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DOI
10.1016/j.measurement.2018.04.066

Publication date
2018

Document Version
Final published version

Published in
Measurement: Journal of the International Measurement Confederation

Citation (APA)
Liu, X., Pang, Y., Lodewijks, G., & He, D. (2018). Experimental research on condition monitoring of belt conveyor idlers. *Measurement: Journal of the International Measurement Confederation*, *127*, 277-282. https://doi.org/10.1016/j.measurement.2018.04.066

Measurement 127 (2018) 277–282

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Experimental research on condition monitoring of belt conveyor idlers

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ARTICLE INFO

Keywords:
Condition monitoring
Belt conveyor
Idler roll
Vibration
Temperature

ABSTRACT

Belt conveyor systems are widely used in bulk material handling and transport applications. Within a belt conveyor, depending on its distance, there can be tens of thousands of idler rolls which face random failure. However, condition monitoring solutions for belt conveyor idlers is underdeveloped. This is because the choice of monitoring parameters is still arbitrary. This paper aims to investigate which parameters can represent technical condition of idler rolls for the purpose of condition monitoring. A belt conveyor test rig is developed in laboratory. Temperature and vibration sensors are applied to monitor idler rolls induced with different types of failures. Patten of temperature evolution and RMS level of vibration are extracted from the signal and analysed. It is concluded that temperature measurement at roll shafts is a straightforward and effective manner for condition monitoring of belt conveyor idlers.

1. Introduction

Belt conveyor systems are widely utilized for continuous transport of dry bulk materials (i.e. coal, iron ore) over varying distances. However, random failure of numerous idler rolls is of major concern for conveyor operators [1,2]. Failed idler rolls not only significantly increase energy consumption, but may damage conveyor belts seriously. This consequently adds up downtime and maintenance cost for belt conveyor systems [3,4].

Idler roll failures can be divided into incipient failure, final failure and catastrophic failure three phases [5]. The malfunction of inner bearings is the most common failure mode for idler rolls [6–8]. The incipient failure phase refers to spalling on bearings reaching 6.25 mm^2 based on research in Ref. [9]. Geesmann et al. define the final failure phase of idler rolls as the loss of suitability for further operation [10]. The catastrophic failure phase refers to seriously failed rolls which cannot operate properly and will cause severe damage to conveyor belts.

Up to date idler rolls are still a challenge to be monitored efficiently due to their large quantity and spatial distribution [11]. The industry traditionally count on human routine inspection to detect faulty rolls, which is labour intensive, inefficient, and high cost [12]. Recently, sensors are introduced into idler inspection, but reported in a very limited number of publications. SKF has developed an idler sound monitoring kit to assist conveyor inspectors to spot idler rolls which generate abnormal sound [13]. However, the representation of the technical condition of idler rolls by using the sound monitoring kit has not been reported. A fire detector was developed to monitor the temperature of idler rolls [14]. Bearing failures were simulated by drilling and introducing sand into bearings. Their results show the effectiveness of the fire detector. However, the accuracy and area of interest of the detector were not provided. A test bench based on vibration measurement was also developed to diagnose detached garland idler rolls [15]. It is recognized that vibration measurement is capable to detect bearing failures. However, the test bench is considered to be over sensitive. Besides that the bench is also not developed for continuous monitoring of idler rolls on site.

To monitor idler rolls efficiently and effectively, it is desired to develop automated condition monitoring systems. For example, the conceptual ”Smart Idler” is prompted to monitor idler rolls and transfer data continuously to maintenance personnel [11,16]. For such systems it is essential to understand which monitoring parameters to choose, considering the amount of data to acquire, transfer, and analyse for diagnosis. Therefore, research is in need to investigate which parameters can represent technical condition of idler rolls for the purpose of condition monitoring.

2. Description of experimental setup

The test rig (Fig. 1) in this study consists of a belt conveyor, an idler frame, a control box, and a data acquisition system. The belt width is 1 m, and the central length of conveyor is 3 m. The maximum belt

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https://doi.org/10.1016/j.measurement.2018.04.066
Received 31 October 2017; Received in revised form 12 March 2018; Accepted 16 April 2018
Available online 31 May 2018

Fig. 1. The test rig. *Note: 1 is data acquisition system, 2 is control box, 3 is idler frame, 4 is belt conveyor.*

Table 1
Summary of intact bearing and bearings with defect.

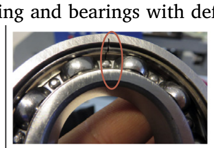
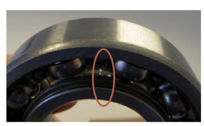
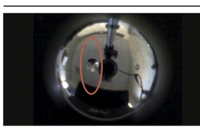
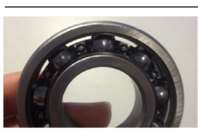
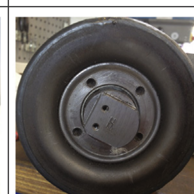
 Roll code: A **No defect**	 Roll code: B **Outer race defect** Defect details: Scratch perpendicular to raceway, width 1 mm, depth 0.5 mm.	 Roll code: C **Inner race defect** Defect details: Scratch perpendicular to raceway, width 1 mm, depth 0.5 mm.
 Roll code: D **Rolling element defect** Defect details: damage on one element, diameter 0.5 mm, depth 0.5 mm.	 Roll code: E **Debris in lubricant** Defect details: MICRON+ MDA particles, size 0.04 - 0.08 mm, contamination level 5 vol.%.	 Roll code: F **Radial overloading** Defect details: applying 18 kN radial load, duration 0.5-2 hours.
 Roll code: H **No lubrication** Defect details: new bearings without any lubricant.	 Roll code: I **Corrosion** Defect details: one week in salty water, one week in air.	

Table 2
Summary of induced bearing damages.

 Roll code: G1 Damage details: dust cover damaged using a hammar	 Roll code: G2 Damage details: a hole drilled through the dust cover and seals till the bearing	 Roll code: G3 Damage details: three holes drilled into the bearing, filled with metal particles, cage damaged.
 Roll code: K1 Damage details: five holes drilled into the bearing, cage damaged.	 Roll code: K2 Damage details: five holes drilled into the bearing, filled with metal particles, cage damaged.	 Roll code: K3 Damage details: covers removed from bearing house, cage damaged.

velocity is 1.8 m/s. The belt velocity and belt tension are adjustable. The trough angle of idler frame can be changed up to 15°. With installation of load cells underneath the idler frame, the load on each idler roll from the belt can be determined.

The rolls used in this study have shell diameter of 108 mm, shell length of 380 mm, and shaft diameter of 30 mm. The bearing type is deep groove ball bearing 6206. Idler Rolls in incipient failure phase are simulated by mounting bearings with induced defects. The inducement of bearing defects is summarized in Table 1. Four sample rolls are prepared for each defect type by Rulmeca Holding S.p.A.

Damages are also induced to rolls in order to simulate rolls in final failure phase. The inducement of damages is presented in Table 2. The inducement of damages to rolls G3, K1 and K2 is similar to the way in Ref. [14].

This study focuses on temperature and vibration measurements. For temperature measurement, thermocouple RS BMS-K-C70-MP with measurement range of −50° to 250°C is selected. The thermocouple is installed directly on shaft end. For vibration measurement, accelerometer ADXL337 with measurement range of ± 3g is selected. The accelerometer is bolted onto shaft end, with the X-axis in horizontal direction and Y-axis in vertical direction.

3. Results and discussion

Three types of experiments are conducted: defect roll tests, damaged roll tests and endurance tests. A detailed description of experimental procedures and data processing can be found in Ref. [5].

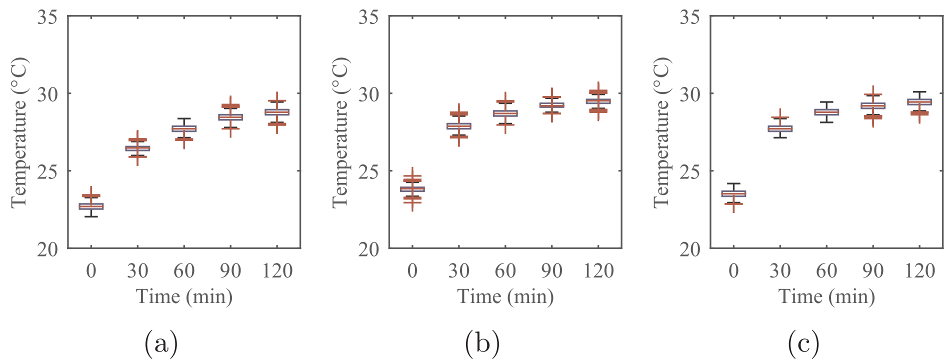


Fig. 2. Temperature measurement by thermocouple at shaft end for roll A (a), roll B (b), and roll F (c) *Note: The rolls were tested under conditions with load on the bearing of 766.5 N, belt velocity 1.8 m/s. The duration of tests was 120 min.*

Table 3
Summary of temperature increase during the defect roll tests.

test		shC1_1	shC1_2	shC1_3	shC1_4	shC2_1	shC2_2	Trough_shR1_1	Trough_shR1_2
test condition	load on bearing of interest (N)	566.0	566.0	766.5	766.5	965.1	965.1	674.1	674.1
	belt velocity (m/s)	1.8	1.8	1.8	1.8	1.8	1.8	1.0	1.0
temperature measurement (°C)	roll A	7	5	6	7	6	7	4	3
	roll B	7	6	7	7	7	7	5	3
	roll C	8	6	7	8	8	5	6	4
	roll D	6	5	8	9	8	6	5	5
	roll E	7	5	8	30	7	19	7	6
	roll F	8	6	7	7	7	7	5	4
	roll H	6	5	8	7	7	7	5	4
	roll I	8	6	9	8	8	7	6	4

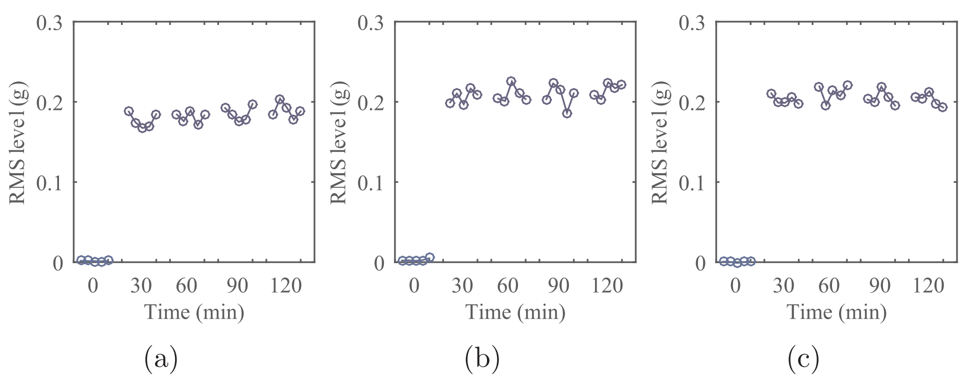


Fig. 3. RMS level of vibration in horizontal (X) direction for roll A (a), roll C (b) and roll F (c) during test ShC1_3.

Table 4
Summary of the RMS levels of the vibration during the defect roll tests.

		Tests							
RMS level		ShC1_1	ShC1_2	ShC1_3	ShC1_4	ShC2_1	ShC2_2	Trough_ShR1_1	Trough_ShR1_2
RMS level of horizontal (X) vibration (g)	A	0.16	0.21	0.19	0.20	0.14	0.10	0.17	0.15
	B	0.19	0.20	0.20	0.21	0.13	0.11	0.20	0.13
	C	0.20	0.17	0.21	0.19	0.15	0.11	0.20	0.13
	D	0.18	0.17	0.23	0.20	0.15	0.11	0.18	0.13
	E	0.19	0.17	0.23	0.30	0.15	0.17	0.21	0.14
	F	0.21	0.18	0.23	0.18	0.14	0.11	0.23	0.11
	H	0.19	0.18	0.22	0.20	0.13	0.11	0.16	0.12
	I	0.19	0.18	0.20	0.19	0.14	0.11	0.17	0.12
RMS level of vertical (Y) vibration (g)	A	1.01	0.99	1.01	1.02	1.01	0.96	0.98	0.91
	B	1.01	1.00	1.01	1.02	1.01	0.96	0.98	0.91
	C	1.01	0.98	1.01	1.02	1.03	0.97	0.98	0.92
	D	1.00	0.98	1.01	1.02	1.02	0.96	0.99	0.92
	E	1.01	0.99	1.01	1.04	1.01	1.01	0.99	0.93
	F	1.00	0.98	1.01	1.02	1.00	0.96	0.98	0.91
	H	1.00	0.99	1.01	1.02	1.02	0.98	0.99	0.91
	I	1.01	0.98	1.01	1.01	1.01	0.96	0.98	0.91

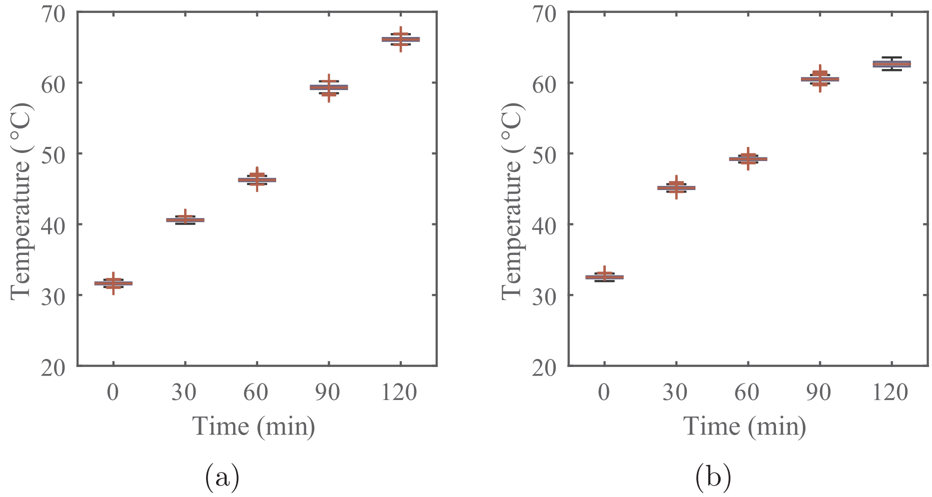


Fig. 4. Typical temperature evolution of damaged rolls, (a) damaged roll G1, (b) damaged roll G3.

3.1. Defect roll tests

Idler rolls with defect inducement in Table 1 are used in defect roll tests. Typical evolution of temperature for intact and defect rolls are shown in Fig. 2. A regressive pattern can be observed for all three rolls. From Fig. 2, a very small difference is observed between intact roll A and defect rolls regarding temperature increase after 120 min running. The temperature increase of intact roll A is 6 °C while those of defect

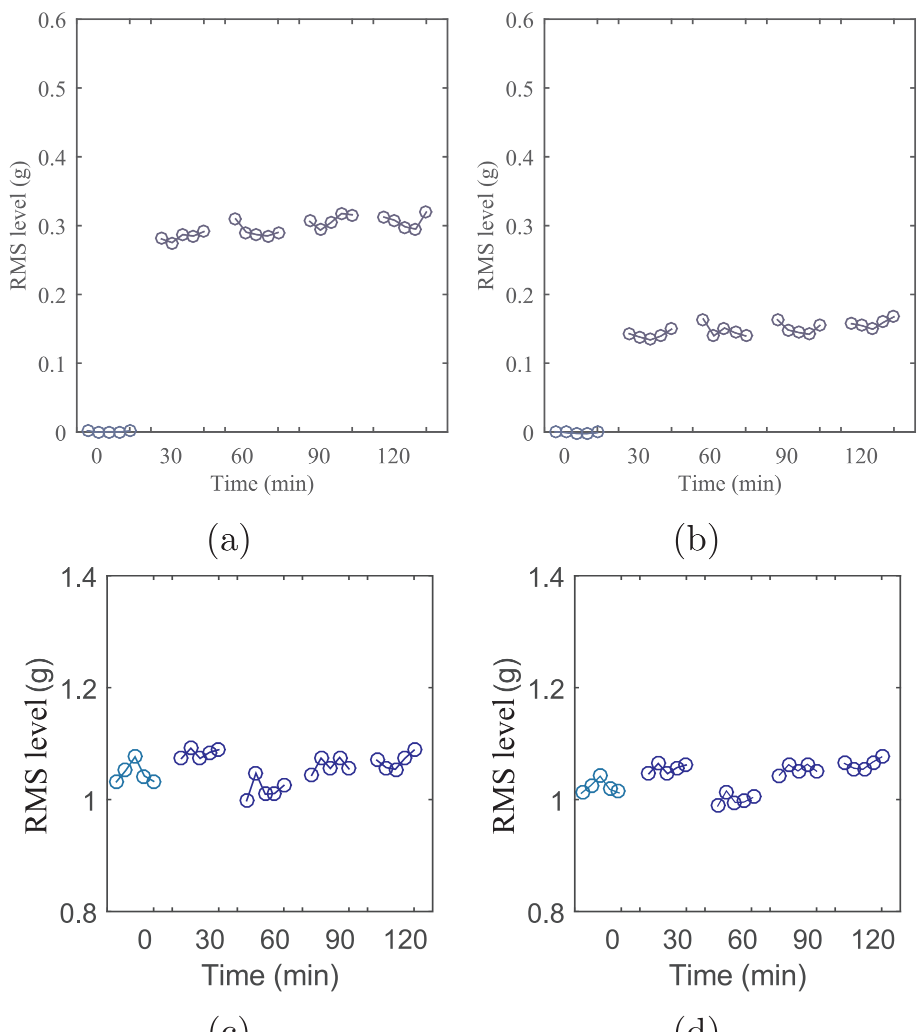


Fig. 5. RMS levels of vibration, (a) horizontal direction of damaged roll G1, (b) horizontal direction of intact roll A, (c) vertical direction of damaged roll G1, (d) vertical direction of intact roll A.

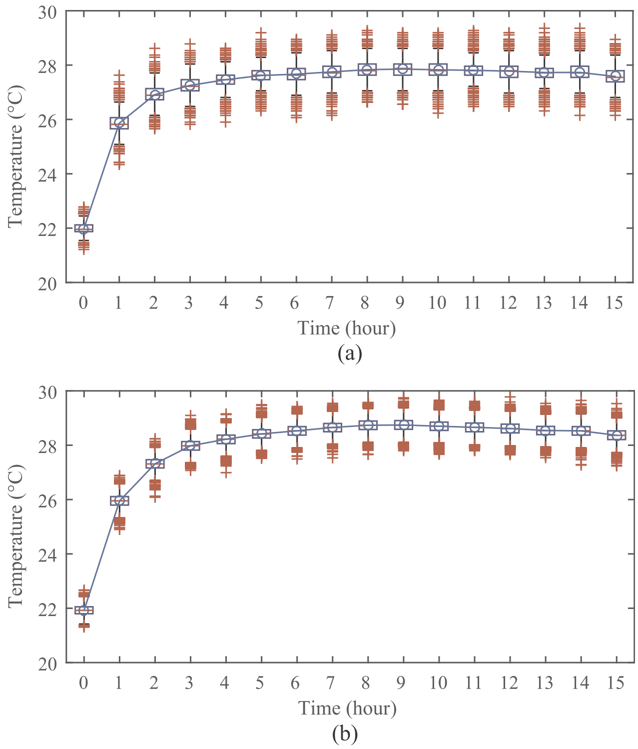


Fig. 6. Temperature evolution from endurance test, (a) intact roll A, (b) defect roll B.

rolls are 7 °C. Considering the accuracy (1 °C) of the thermocouple, it is difficult to distinguish the defect rolls from intact rolls.

A summary of temperature increase of idler rolls during defect roll tests is presented in Table 3. In general, the defect rolls are observed to have a slightly higher temperature increase than the intact rolls. It can be explained that bearing defects induce extra thermal energy during rotation. However, the difference of temperature increase is very small. In most cases the difference is just 1–2 °C. Considering the accuracy of the thermocouple, it cannot be verified that the difference of temperature increase is caused by the induced bearing defects. In two cases the temperature increase of defect rolls is much bigger than intact rolls. It was figured out that the high temperature is caused by abnormal vibration between roll shaft and bracket. Therefore, temperature measurement with the thermocouple is not capable to distinguish defect rolls from intact rolls under the test conditions in this study.

The analysis of vibration signal focuses in time domain. RMS level is chosen as it is one of the most widely used parameters to investigate the vibration amplitude of rotating elements [17,18]. The RMS level X_{RMS} can be expressed as:

$$X_{RMS} = \sqrt{\frac{1}{N} \sum_{n=1}^{N} |X_n|^2} \tag{1}$$

in which N is the total number of samples (200 samples in this case) in one calculation, X_n is the nth sample of a vibration measurement.

Fig. 3 illustrates the RMS level of vibration in horizontal direction for three rolls. It can be seen that the RMS level of three rolls are all around 0.2 g. There is hardly noticeable difference between the RMS level of intact roll A and those of defect rolls.

RMS levels from the defect roll tests are calculated and presented in Table 4. In general, there is no distinguishable difference between the defect rolls and intact rolls in both horizontal and vertical directions. Therefore, it can be concluded that RMS level is not capable to distinguish defect rolls from intact rolls.

From above, it can be concluded that with the test rig and defect rolls it is not possible to detect a roll in incipient failure phase by parameters like temperature increase or vibration RMS level.

3.2. Damaged roll tests

Idler rolls with damage inducement in Table 2 are used in the damaged roll tests. The force on the damaged rolls during the defect roll tests is in a range of 1150 up to 1970 N. Typical temperature evolution of damaged rolls is presented in Fig. 4. The temperature of roll G1 rose up to 66 °C (Fig. 4(a)), and the temperature of roll G3 increased to 63 °C (b) after 120 min running time. Compared with Fig. 2, the damaged rolls show significant raise in temperature which can be picked up by the thermocouples. Therefore, a certain threshold of temperature exists which can distinguish the damaged rolls from intact rolls. The exact value of such threshold is out of scope of this research.

The achievable temperature increase of damaged rolls may vary significantly based on the loading level and rotational speed. For instance, Hawksworth et al. obtained temperature evolution of a failed roll bearing which steadily rose up to around 100 °C followed by sharp increase to 200 °C within 60 min [19]. The failure of roll bearing in their case was induced by 125 percent axial overloading, 1200 kN radial force, and rotational speed of 570 rpm. Due to the limitations of test rig, the damaged idler rolls in this study did not achieve so big temperature increase. However, it can already be concluded that temperature measurement is capable to detect damaged rolls in the final failure stage.

From the perspective of vibration signal analysis, the RMS level of horizontal vibration shows distinct difference between damaged rolls and intact rolls. Fig. 5(a) and (b) show the RMS levels from horizontal vibration for damaged roll G1 and intact roll A respectively. It can be seen that the RMS level of damaged roll G1 is around 0.3 g while that of intact roll A is around 0.15 g. Therefore, the RMS level of horizontal vibration can distinguish a damaged roll from intact rolls.

Meanwhile, the RMS level of vertical vibration cannot provide distinguishable differences between damaged rolls and intact rolls. The RMS levels of vertical vibration of damaged rolls are very close to those of intact rolls as shown in Fig. 5. This is because the conveyor belt provides much higher load in the vertical direction to idler rolls than the load in the horizontal direction. Therefore, the shaft ends of rolls are very difficult to vibrate in the vertical direction.

For the analysis of vibration signal, frequency domain analysis was also carried out by using FFT. However, it was recognized that the signal was largely influence by the eigenfrequency of the idler frame which is used in the experiments [5].

Therefore, both temperature increase and RMS level in horizontal direction indicators of damaged rolls in final failure phase.

3.3. Endurance tests

The force on the tested rolls during the endurance tests is around 1910 N. Fig. 6 illustrates the temperature evolution of intact roll A and defect roll B over fifteen hours running time. For both rolls, a regressive pattern of temperature evolution can be recognized. After about eight hours, the temperature of rolls A and B stabilizes at about 28 °C till the end of test. This reconfirms that there is no distinct difference between an intact roll and defect rolls in long period of time.

Fig. 7 presents the temperature evolution of damaged roll G3 and intact roll A during 100 h endurance test. From Fig. 7(a), it can be seen that the temperature of damaged roll G3 increases sharply in the first two hours up to 74 °C. After that, the temperature decreases moderately and stabilizes at around 50 °C. It is considered that the bearing defects and induced metal particles cause extra friction during rotation which generates additional thermal energy and therefore temperature increase. After 2 h of rotating, metal particles are believed to be pushed away from bearings. Consequently, the temperature drops a bit as a result of less generated thermal energy. It was observed that there was no obvious corresponding reduction in vibration level after 2 h test.

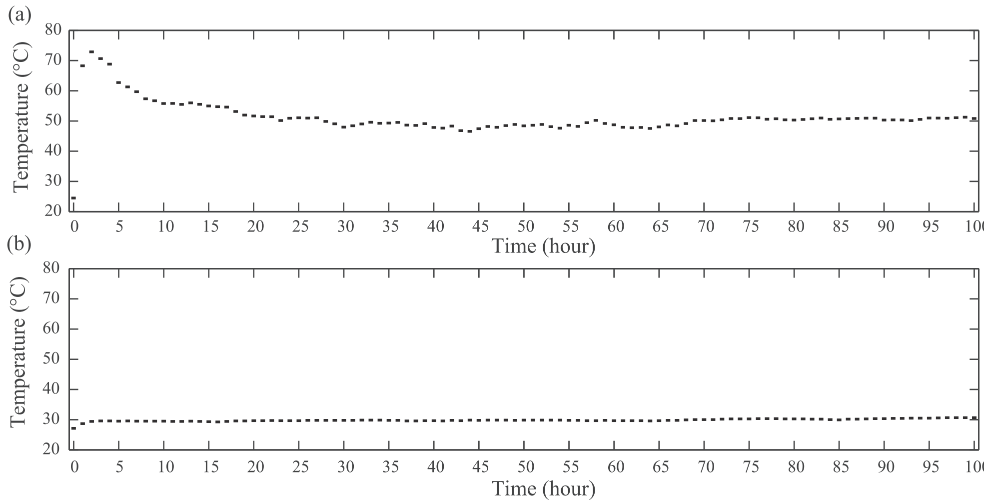


Fig. 7. Temperature evolution from endurance test, (a) damaged roll G3, (b) intact roll A.

Similar temperature trend as Fig. 7(a) was observed in other endurance tests of failed idler rolls as well (for instance Fig. 5.19 in Ref. [5]). Fig. 7(b) shows the temperature of intact roll A increases in the first three hours and then maintains at around 30 °C. Comparing Fig. 2(a) and (b), a distinct temperature difference consistently exists during the test.

4. Conclusions

Three conclusions can be drawn from this study:

- Idler rolls in final failure phase can be detected. However, idler rolls in incipient failure stage cannot be detected under the laboratory test conditions.
- Temperature increase and RMS level in horizontal direction are indicators of failed rolls in final failure phase.
- Measurement of temperature at shaft end of idler rolls is a straightforward and effective approach to detect idler roll failures.

From the conclusions of this research, it is recommended that periodical measurement of temperature at roll shaft end is a straightforward and effective solution for condition monitoring of belt conveyor idlers.

The laboratory idler experiments in this study are limited by test rig conditions such as low achievable belt velocity and load on idler rolls. Two recommendations for further research are proposed. The first recommendation is to investigate an appropriate threshold value for temperature monitoring for the diagnosis decision making. The second recommendation is to investigate the achievable operating time of idler rolls between the final and catastrophic failure phase.

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