Operating Problems of Lubrication of Friction Nodes in Mining Machines Working in an Aggressive Environment

Grzegorz Wszelaczyński[1], Dymitry Capanidis[2], Maciej Paszkowski[2], and Tadeusz Leśniewski[2](✉)

[1] Systemy Smarowania Maszyn, (A.A.L.S. S.A), Legnica, Poland
[2] Department of Fundamentals of Machine Design and Mechatronic Systems, Wroclaw University of Science and Technology, 27 Wybrzeże Wyspiańskiego Street, 50-370 Wrocław, Poland
tadeusz.lesniewski@pwr.edu.pl

Abstract. The paper presents problems related to the lubrication of moving machine nodes that are operating in an aggressive environment occurring in copper mines. The analysis was based on the exploitation of self-propelled wheeled machines, such as transport vehicles, loaders, drilling and anchoring cars. In self-propelled machines there are from 15 to 40 moving parts exposed to high impact loads and stresses. These are mainly bolted joints performing swinging motion as well as rotary motion at low rotational speeds up to 10 rpm. Observations and operational tests of several dozen manifolds and pumps operating in the environment occurring in KGHM Polska Miedź copper mines were carried out during two years. It was stated that elements made of aluminum or its alloys should not be used, and should be replaced with bronze (the proposal results in the increase of weight and costs of the system, but observational studies have shown that the durability and reliability of pumps increased more than three times, and the durability of the manifolds with the bronze body has increased more than five times). It was recommended to avoid the use of electronic systems on actuators in central lubrication systems (control systems should be encapsulated) and to use pumps with a hydraulic drive, which is commonly used in the working elements of machines used in a copper mine. The proposed lubrication system made of bronze and with hydraulic drive is several times more durable and cheaper to operate compared to the central lubrication systems used so far.

Keywords: Mining machinery · Exploitation · Grease · Central multi-circuit lubrication · Progressive lubrication

1 Introduction

Skillful and effective lubrication of machines is very important from the profitability of modern industry point of view. Primarily, it is associated with the extension of the service life of lubricated equipment, reduction of production interruptions and reduction

J. Stryczek and U. Warzyńska (Eds.): NSHP 2020, LNME, pp. 228–238, 2021.
https://doi.org/10.1007/978-3-030-59509-8_20

of production costs. Appropriate selection of lubricant is the easiest way to extend the life of machines [1–5]. In many cases, a slight modification or change of the lubricant [6, 7] extends the life of the element, slightly (or not at all) increasing the cost of use. It is much cheaper procedure than changing materials from which the cooperating elements are made.

Another and even the main condition for effective lubrication is its automation. Lubrication systems primarily enabled the precise supply of the right amount of lubricant to all tribological nodes, and also minimized the possibility of omission by the lubricating person hardly accessible and invisible at first glance friction pairs. Lubrication systems, by rational dosing of plastic greases and lubricating oils in terms of the quantity and frequency of lubrication of friction pairs, have contributed to more effective protection of the natural environment. This is of great importance considering the amount of lubricants used in highly industrialized countries. For example, in 2015 global consumption of lubricants was recorded at 35.6 million m^3, while only in the United States about 9 million m^3 was used at the time [8]. In special cases, centralized lubrication systems compared to traditional lubrication have reduced lubricant consumption by up to 90% [9].

An optimally designed lubrication system should reliably distribute lubricant to specific collection points. Designing such a system is particularly difficult if it supplies heavily loaded machinery with lubricant, containing a large (up to several hundred) number of various types of friction nodes, arranged non-linearly, at a large distance from each other. Extremely important problem, often ignored by engineers, are difficult environmental conditions in which lubrication systems are operated (e.g. high humidity, pollution with coal dust, water, brine). All these factors makes it a big challenge to design a lubrication system that works well even for an experienced designer specializing in this particular field.

The aim of this study is to present the main problems encountered during the exploitation of a fully automated lubrication systems of friction nodes of mining machines working in underground mines. Problems related with lubrication of machine moving nodes operating in an aggressive environment occurring in copper mines, with particular emphasis on the mining plants Polkowice-Sieroszowice and Rudna, belonging to the KGHM Polska Miedź S.A. group were presented. The analysis was based on the operation of self-propelled wheeled machines, such as transport vehicles, loaders, drilling and anchoring cars. In these machines there are from 15 to 40 moving elements that are subjected to high impact loads and stresses (high pressure with concentrated contact, which is the worst type of contact of cooperating elements). These are mainly bolted joints, which perform swinging motion, as well as rotary motion at low rotational speeds up to 10 rpm. Centralized lubrication systems of self-propelled wheeled machines supplying lubricants from a dozen to several dozen tribological nodes have been analyzed. The work contains the test results of structural components of lubrication systems, including manifolds and valves, which are elements of the hydraulic system deciding on the value of basic parameters that significantly affect the work of the energy receiver and the entire hydraulic system [10, 11]. The paper also provides valuable tips for future designers and constructors of central lubrication systems for mining machines.

2 Machines and Environmental Parameters in Selected Copper Mines

Mining machines working in copper mines have a specific design and size. For example, the total height of the machine does not exceed the average human height and is a maximum of 1800 mm. This parameter and other construction and operational requirements set for mining machines result from many factors. They consist of geological factors determining the dimensions of excavations, safety and employee protection recommendations, as well as a number of construction and material guidelines determining many parameters of machines. Additionally, recommendations and limitations resulting from the experience of employees and broadly understood human factors should be remembered. Figures 1 and 2 show examples of self-propelled mining machines operating in copper mines.

Fig. 1. Self-propelled loading vehicle [12].

Fig. 2. Self-propelled drilling and anchoring vehicle Face Master 1.7 [13].

Observation and analysis of lubrication systems were carried out in the mining plants of ZG Polkowice-Sieroszowice and ZG Rudna belonging to KGHM Polska Miedź S.A. The operational tests of these elements depended on the ambient conditions, which are not identical in both mines. Environmental and operating conditions of these elements are presented in Table 1 [14].

Copper ore deposits in these mining plants are located at a depth of 500 m to over 1100 m. The depth of copper deposits and a high geothermal degree in this region of Poland on average 32.8 m/1 °C [15] (the average geothermal gradient is therefore

Table 1. Working conditions of machines in the analyzed coal mines KGHM Polska Miedź S.A.

	Department of ZG Rudna	Department of Polkowice-Sieroszowice
1. Climatic conditions:		
a. air temperature [°C]	47	41
b. air humidity [%]	95%	97
c. dust [mg/m^3]	20	19.31
d. air composition [mg/m^3]:		
- Carbon monoxide - nitric oxide - Sulphur dioxide - hydrogen sulfide	180 10 5 (only for NDS-10) 10	120 3 0.2 20
2. Water pollution [g/l]		
a. index pH	7	7.81
b. total dissolved substances	270	311.2
c. dissolved mineral substances	250	297.2
d. salt content	250	297.2
e. chlorides	145	193.23
f. sulfate content	2.5	5.59
g. sodium content	85	126.7
h. potassium content	1.2	2.140
i. magnesium content	1.5	2.04
j. calcium content	9	2.108
k. mineralization	250	311.2
3. Type of work:	a. work in four-shift system b. working time during the shift is about 5 h c. working time with a maximum allowed efficiency of about 85%	

3 °C/100 m) imposes high working temperature of machines and people. The ambient temperature assuming the degree of geothermal and heat generated by the operating machines underground is from 25 °C to 40 °C. It can be concluded that the lubricating nodes described in this article operate at elevated temperatures (in fact, the operating temperature of the node is higher than the ambient temperature). In addition, copper ore deposits are irregularly located, and sometimes arranged in bands about 1 m high, with a tendency to 'fall down'. It should be noted that the geological structure is complex. Above the copper deposits at a depth of 300–500 m there are rich salt beds after the previous presence of a lake or salt sea.

Taking into account the geological factors and temperature it should be noted that working conditions of machinery and equipment are very unfavorable underground. The geological structure of copper ore, the presence of NaCl salts, high humidity and the emission of other chemical compounds cause that pumped from the earth's surface air contains a lot of compounds that negatively affect mining machines and people working there. The content of these compounds in the atmosphere is shown in Table 1.

Analyzing the presented data, it should be clearly stated that mining machines work in a chemically aggressive environment and at elevated ambient temperature. Due to these difficult operating conditions, since the 90 s in over 80% of all self-propelled machines central lubrication systems have been used in their moving nodes. Most solutions use progressive multi-circuit systems with automatic steering and control. The lubricant is plastic greases with various thickeners and base oil. Lubricants with a consistency of NLGI 1 or 2 are used [9, 16, 18–20].

3 Central Lubrication Systems

The purpose of using central lubrication systems (CUS) is to extend the machine's operating time by preventing seizure of bolt connections in their operating systems. The simultaneous use of CUS eliminates the human factor for carrying out maintenance and conservation activities in the these machines.

3.1 Characteristics of Research Objects and Operational Tests

Figure 3 shows a diagram of a typical central lubrication system used in the observed mining machines [17].

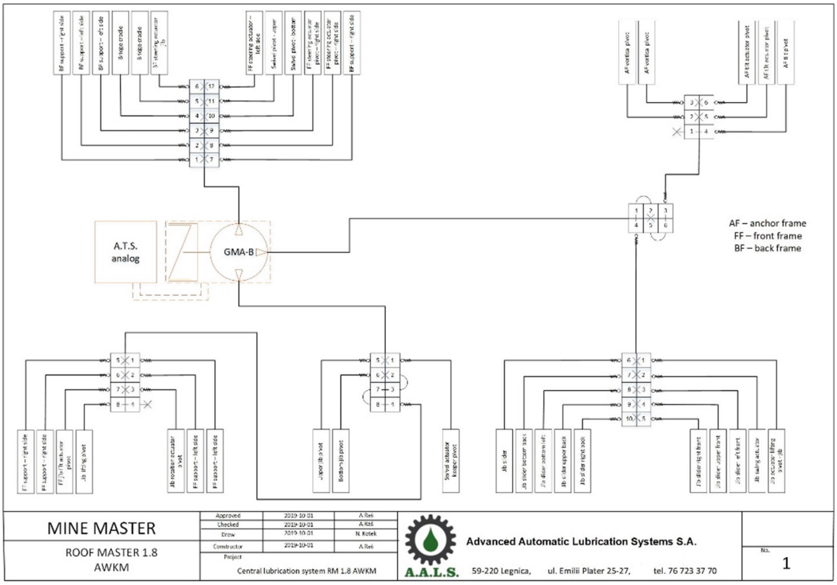

Fig. 3. Diagram of central lubrication system [17].

The presented central lubrication system is a three-circuit progressive system. It uses a pump with an electric drive with a 24 V DC motor, where the pump body is made of aluminum alloys. The progressive distributors installed in it also had aluminum bodies. On grease supply lines polyurethane (PUR) with a textile braid and a polyethylene (PE), polyurethane or polypropylene (PP) sheath is used.

The solution with the use of aluminum and their alloys allowed the installation of lubrication systems with lower weight than other metals and their alloys. This approach is right, because taking into account the criterion of minimum emissions from combustion engines driving machines and their operating systems, the design of these machines strives to keep their total weight as low as possible with maximum reliability and efficiency.

Figure 4 presents photos of pumps, distributors and accessories installed in mining machines equipped with lubrication systems.

a) b)

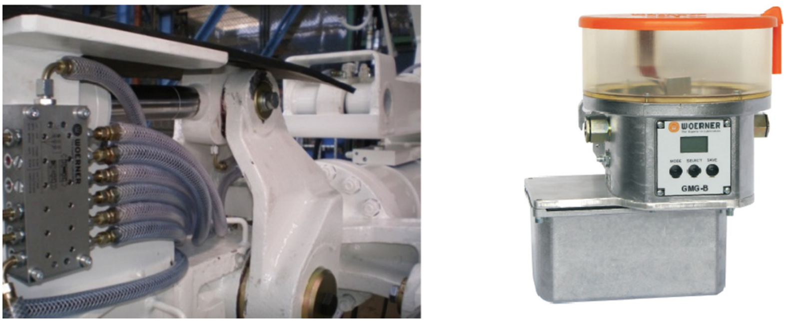

Fig. 4. Elements of the central lubrication system: a - distributor, b - pump aggregate [17].

In the years 2017–2018 at the mining departments of the plants belonging to the company KGHM Polska Miedź S.A. operational observations were carried out and an analysis of the failures of these lubricating system components was carried out. Table 2 contains the type and number of lubrication system components evaluated for durability and reliability during their operation.

Table 2 presents a summary of the assessment results of the operational reliability of lubrication system components. Together, 36 manifolds with an aluminum housing were used for the tests, which were subject to frequent failures during the tests and observations. The main cause of damage was corrosion of housings, resulting in a total failure of the machine's lubrication system. Distributor housing and its condition prevented further repairs, which necessitated the replacement of these elements with new ones. It was similar with fixing elements, which together with the distributor were also damaged and had to be replaced. An example of manifold corrosion is shown in Fig. 5, where numerous pits, body defects and breaking off of fixing elements of the lubrication system are visible. They perfectly show how destructively aggressive mine environment affects the machine and its components - and only after less than 3 months of work.

Table 2. Description of failure of analyzed lubrication system elements during exploitation.

Item	Item name	Quantity	Description of wear or failure
1	Distributor progressive type VPB-B/6/with housing made of AL	21	Housing material loss due to corrosion. Corrosion of steel structural elements of the manifold (elements sealing the flow of grease in the manifold housing) with few defects in the components. Few leakage of grease between the distributor housing and connecting elements with the central lubrication system
2.	Distributor progressive type VPB-B/8/with housing made of AL	9	
3.	Distributor progressive type VPB-B/10/with housing made of AL	6	
4.	GMG-L series lubrication pump with built-in electronic controller with system operation control	5	Numerous failures of the control system. Corrosion of electronic systems. Corrosion of the pump's aluminum components. Electric drive failure

Fig. 5. Grease distributors after the service life.

Five GMG-L lubrication system pumps were also selected for operational tests. These are electrically driven pumps with a built-in pump control and monitoring system. This hybrid is widely used in mobile central lubrication systems. However, as shown by operational observations, such a system is not suitable for use in a copper ore mine. The mine's environment had a destructive effect on the aluminum components of the pump housing and on the controller electronics. The average trouble-free operation of the pump controller was two months. After this period, it was necessary to replace it with a new one. On average, every 3 months, the pump housing components were cleaned, maintained and repaired.

Figure 6 shows an example of the pump after about three months of operation. Pay attention to manifolds and their corrosion throughout (Fig. 8). These elements worked many times directly in the water on the mine floor.

Fig. 6. Grease pump during operation.

3.2 Design Recommendations and Operational Tests of Modified Lubrication Systems

After analyzing the wear, efficiency and failure rate of UCS machines and components, and determining the permissible time of their operation (durability), new construction solutions were proposed. Instead of aluminum manifolds, new manifolds of similar design and performance have been used, but with a bronze housing. The capacity, dimensions and connections of the manifolds have been the same as for the manifolds with aluminum housing.

A hydraulic drive pump with a carbon steel body, protected with a varnish coating (urea paint) and progressive distributors with a bronze body were also introduced.

Figure 7 shows a GAT hydraulic drive pump, and Fig. 8 shows a photograph of a progressive distributor which body is made of bronze.

The results of operational research are shown in Table 3.

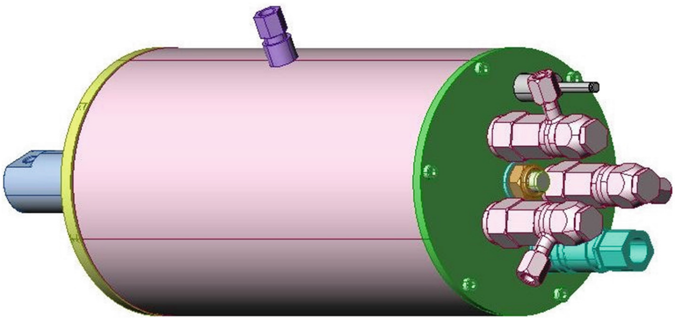

Fig. 7. Pump with GAT hydraulic drive.

After operational tests of 11 new manifolds, it turned out that the bronze housing is very resistant to corrosion caused by the aggressive environment in the copper ore mine. The distributors, after some time, about 2 months, were covered with a corrosion layer of copper sulphide, but the corrosion did not continue. A thin layer of green copper sulphide and copper compounds acted as a natural anti-corrosion agent and the distributors were

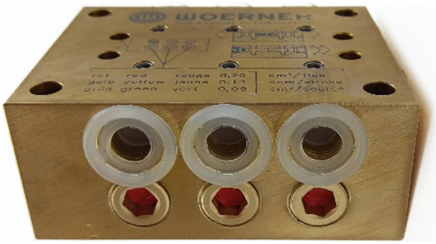

Fig. 8. Progressive distributor with a bronze body.

Table 3. Description of failures of modified lubrication system elements.

Item	Item name	Quantity	Description of wear or failure
1.	Distributor progressive type VPB-H/6/with a bronze housing	4	Few corrosion of the housing. The change of the housing color to green due to the mine environment - separation of the copper sulphide layer limited further corrosion of the housing
2.	Distributor progressive type VPB-B/8/with a bronze housing	5	
3.	Distributor progressive type VPB-B/10/with a bronze housing	2	
4.	Pump with hydraulic drive, GAT series	2	Sparse failures sensor lubricant level in the pump

working properly. Only a few lubricant leaks appeared in the housing connections with the grease lead connector, but it was possible to quickly eliminate leaks or replace these fixing elements.

The situation was similar with modified pumps. New generation GAT series pumps with a hydraulic drive, which were used in operational tests in the number of 2, did not show any defects in electrically driven pumps. The pump control of the GAT series is placed in the central controller of the working machine and in the housing resistant to the atmosphere of the mine. Only a few, about three, cases of incorrect reading of the location of the grease level sensor in the tank were found, which were quickly repaired and it did not have significant meaning in the operation of the lubrication system. This is the only element mounted outside the pump body.

However, The introduced modifications also have disadvantages. The design solution of lubrication systems using a pump with a hydraulic drive and manifolds with a bronze body, increased the weight of the entire UCS system by over 100%. However, operational observations showed that the durability and reliability of the pumps increased more than 3 times. Electrical failure caused by corrosion or interruption of the electric wires supplying and controlling the pump have been eliminated. The durability of distributors with a bronze body compared to those with an aluminum body increased more than five times.

3.3 Summary and Conclusions

The paper presents problems related to the lubrication of moving nodes of self-propelled wheeled machines, operated in an aggressive environment and at elevated temperatures occurring in copper mines. Observations and operational tests of several dozen manifolds and pumps operating in the environment occurring in KGHM Polska Miedź copper mines during two years allowed to draw a number of conclusions:

- elements made of aluminum or its alloys should not be used, and should be replaced with bronze (the design solution of lubrication systems using a pump with a hydraulic drive and manifolds with a bronze body resulted in an increase in the weight of the entire UCS system by over 100%, however, operational observations showed that pump durability and reliability increased more than three times, and manifolds with bronze body increased more than five times),
- the use of electronic systems on actuators in central lubrication systems should be avoided (eliminated electrical failures caused by corrosion or interruption of the electric wires supplying and controlling the pump by enclosing the control systems),
- hydraulic drive, which is widely used in the working elements of machines used in a copper mine, turned out to be the optimal drive in central lubrication pumps.

The above observations are very promising, because even considering the fact that elements made of aluminum are 3 times cheaper than those made of bronze, and the hydraulic drive is about 2 times more expensive than the electric drive, the proposed lubrication system made of bronze and with hydraulic drive is several times more durable and cheaper in operation compared to the central lubrication systems used so far. It should be remembered that the cost of production alone does not affect the final price of the device, because the cost of downtime and repairs is an important economic component.

During the work, further issues emerged that should be considered during subsequent work aimed at improving the lubrication systems of mining machinery friction nodes. The problems related to the flow and thixotropy of lubricants should be solved and the design of the pin and bearing (operating node) should be adjusted in terms of optimizing the lubricant supply to the node. A separate issue is the impact of individual types of grease on the durability of pins and bushes in working nodes, and the impact of the materials from which these elements were made.

References

1. Krawiec, S.: Kompozycje smarów plastycznych i stałych w procesie tarcia stalowych węzłów maszyn. Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław (2011)
2. Capanidis, D., Wieleba, W., Kowalewski, P.: Wpływ wybranych smarowych preparatów eksploatacyjnych na właściwości tribologiczne materiałów polimerowych podczas tarcia ze stalą. Tribologia **6**(41), 11–23 (2010)
3. Lugt, P.: Grease Lubrication in Rolling Bearings. Wiley, Chichester (2014)
4. Bruce, R.: Handbook of Lubrication and Tribology. CRC Press, Boco Raton (2012)
5. Bruce, R.: Handbook of Lubrication and Tribology, vol. II. CRC Press, Boco Raton (2012)
6. Krawiec, S., Krawiec, M., Leśniewski, T.: The influence of the type of grease on the synergy of its composition with PTFE powder and copper powder. Tribologia **1**(47), 45–55 (2016)

7. Leśniewski, T., Krawiec, S.: The effect of ball hardness on four-ball wear test results. Wear **264**, 662–670 (2008)
8. Paszkowski, M.: Przepływy smarów plastycznych w układach smarowniczych i węzłach tarcia. Wybrane zagadnienia, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław (2017)
9. Czarny, R.: Smarowanie układów jezdnych maszyn roboczych i pojazdów. Oficyna Wydawnicza Politechniki Wrocławskiej, Seria: Navigator 11, Wrocław (1998)
10. Stosiak, M.: Ways of reducing the impact of mechanical vibrations on hydraulic valves. ACME **15**, 392–400 (2015)
11. Stosiak, M.: The modelling of hydraulic distributor slide-sleeve interaction. Arch. Civil Mech. Eng. **12**(2), 192–197 (2012)
12. KGHM Zanam Homepage. https://www.kghmzanam.com/produkty/maszyny-gornicze/ladowarki/lkp0405. Accessed 11 Feb 2020
13. MineMaster Homepage. https://www.minemaster.eu/pl/wiertnice/face-master-1-7. Accessed 11 Feb 2020
14. Operating information in mining plants of KGHM Polska Miedź S.A
15. Majorowicz, J.: Zakład Geofizyki Instytutu Geologicznego w Warszawie (1971)
16. Lawrowski, Z.: Technika smarowania. Wydawnictwo Naukowe PWN, Warszawa (1996)
17. Company materials Woerner Zentralschmieranlage i Elektroluber S.C. (previously A.T.S. Electro-Lube Polska)
18. Wysocki, M.: Systemy smarownicze w przemyśle ciężkim. Wydawnictwo "Śląsk", Katowice (1971)
19. Zwierzycki, W.: Oleje, Paliwa i Smary dla przemysłu. Wydawnictwo i Zakład Poligraficzny Instytutu Technologii Eksploatacji, Radom (2001)
20. Totten, G., Gresham, R.: Lubrication and Maintenance of Industrial Machinery: Best Practices and Reliability. CRC Press/Taylor & Francis Group, Boca Raton (2009)