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Lubrication Monitoring of Roller Chains via Contactless Temperature Measurement

Jonas Nölcke[1*], Robert Schulz[1]

[1] *Institute of Mechanical Handling and Logistics, University of Stuttgart, 70174 Stuttgart*

* *Correspondence: jonas.noelcke@ift.uni-stuttgart.de; Tel.: +49-711-685-83967*

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ABSTRACT An appropriate lubrication of roller chains is of great significance for their life expectancy. Considering economical and ecological aspects, a minimal but still sufficient application of lubricant is desirable. A prerequisite for this is, however, a reliable determination of the current lubrication state of the chain. This paper presents a series of experiments in which three different chains were tested on a chain test rig at different lubrication levels while the chain temperature was measured with contactless infrared thermometers. All chains show a significant dependency of the chain temperature on the lubrication level, this influence grows with increasing wear. Simultaneously, the influence of chain wear on the chain temperature is significantly smaller. The results show that measuring the chain temperature with contactless infrared thermometers offers a simple and cost-efficient option to monitor the lubrication state of roller chains.

KEYWORDS Roller chain, Predictive Maintenance, Condition monitoring, Lubrication, Temperature measurement, Radiation thermometry

1. Introduction

Roller chains are common machine elements for high power transmission. Sufficient lubrication of the chain joints and rollers is indispensable to avoid increased wear and early replacement of the chain. Beyond that, a lack of lubrication leads to increased noise levels and reduced efficiency of the chain drive. A preventive, intense use of lubricant seems inappropriate, considering economical and ecological aspects. To maximize chain life time while also minimizing lubricant consumption, measuring the current lubrication state of the chain is essential.

The general influence of lubrication technique, amount and application location on chain wear was researched by Coenen in extensive experiments [1]. While the lubrication state is already commonly monitored for certain machine elements like roller bearings or machine axes, for example in [2–4], there are to the knowledge of the authors no studies about measuring the lubrication state of chains during operation. The goal of the presented experiments is to investigate the extent to which contactless temperature sensors can detect the lubrication state of roller chains and whether there is potentially even a quantitative correlation between the extent of the lack of lubrication and the chain temperature.

2. Methods

The experiments presented in this article feature a comparison of the temperature of three chains at different lubrication levels using contactless infrared thermometers.

2.1. Radiation thermometry

Contactless infrared thermometry is based on the effect of heat radiation. Any object at thermal equilibrium emits electromagnetic radiation whose intensity correlates with the temperature of the object. By measuring the intensity of the emitted radiation at a given wavelength, the temperature of the emitter can be determined. Further information on the physical details of radiation thermometry can be found for example in [5].

Advantages of IR temperature measurements are the extremely fast measurements compared to contact thermometers which have to reach thermal equilibrium with the object of interest, as well as the contactless measurement which makes them well suited for rotating machinery. On the other hand, to accurately measure the temperature of an object, the emissivity of the object's surface must be known, i.e. the ratio of the emitted radiation of the real object to that of an ideal emitter. For applications in condition monitoring, the standard ISO 18434 [6] specifies fundamentals and general procedures. According to [6], the emissivity value may be estimated for those surfaces of similar emissivity, such that the result is a sufficient approximation of the true temperature of the measured objects. As such, the results presented in section 3 are, strictly speaking, merely signals correlated to the true temperature of the chains, but get presented in degrees Celsius for better readability.

2.2. Test setup

The presented tests were performed on the chain test rig at the Institute of Mechanical Handling and Logistics (IFT) at the University of Stuttgart. It features two electric motors of which one acts as driving motor while the other one, switched as a generator, provides a variable load torque of up to 600 Nm on the driven sprocket. Additionally, the variable shaft distance provides chain tensioning with up to 65 kN force per chain span via a pneumatic cylinder. Figure 1 shows a schematic of the chain test rig, an example chain drive during testing is shown in Figure 2.

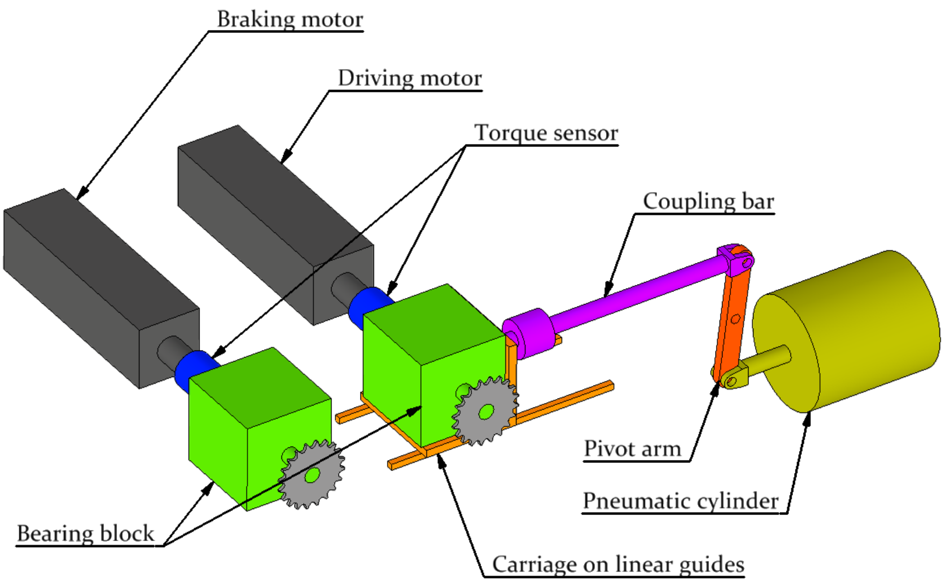

Figure 1: Schematic of the chain test rig at the Institute for Mechanical Handling and Logistics (IFT)

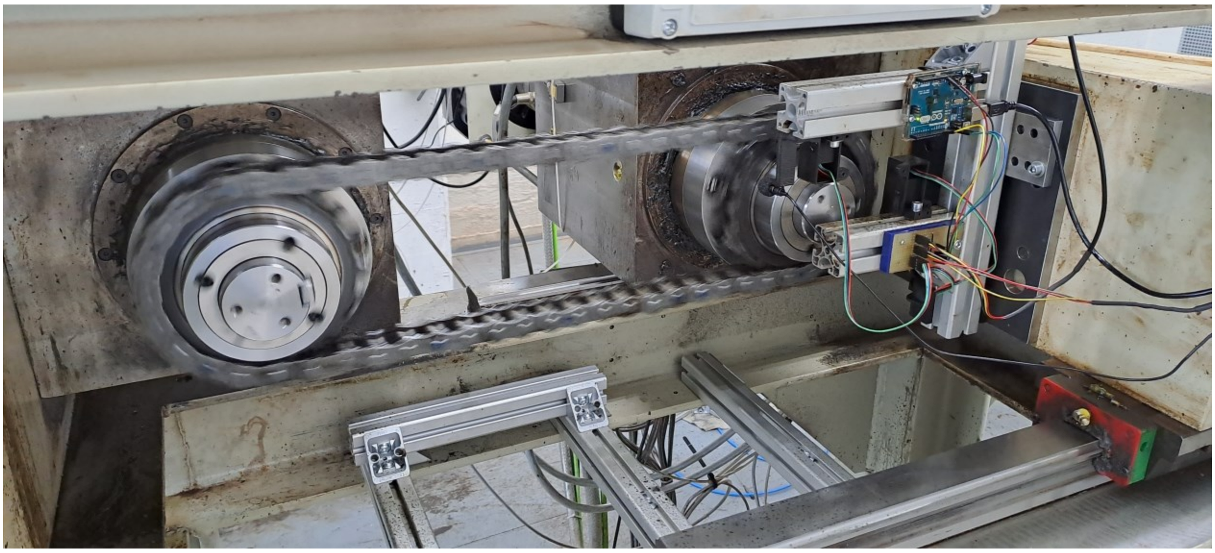

Figure 2: Roller chain during testing on the chain test rig of IFT. The assembly in front of the right sprocket shows the two infrared temperature sensors and the microcontroller extracting their data.

The experiments were conducted with three identical 12B-2 standard roller chains, only differing by their wear state, 0 %, 1.8 % as well as 3.8 % elongation. This way, possible influences of chain wear on the chain temperature can be investigated as well. All chains used during the experiments consist of 96 links, i.e. approximately 1830 mm chain length. To investigate the influence of the lubrication state, the chains were tested at four different lubrication levels. After initially degreasing all chains, the different lubrication levels are created by submerging the chains in lubricant and gradually reducing the amount of available lubricant with a degreasing agent. The lubricant used in the experiments is a fully synthetic oil specifically designed for chain lubrication.

The resulting lubrication states are as follows:

- Sufficiently lubricated after submerging the chain in an oil bath
- Moderately lubricated after degreasing the chain on the outside
- Barely lubricated after submerging the chain shortly in a degreasing agent
- Unlubricated operation after washing the oil out of the chain joints by submerging the chain in a degreasing agent

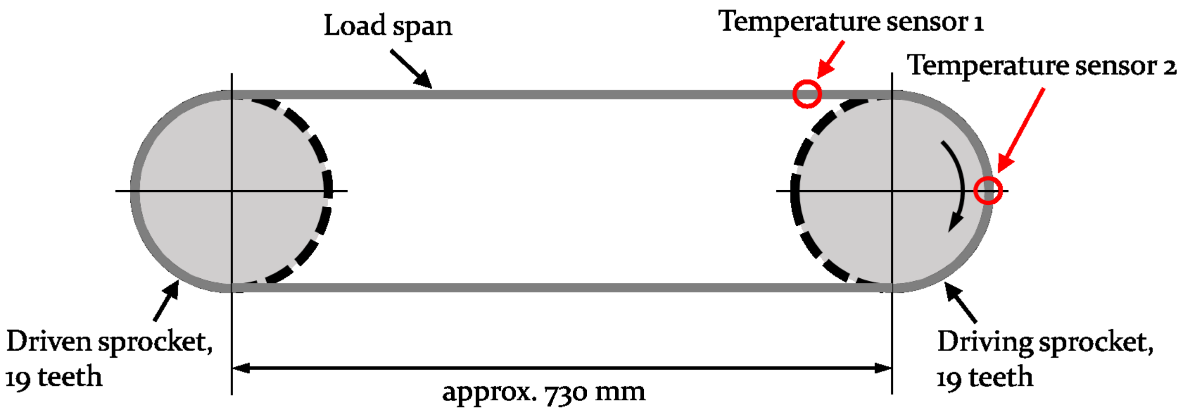

Figure 3: Schematic of the chain drive during the presented experiments. The temperature sensors are both placed near the driving sprocket, one right before the load span engages the driving sprocket and the other at the vertex of the sprocket.

The chain drive as employed during the experiments is shown schematically in Figure 3. It features two 19 teeth sprockets that were kept the same for the entirety of the experiments, the chain is tensioned via the pneumatic cylinder of the test rig. Two temperature sensors near the driving sprocket, one right before the engagement of the load span and one at the vertex of the sprockets, measure the temperature signal of the chain once every three seconds. Additionally, two PT1000 temperature sensors placed near the chain drive measure the ambient temperature of the room.

The chains were tested at two different load-speed scenarios, with the chain load chosen as a fraction of the total breaking force of the chain. The parameters of the different load-speed scenarios are listed in Table 1. The tensioning force causes a load on the free span as well, which can influence the lubrication behaviour in the free span. However, to judge whether the temperature sensor can detect a difference in the static lubrication state of the chain, this influence gets neglected.

Table 1: Load-speed conditions of the two tested operating points.

Operating point	Chain speed	Tension force	Brake torque	Chain load	Portion of total breaking force
A	1.5 m/s	2 kN	52 Nm	2.9 kN	5 %
B	1 m/s	3 kN	78 Nm	4.3 kN	7.5 %

In total, 24 experiments were conducted, consisting of three different chains at four different lubrication conditions and two different load-speed-combinations.

During each single experiment, the chain runs for 15 minutes, starting from ambient temperature. In between experiments, each chain has sufficient time to cool down back to ambient temperature. To prevent influence from the sprockets, especially after tests with high temperature increase, the sprocket temperature gets measured and each test only started once the sprockets have cooled down.

3. Results

The results of the experiments are presented as the average of both chain temperature sensors as well as the average of both ambient temperature sensors for each time step. The ambient temperature is marked by a dashed line in the plots.

Figure 4 shows the temperature behaviour of the new, unworn chain at different lubrication levels. While the difference between the three sufficiently to barely lubricated states are similar, reaching terminal temperatures between 24 and 28 °C, the dry operation shows a significantly higher temperature level of about 40 °C. There is a difference in behaviour of lubricated and partially degreased chain between the two parameter sets, though the absolute temperature difference is only about 1 °C.

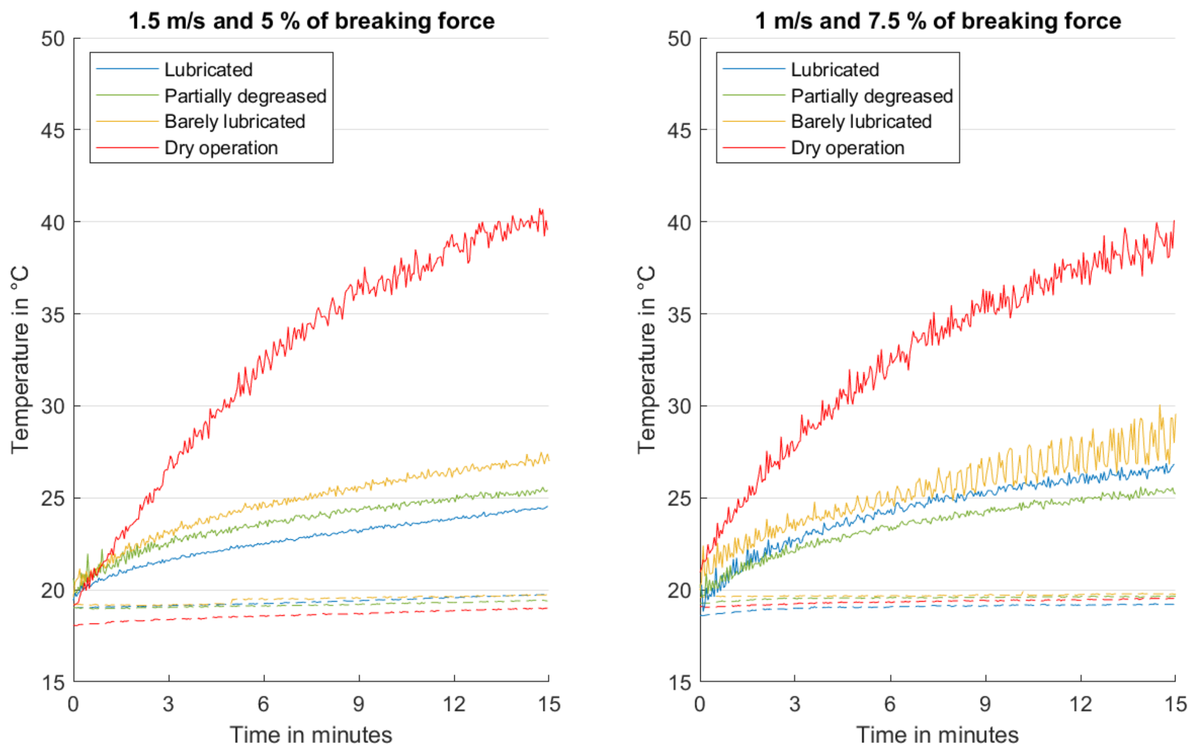

Figure 4: New chain with different lubrication levels, 1.5 m/s at 5% breaking force. The dashed lines mark the ambient temperatures.

Compared to that, the measurement data of the moderately worn chain with 1.8 % elongation in Figure 5 shows a similar terminal temperature of approximately 27 °C for the sufficiently lubricated and partially degreased chain for both parameter sets, whereas the barely lubricated chain shows significantly higher temperature of up to 40 °C. The chain at dry operation reaches a terminal temperature of up to 45 °C, although the difference between barely lubricated and dry operation is very small for the parameter set in the right half of Figure 5.

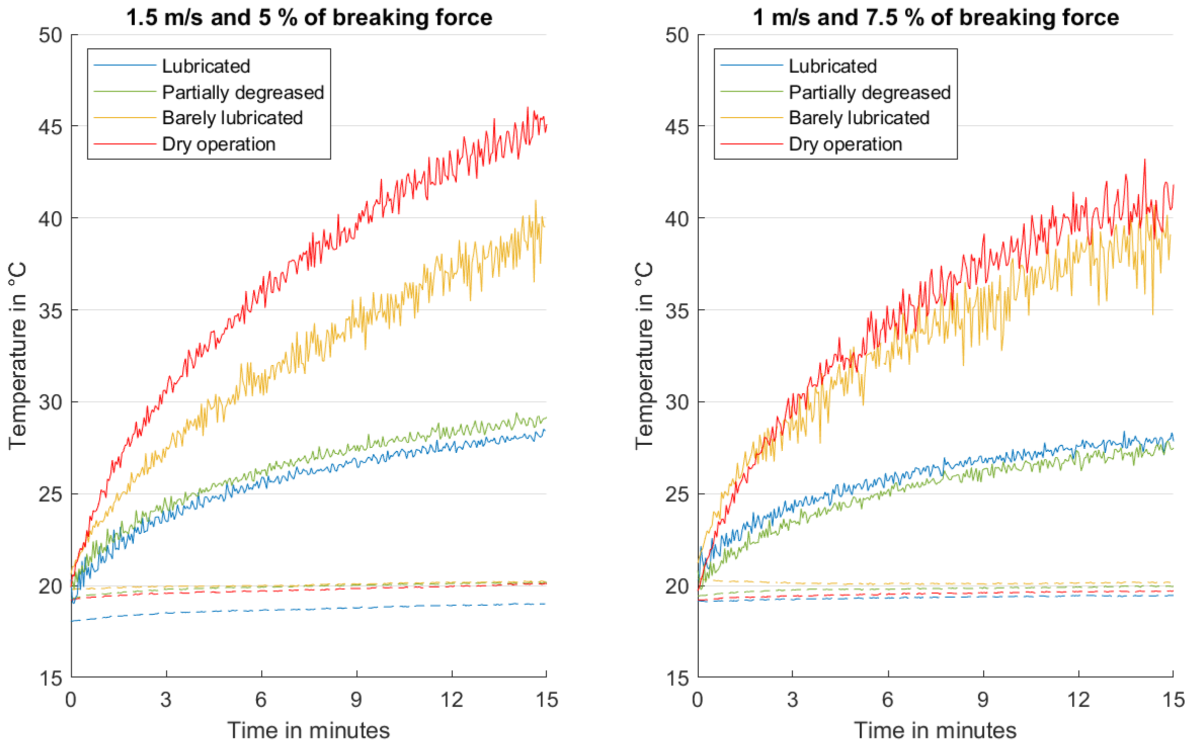

Figure 5: 1.8 % elongated chain at different lubrication levels, 1.5 m/s at 5% breaking force. The dashed lines mark the ambient temperatures.

The most worn chain however, shown in Figure 6, reaches significantly lower terminal temperatures than the other two chains, even for the dry operation, of only 35 °C. It is noteworthy that for all three chains, the sufficiently lubricated state reaches lower temperatures than the partially degreased state for the first parameter set, while reaching higher temperatures for the second parameter set. However, this difference between the two temperatures is in most cases very small.

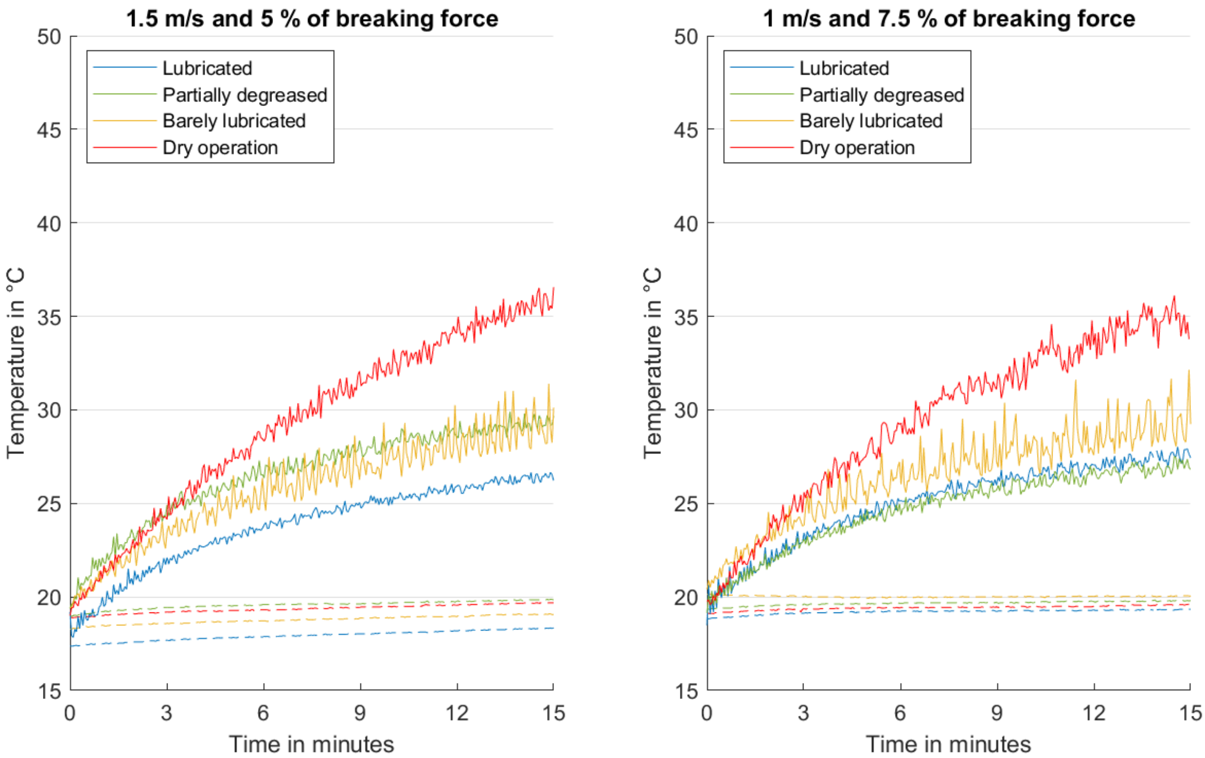

Figure 6: 3.8 % elongated chain at different lubrication levels, 1.5 m/s at 5% breaking force. The dashed lines mark the ambient temperatures.

Besides the influence of the lubrication level on the chain temperature, a potential influence of the wear state can be estimated when comparing different chains at the same lubrication level. Since the intermediate lubrication levels, i.e. partially degreased and barely lubricated, cannot be reproduced reliably across different chains, only the sufficiently lubricated state as well as the dry operation are considered. In Figure 7, the temperature data of the three different chains is shown for the case of sufficient lubrication. The new chain not only shows the lowest terminal temperature values of the three chains, but even does so despite starting at the highest initial temperature. The moderately worn chain as well as the most worn chain show the same curve, only differing by an approximately constant offset from the beginning to the end of the experiment. For the second parameter set, almost no difference in temperature between the different chains can be observed.

In case of the dry operation (Figure 8), all chains start at approximately the same temperature level, whereas the terminal temperature levels differ by 10 °C in the first workpoint between the highest and lowest result, for the second parameter set this behaviour is slightly less distinct. The previous observation of the most worn chain showing a significantly lower temperature than the other two chains is well visible in both parameter sets.

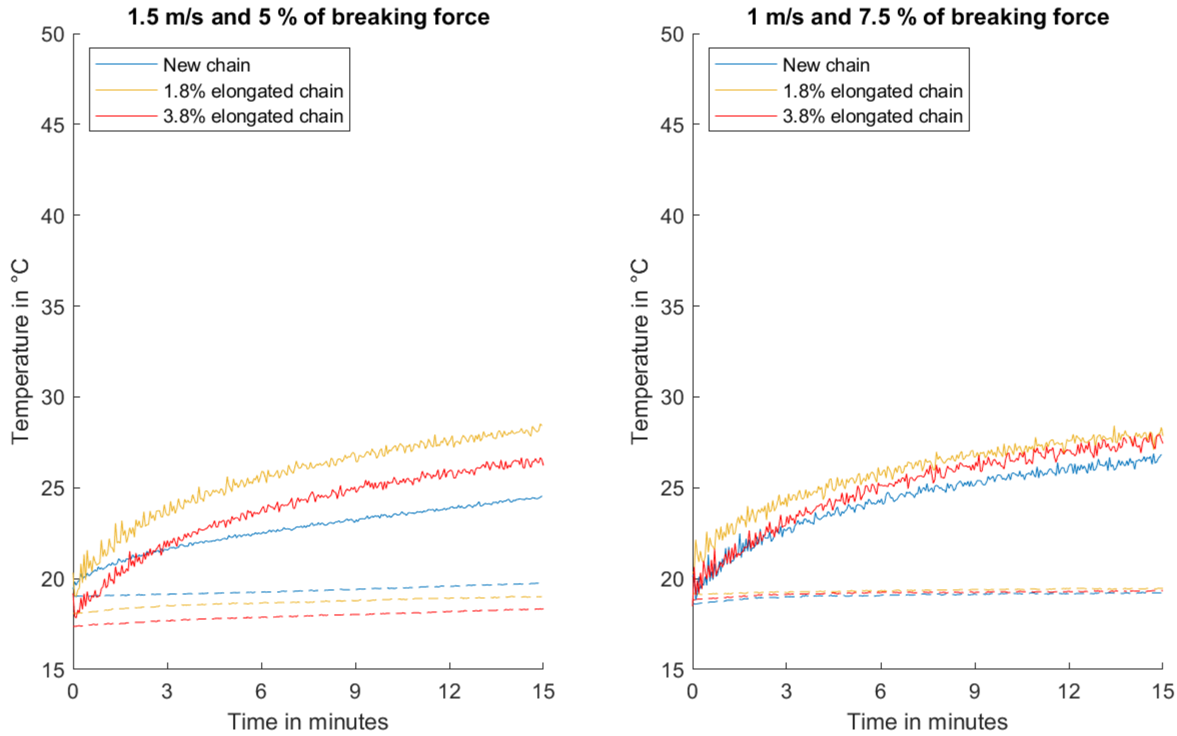

Figure 7: Differently worn chains with sufficient lubrication, 1.5 m/s at 5% breaking force. The dashed lines mark the ambient temperatures.

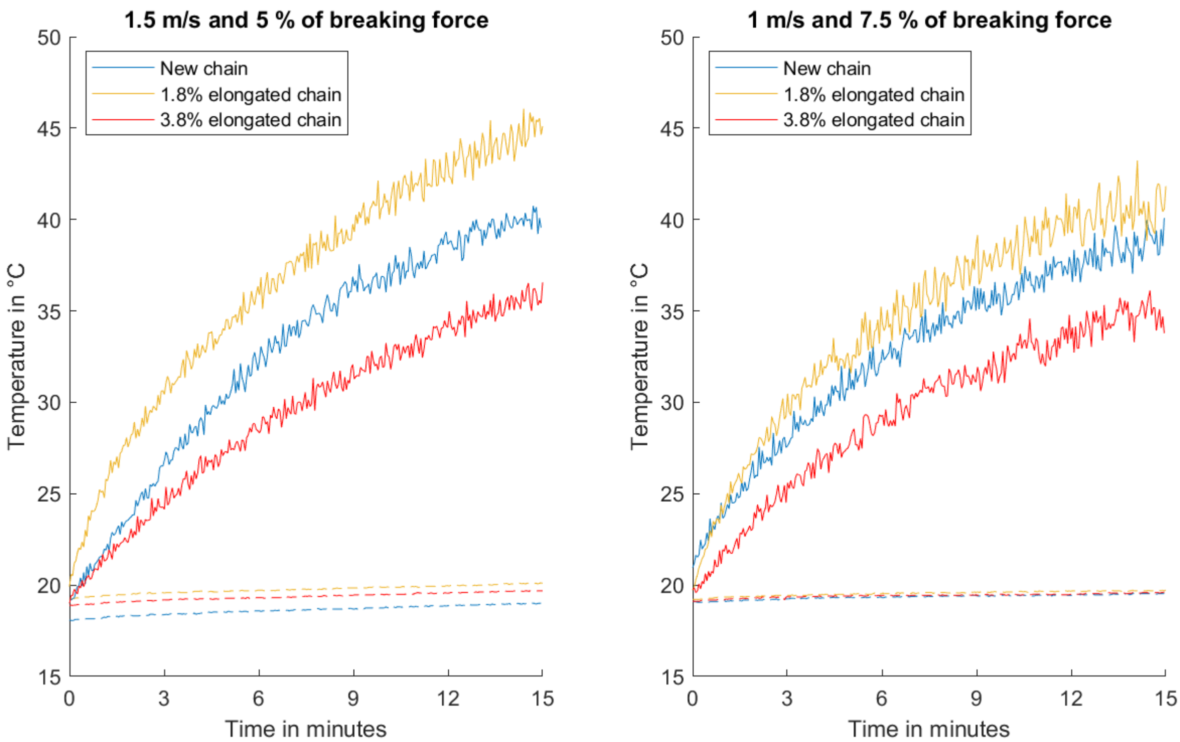

Figure 8: Differently worn chains at dry operation, 1.5 m/s at 5% breaking force. The dashed lines mark the ambient temperatures.

4. Discussion

The results of the new chain (Figure 4) show what can be interpreted as a robustness towards lack of lubrication for new chains, where only the completely dry operation leads to a noteworthy temperature increase. With progressing wear, this robustness seems to diminish as the moderately worn chain (Figure 5) shows a significant temperature increase already in the barely lubricated state. Furthermore, the results of the moderately worn chain indicate a quantitative correlation between lubrication state and chain temperature, as the partially degreased, barely lubricated and dry operation can be clearly distinguished by their respective temperature measurements in the case of the first parameter set. The significantly lower results of the most worn chain (Figure **6**) appear less intuitive in comparison to the other two chains. However, with an elongation of 3.8%, the chain is beyond its replacement level of 3% and may show unexpected behaviour. The large joint clearance due to the extreme wear might also reduce the overall friction in the chain joints and thus lead to a lower temperature increase, however, this hypothesis needs to be investigated further in additional experiments. The comparison by elongation (Figure 7 and Figure 8) shows some influence of the wear on the chain temperature, albeit not for all parameter sets and also significantly smaller than the influence of the lubrication level. The differences between the curves of the new and the worn chains in Figure 7 may stem from the running in of the new chain not yet being completed, leading to differences in the joint friction. Generally, it should be considered that lubrication level of a chain changes significantly faster than the elongation, so by taking into account how fast the temperature increases at constant load and speed parameters, it can be determined whether the increase is a result of low lubrication level or progressed wear.

In summary, the presented experiments show that the chain temperature is a viable indicator for the lubrication state of a chain and differences between the extent of lubrication levels can be distinguished in some cases. Accordingly, a contactless temperature measurement of roller chains allows the monitoring of the lubrication level during operation and can support condition-based maintenance of roller chains. Further research features additional tests to increase the amount of available data. In a successive experiment at IFT, an automatic chain lubrication system is tested to compare temperature-based lubrication with time-based lubrication.

Acknowledgement

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References

[1] W. Coenen, "Einfluss der Schmierung auf das Verschleißverhalten von Rollenketten," Dissertation, Institut für Maschinenelemente und Maschinengestaltung, RWTH Aachen, Aachen, 1984.

[2] C. Brecher, D. Christoffers, and S. Neus, "Dynamische Schmierzustandserkennung Öl-Luft-geschmierter Spindellager," *Zeitschrift für wirtschaftlichen Fabrikbetrieb*, vol. 115, no. 5, pp. 327–330, 2020.

[3] P. Boškoski, J. Petrovčič, B. Musizza, and Đ. Juričić, "Detection of lubrication starved bearings in electrical motors by means of vibration analysis," *Tribology International*, vol. 43, no. 9, pp. 1683–1692, 2010, doi: 10.1016/j.triboint.2010.03.018.

[4] C. Radu, "The Most Common Causes of Bearing Failure and the Importance of Bearing Lubrication," Feb. 2010.

[5] P. Saunders, *Radiation thermometry: Fundamentals and applications in the petrochemical industry* (Tutorial texts series TT 78). Bellingham Wash.: SPIE Press, 2007.

[6] *Condition monitoring and diagnostics of machines - Thermography: Part 1: General procedures*, 18434-1, International Standard, Mar. 2008.