connects to one or more base stations next to the belt.

Figure 2 shows a laboratory prototype of the sensor system. It consists of one thermopile, a unit for signal multiplexing and amplifiers for several thermopiles and a unit for system management and data transmission. Thermopiles make it possible to measure very small temperature changes. The resolution of the temperature sensor is 4,9 µK.

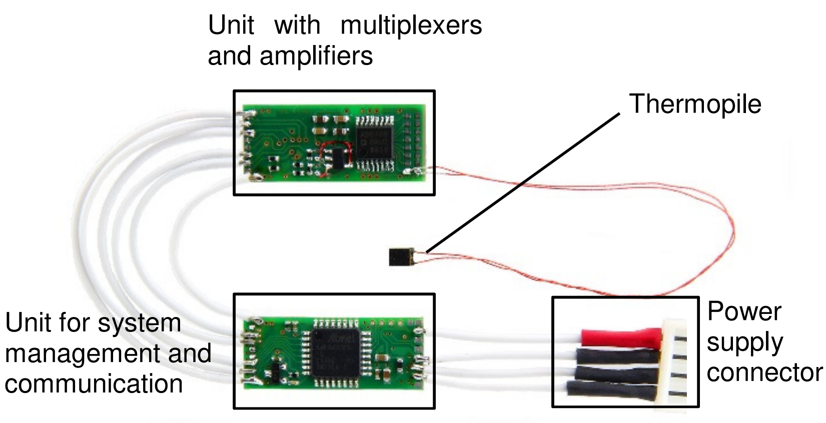

Fig. 2. Laboratory prototype of the sensor system.

Model for the steady state heat transfer in a roller

The development of a heat transfer model in a roller is based on measurements in a test mockup, that emulates a one-sided bearing damage by heating one of the rollers front surfaces with a Bunsen burner.

The test mockup consists of a small belt conveyer system with adjustable conveying velocity and one roller of a large belt conveyor system from an opencast mining site. This roller is heated at its front surface and monitored at its shell surface by a thermal imaging camera. Fig. 3 shows the test mockup.

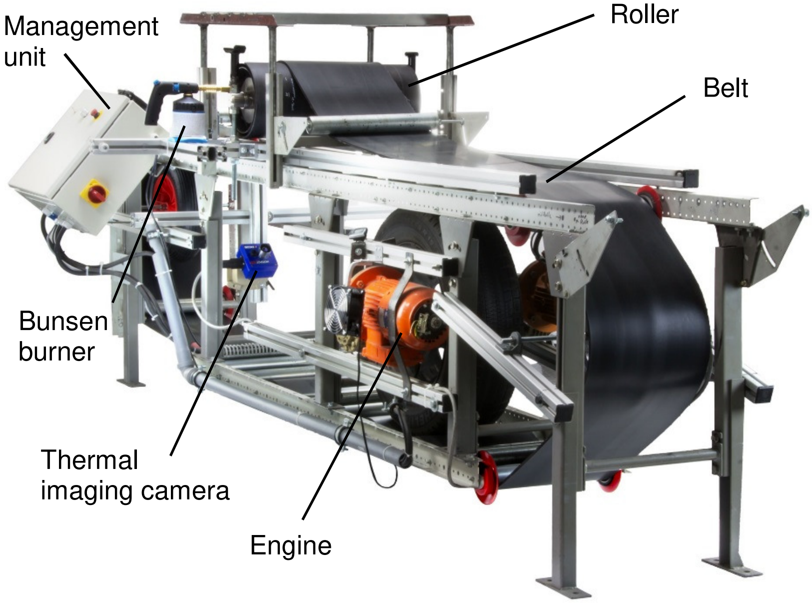

Fig. 3. Test mockup of a belt conveyor system.

A theoretical analysis of the temperature of the roller surface $\vartheta_{\mathrm{M}}(z)$ in axial direction z shows that the surface temperature depends on geometrical data and heat power at the damaged bearing. The temperatur profile corresponds to that of a cylindric cooler:

$$\vartheta_{\mathrm{M}}(z) = (\vartheta_{\mathrm{B}} - \vartheta_{\mathrm{amb}}) \cdot \frac{\cosh(m_{\mathrm{R}} \cdot (z - l_{\mathrm{R}}))}{\cosh(m_{\mathrm{R}} \cdot l_{\mathrm{R}})} + \vartheta_{\mathrm{amb}} \quad \text{(Eq. 1)}$$

where ϑ_{amb} and ϑ_{B} denote the ambient and bearing temperature, respectively m_{R} is a geometry and material parameter, and l_{R} is the length of the roller. Experiments had shown that any dependence on other operating parameters like the belt velocity can be neglected.

Figure 4 shows the temperature profile according to the model (Eq. 1) and the measured temperature profile of the roller surface. It is important to see that the temperature of the roller surface decreases fast as a function of axial position *z*. Even at high maximum temperature ϑ_B the potentially dangerous area with temperatures dangerous for the belt is small and in this case about 100 mm. Temperature sensors should therefore be integrated closely to the edge of the belt.

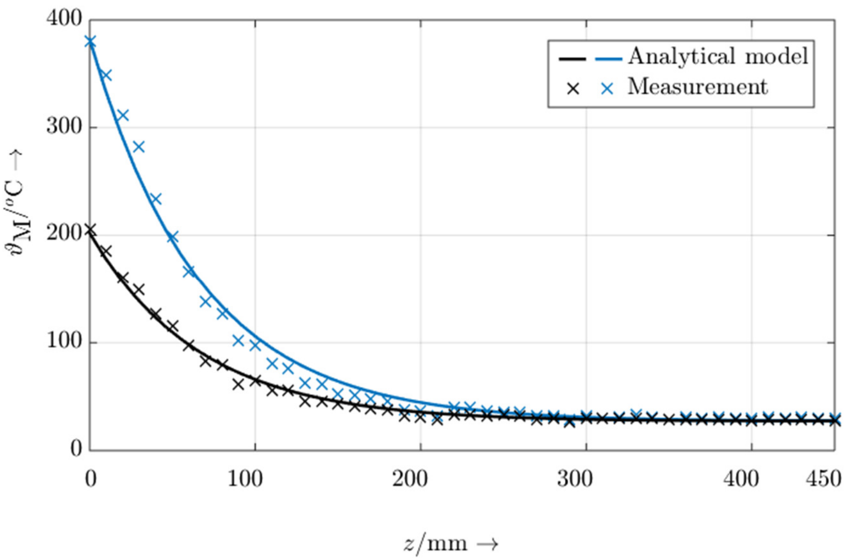

Fig. 4. Temperature on a roller with overheated bearing as a function of axial position.

Model for heat transfer in a belt

Since the temperature sensors will be heated by an overheated roller during a time interval of only a few milliseconds, the dynamic behavior of the integrated temperature sensors has to be analyzed. To characterize the developed temperature monitoring system, a model of the transient heat transfer within the belt was developed and experimentally verified. This analytical model describes the transient heat transfer in multilayer materials (see Fig. 5) for any time dependence of the material surface.

The heat transport within the layered structure is described by the thermal resistance and thermal capacity of the different layers. The analysis is carried out using an electrical equivalent circuit for each layer according Fig. 6 where voltage corresponds to temperature in the original system. Typically, n = 20 to 50 RC-elements need to be taken into account in order to get results close to $n \to \infty$. On the other hand, a direct solution for $n \to \infty$ based on transmission line theory can be found easily.

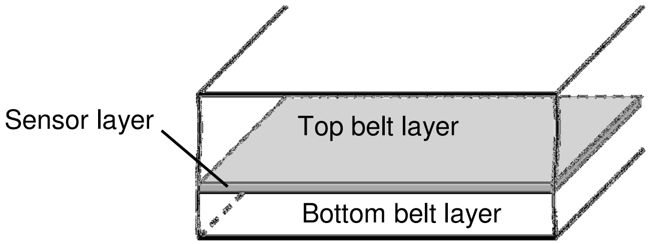

Fig. 5. Model for the heat transfer in a rubber belt with integrated sensor element: Top and bottom layers: rubber, central layer: temperature sensor.

Analyzing the transmission behavior of the overall circuit, three circuits according to Fig. 6 corresponding to the three layers of Fig. 5 have to be connected to each other. Since the overall system is linear, its transmission behavior is described by its impulse response.

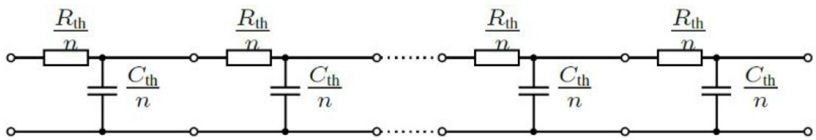

Fig. 6. Electrical equivalent circuit of each belt layer.

The two-port theory allows to determine the transfer properties of the RC chain with *n* RC elements shown in Fig. 6 – a corresponding chain matrix **A** can be calculated. Alternatively, a direct solution for the chain matrix based on transmission line theory can be found for $n \to \infty$.

For calculation of the voltage (temperature) across the sensor layer, the chain matrix **A** of each layer may be transformed to an equivalent electrical circuit. Corresponding equivalent networks for the belt with implemented sensor system consist of three single equivalent circuits in form of a T- or a π-circuit (Fig. 7). The system's input variables are the difference between a homogenous start temperature of the system ϑ_0 and the top belt layer's surface temperature $\Delta\vartheta_L = \vartheta_L - \vartheta_0$ as well as the bottom belt layer's surface temperature $\Delta\vartheta_T = \vartheta_T - \vartheta_0$.

The measured and analytically calculated impulse response is shown in Figure 8 [4]. The impulse response describes the relation between the temperature signal $\Delta\vartheta_T(t)$ at the surface of the belt created by an overheated roller and the response $\Delta T_S(t)$ of the temperature sensor inside the belt.

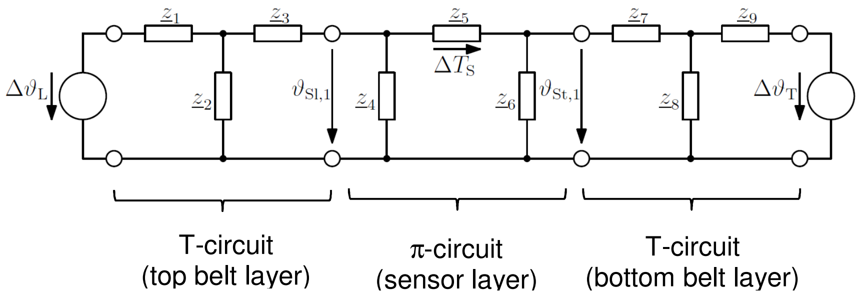

Fig. 7. Electrical equivalent circuit of the belt with implemented sensor system.

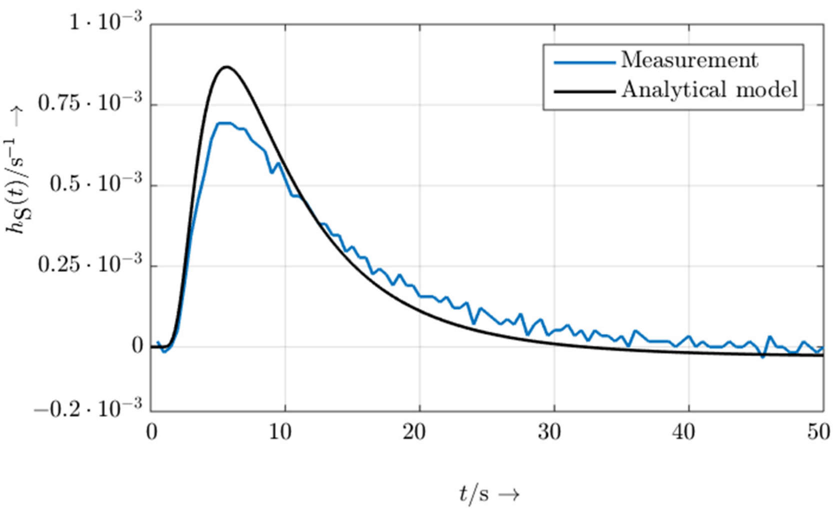

Fig. 8. Measured and analytically calculated impulse response.

Detection system

Based on the sensor system's impulse response, output signals for a system stimulation by an overheated roller and by noise signals have been investigated. Figure 9 shows output signals for a system stimulation by an overheated roller with different conveying velocities and roller surface temperatures ϑ_C keeping the product of difference temperature $\Delta\vartheta_T$ and conveying velocity constant. A variation of the conveying velocity effects in a variation of the contact time t_k between the roller and a segment of the belt.

A result of this work is that the system's response signal for an overheated roller does not change if the product of difference temperature $\Delta\vartheta_T$ and conveying velocity constant. The system's response is approximately equal to the shape of the system's impulse response. This is valid for input signals which are significantly shorter than the duration of the system's impulse response and therefore valid for all usual operation velocities of a belt conveyor system. Contact time t_k and temperature ϑ_C only effect on the signal amplitude, not the shape of the signal.

Due to the unique signal shape to be detected, a matched filter is used for signal detection. Matched filters are capable to detect a known signal form in additive noise. The impulse response of the matched filter is the mirrored, time-shifted and normalized signal, shown in figure 8. Figure 10 shows the impulse response

$$h_\mathrm{m}(t) = k \cdot h_S(t_1 - t) \cdot \mathrm{rect}\left(\frac{t-t_1/2}{t_1}\right) \qquad \text{(Eq. 2)}$$

where $h_\mathrm{S}(t_1 - t)$ is the time-shifted and mirrored impulse response $h_\mathrm{S}(t)$ of the measurement system and k is a normalization factor. t_1 is the time delay needed to create a causal matched filter.

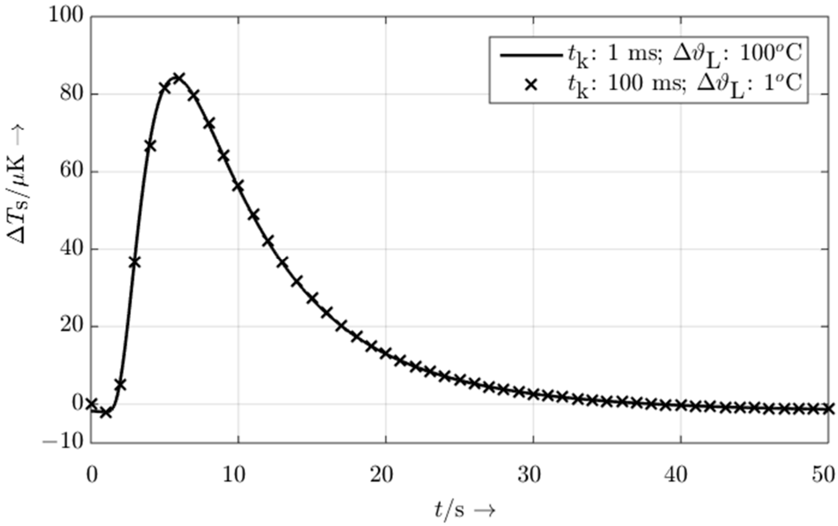

Fig. 9. Simulated sensor system's output signal for different input signals of overheated rollers.

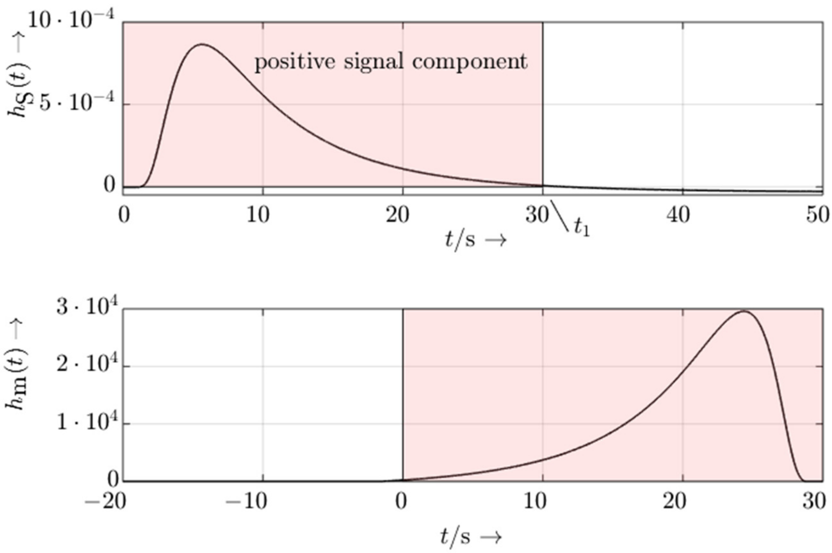

Fig. 10. Impulse responses of the sensor system $\boldsymbol{h}_\mathbf{S}(\boldsymbol{t})$ and the matched filter $\boldsymbol{h}_\mathbf{m}(\boldsymbol{t})$.

By a suitable selection of k the matched filter's output signal can be directly scaled to the rollers surface temperature ϑ_C at the contact point between the roller and the belt. Figures 11 and 12 show input and output signals for an overheated roller, typical noise and a superposition. The noise signal consists of a large number of rectangular pulses, created by small temperature differences between different rollers and the belt in normal operation, measured by an infrared camera system. The distance between the pulses corresponds to a distance of 1.5 m between consecutive rollers and a conveying velocity of 2 m/s.

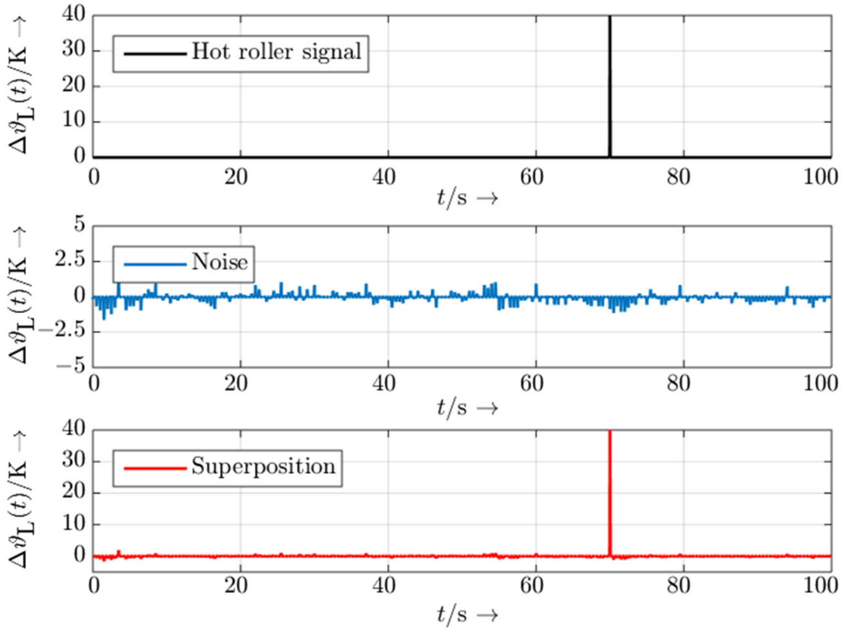

Fig. 11. Input signals for the matched filter. Top: Hot roller signal, middle: noise, bottom: superposition of hot roller signal and noise.

The hot roller signal in the top diagram of figure 11 appears at the time $t_0 = 70\ s$. In Figure 12 it is shown that the amplitude of the matched filter's output signal can be normalized to the temperature of a single hot roller at the time $t_0 + t_1$.

In addition, Fig. 12 shows the influence of the additive noise: Although the noise creating temperature differences of the correctly working rollers are small, the sum of all roller contributions creates quite large matched filter output signals (blue curve). The influence of the measurement error caused by such kind of noise decreases with increasing hot roller temperature. By taking into account that the belt's ignition temperature is about 500°C or more, the presented method is applicable to detect overheated rollers, before they become a risk for operation of the belt conveyor system.

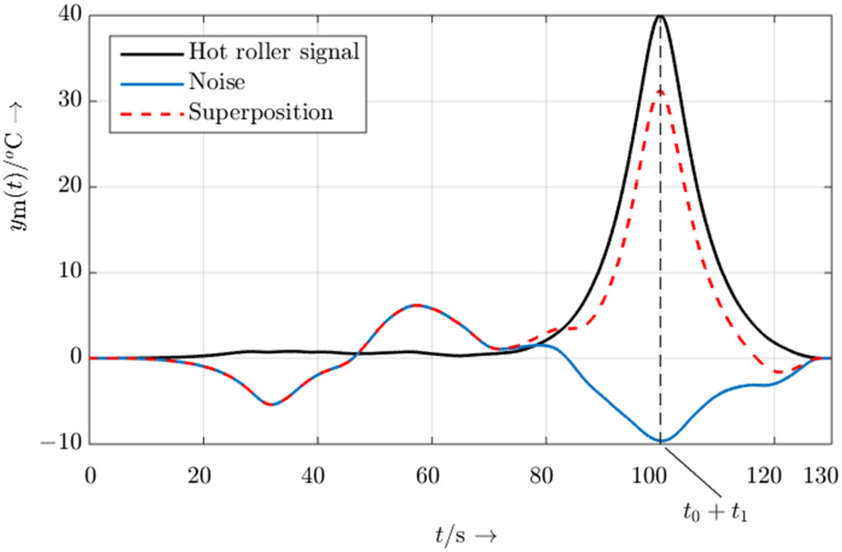

Fig. 12. Output signals for the matched filter: Contributions of the hot roller, the noise, and superposition of hot roller and noise.

Acknowledgements

This work was supported by the German Federal Ministry of Economic Affairs and Energy (BMWi) with the "Central Innovation Programme for SMEs" (ZIM).

References

[1] M. Fernandez, A. Rodriquez and J. Pruchicka. "*Early detection and fighting of fires in belt conveyor*", Publications Office of the European Union, 2013.

[2] S. Trippler, "*A monitoring system for bearings at conveyor belts*". AUBE Proceedings, 2014.

[3] S. Trippler, "*Detektion überhitzter Tragrollen an Gurtförderanlagen*", 20. Fachtagung, Schüttgutfördertechnik Magdeburg, 2015.

[4] S. Trippler, "*Schadenerkennung durch Temperaturmessung an Tragrollen in Gurtförderanlagen*", Ph.D. Dissertation at the University Duisburg-Essen, 2016.