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THE LUBRICITY AND LOW FRICTION ADDITIVES FOR TRANSMISSION OIL

SMARNOŚĆ A DODATKI NISKOTARCIOWE DO OLEJÓW PRZEKŁADNIOWYCH

Key words: lubricating oils, gear box, friction, lubrication, boundary layer, low friction additives, acoustic emission.

Abstract The subject of this paper is the extension of the durability of multi-stage gear units working in moments or constant overloads. Gear oils in sugar conveyor systems of the DC tray extractor were tested. Lubrication parameters and modifications of this parameter have been studied by adding additional materials to the oil. Additionally, the noise levels emitted by practical transmissions before and the addition of modifiers were measured. The lubrication tests were carried out on a semi-Timken apparatus, for example, friction roller friction – roller, in oils extracted from the gear unit. Sound level tests were performed using the SoundMeter application with a MIC001 microphone adapter. The results confirmed the effectiveness of the modified equipment, which was raised to a higher value, and also the noise level of the working gear was reduced. It has been shown that, in the current operating systems, a method of increasing the lubricant parameters of the gear oils is required, which translates into the durability of the gear pairs during operation.

Słowa kluczowe: oleje smarowe, przekładnia zębata, tarcie, smarność, warstwa graniczna, dodatki niskotarciowe, emisja akustyczna.

Streszczenie Przedmiotem niniejszych badań jest problem wydłużenia trwałości wielostopniowych przekładni zębatych pracujących w chwilowymi lub stałymi przeciążeniami. Badaniom podlegały oleje przekładniowe stosowane w systemach transmisji mocy cukrowniczego ekstraktora korytowego typu DC. Badano parametr smarności olejów i możliwości modyfikacji tego parametru poprzez wprowadzenie dodatków niskotarciowych do oleju. Dodatkowo pomierzono poziom hałasu emitowanych przez pracujące przekładnie przed i po dodaniu modyfikatorów. Badania smarności przeprowadzono na aparacie semi-Timken, na którym zacierano pary cierne rolka–wałek w obecności olejów pobranych z przekładni. Do badań poziomu emisji hałasu wykorzystano aplikację SoundMeter z przystawką mikrofonową MIC001. Wyniki badań potwierdziły skuteczność modyfikatorów – uzyskano wyższe wartości obciążeń zacierających, a także obniżono poziom emisji hałasu pracujących przekładni. Wykazano, że w rzeczywistych systemach eksploatacyjnych istnieje możliwość podniesienia wartości parametrów smarności olejów przekładniowych, co ma bezpośrednie przełożenie na trwałość par ciernych przekładni w trakcie eksploatacji.

INTRODUCTION

The short processing period of raw material preferred in the sugar industry is mainly due to the instability of the sugar beet, changes in its technological parameters, and the break-down and loss of sucrose over time. For this reason, we can observe the trend of successively increasing the daily norms of processing of individual sugar mills.

At present, some sugar mills in Poland process more than twice the nominal value of daily processing. For example, at the end of the 1990s, the average sugar factory nominally processing around 2400 tons of beets per day is currently processing 5000 tons of raw material per day.

Naturally, such a mill undergoes a series of upgrades that allow such a large increase in processing. All departments together with the machines and equipment installed in them are subject to redevelopment aimed at increasing production capacity. However, there is equipment that arbitrarily raises the nominal processing load by up to 150% without changing the main design

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features. DC tray extractors can be classified in this group of machines. These units, which have been installed in sugar factories, manufactured since the early 1960s, are operated today without interfering with their main structural, technological, and geometrical parameters. When increasing the daily processing norms of the tray extractor, its transmission system is not significantly modernized.

In a tray extractor, power is transmitted from the electric motors through the reduction gearboxes. Each power unit has a multi-stage gearbox lubricated with circulating gear oil. These gearboxes work at full load, transferring the maximum torque values. Momentary overloads that go beyond the range of acceptable loads can cause adverse phenomena such as dry friction, or even pitting or spalling. During momentary overloads, there is also an increase in noise and vibration emissions from the friction elements of the gearbox. As a result of these cyclic repetitive overloads, accelerated wear and even damage of the gearbox can occur.

With the development of gearboxes, there has been a need for high quality gear oils that meet a number of criteria, including kinematic viscosity, viscosity index, lubricity, pumping ability, foaming resistance, stability, corrosion inhibitor content, dispersing and washing properties, and many others. Among the aforementioned characteristics of oils, a critical feature, from the standpoint of the life of the gearbox, is the lubricity, which is expressed as the ability to maintain the boundary layer separating the friction pairs.

The lubricity of mineral gear oils and thus the stability of the boundary layer can be modified using various low friction additives. In the literature, there are many studies on the modification of engine oils **[L. 1–3]** and gear oils used in small gearboxes **[L. 4]**. According to the authors **[L. 4]**, it is not recommended to modify synthetic lubricating oils using low friction additives, due to the possibility of the occurrence of mutual antagonism phenomena of additives added to the finished oil with chemicals already contained in high quality synthetic oils.

In all the aforementioned studies, modification of the lubricant has improved the tribological properties of the friction coupling. Tests were performed on a four-ring machine, but no noise emission tests were performed.

PURPOSE OF THE TESTS

During the prolonged process of oil use, physicochemical changes occur resulting in the degradation of its properties. We are dealing with the phenomenon of oil ageing during operation. This fact can cause viscosity loss, an increasing amount of contamination, and consequently, a reduction in the ability to create a persistent boundary layer. Lubricity is reduced. These changes in gear oils result from the interaction of friction pair components, and also due to impurities from the transmission environment. They are permanent and reflect the appearance of new properties called operational properties. In case of gear oils, we are dealing with a certain value of lubricity which is a critical parameter.

The purpose of the study is to determine the possibility of increasing the oil lubricity value using conventional layered low friction additives and synthetic friction pairs of gearboxes.

The purpose of utilitarian work is to increase the durability of gearboxes. The secondary purpose is to determine the relationship between the parameter determining gear oil lubricity and the gearbox's noise level.

MATERIALS

Orlen Transol SP220 gear oils used in Flender multi-stage angular-cylindrical gearboxes with 160kW transferred power were tested. The nominal amount of oil in each gearbox is 140 litres. The gearboxes are equipped with a circulating lubrication system. The oil circuit is forced by installing an external gear pump with an independent electric drive on each gearbox. The chamber ventilation system of each gearbox is equipped with a particulate filter to prevent impurities from entering the gearbox. Therefore, friction pairs of co-operating metal surfaces can be primarily the source of contamination accumulation in the transmission oil.

The tests covered oils from four gearboxes working in parallel DC diffusers in a single raw material extraction line. Each diffuser is driven by a pair of gearboxes of the same type. Gearboxes work with comparable load in the same raw house building. All gearboxes have a similar level of operational potential.

A characteristic multi-stage gearbox with a visible layout of the circulating lubrication is illustrated in **Fig. 1.** The subject of the presented study is the stability of the boundary layer in gear oils during their use and the possibility of modifying the value of this parameter.

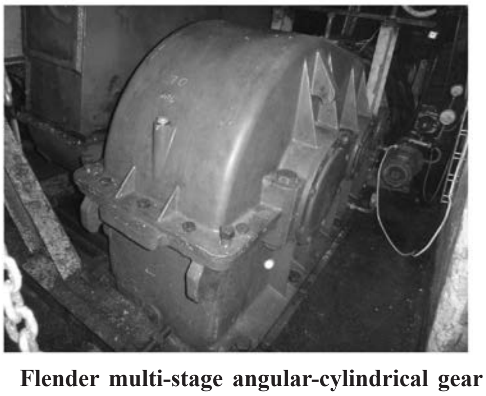

Fig. 1. Flender multi-stage angular-cylindrical gear unit with visible circulating lubrication system

Rys. 1. Wielostopniowa przekładnia kątowo-walcowa typu Flender wraz z widocznym układem smarowania obiegowego

Prior to introducing low friction additives to the gear oil, samples were taken to test selected physicochemical parameters. In order to compare the values of the selected physicochemical parameters declared by the oil manufacturer, samples of fresh oil for refills were also taken.

Low friction additives for oils can be differentiated as conventional additives containing layered solid lubricants (such as graphite, molybdenum disulphide, and boron nitride), soft metal nano-particles, and advanced synthetic low friction additives.

In the tests presented below, modified values of the boundary layer durability parameter were applied, using two types of low friction additives: an additive Molly SP1 based on dispersed MoS_2 slurry in base oil, and an additive with a layered solid lubricant, i.e. Additive Metaltec 1213, which is a synthetic hydrocarbon complex containing active compounds that modify the surface of friction pairs.

Nominal values of Orlen Transol SP220 oil parameters are shown in **Table 1.**

Table 1. Physico-chemical parameters of Orlen Transol SP220 oil [L. 9]

Tabela 1. Parametry fizykochemiczne oleju Orlen Transol SP220 **[L. 9]**

No.	Parameter	Unit	Typical values
1	Kinematic viscosity at 100°C	mm^2/s	19.4
2	Kinematic viscosity at 40°C	mm^2/s	223
3	Viscosity index	–	98
4	Flow temperature	°C	-23
5	Flash point	°C	240
6	Corrosive action in copper plate, 3 h/120°C, degree of corrosion	standards	1b
7	Resistance to emulsification, time Delamination of oil-water emulsion	at least	25
8	Lubrication properties · Consumption indicator under load (I_h)	daN	48
9	Lubrication properties · Weld load (P_z)	kN	3.09
10	Ability to transfer loads in a FZG station, destructive load level, not lower than	–	12

The tests covered oils from four gearboxes working in parallel DC diffusers in a single raw material extraction line. Each diffuser is driven by a pair of gearboxes of the same type. Gearboxes work with a comparable load in the same factory hall. All gears have a similar level of exploitation potential.

The stability tests of the oil's boundary layer were performed using the semi-Timken machine. It is a lubricant lubricity tester built based on the principle of operation of the Timken machine. In addition to structural details that are irrelevant from the point of view of the tests, the semi-Timken machine differs from the Timken machine by the type of initial contact of the sample and the counter-sample. In the Timken machine, the sample, which is a block in the shape of a cuboid, is rubbed on the outer cylindrical surface of a ring, which is the counter-sample. In the semi-Timken machine, the sample is cylindrical in shape and is also rubbed on a ring. Initial sample contact with the counter-sample in a Timken machine is linear, while in a semi-Timken machine, it is a point. The differences between the contact of friction pairs of the sample and the counter-sample are shown schematically in **Figure 2**. The initial contact point of the friction coupling allows for smaller pressures to be applied to the sample during testing. In the friction coupling of a semi-Timken machine, the error of the surface of the ring not being parallel to the surface of the cylinder is also excluded. Such an error can occur in friction pairs in Timken machine samples. The detailed structure of the machine is shown in **Figure 3.**

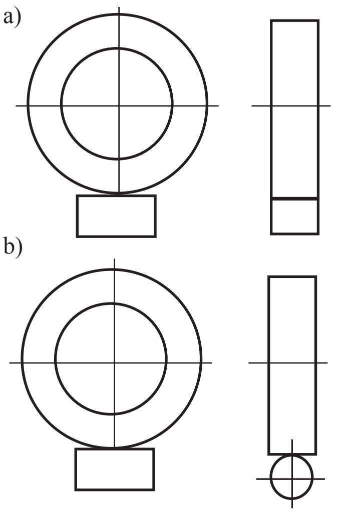

Fig. 2. Diagram of contact of friction pairs: a) Timken, b) Semi-Timken

Rys. 2. Schemat styku skojarzeń trących par ciernych: a) aparatu Timken, b) aparatu semi-Timken

The main components of the semi-Timken tester are the drive system rollers and the lever system responsible for transferring the load to the sample. The tester drive is a 0.25 kW electric motor, which transmits the torque to the roller shaft via the belt drive. Roller speed is 750 rpm. The sample loading system consists of two co-operating levers with a total gear ratio of 1: 20. The oil tested is placed in a special oil pan. The one-time volume of oil during the test is about 3 ml.

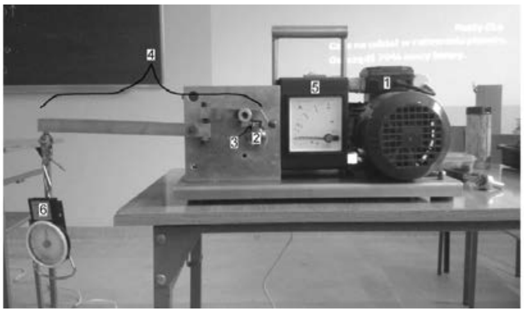

Fig. 3. Tester semi – Timken: 1 – electric motor, 2 – roll, 3 – roller, 4 – level system 5 – ammeter, 6 – dynamomert

Rys. 3. Aparat semi – Timken: 1 – silnik elektryczny, 2 – przeciwpróbka – rolka, 3 – próbka – wałek, 4 – układ dźwigniowy, 5 – amperomierz, 6 – dynamomert

TEST METHODOLOGY

Oil from each gearbox was sampled prior to modification using low friction additives. Samples were taken during operation of the gearbox through a control-measuring hole. The one-time volume of the oil sampled was 150 cm^3 from each gearbox.

The noise levels of gearboxes operating with unmodified oils have also been measured. Due to the high noise level in the raw house building, the gearbox noise measurements were made at a distance of 75 cm from the central part of the gearbox crankcase, 120 cm above the gearbox foundation line.

For further tests, the oils were mixed with low friction additives in the gearboxes.

The Metaltec 1213 additive was added to two gearboxes in the following quantities:

- 2% by volume to the left gearbox of the first diffuser (Fender 1), and
- 5% by volume to the right gearbox of the first diffuser (Fender 2).

The Molly SP1 additive was added to the remaining two gearboxes in the following quantities:

- 2% by volume to the left gearbox of the second diffuser (Fender 3), and
- 5% by volume to the right gearbox of the second diffuser (Fender 4).

The amounts of the admixed additive were taken according to the recommendations of the manufacturers. A dosage of 2–5% is recommended for gear oils. The lower and upper dosage limits have been adopted.

After admixing the additives in the gearboxes, the oils were re-sampled after a period of 20 hours.

At the same time, regular noise emission measurements were made. The first measurement took place after three hours of the operation of the gearbox using modified oil, with subsequent measurements every three hours for the first 12 hours. Then the noise emission was measured every 12 hours. Noise measurements were completed after 154 hours of operation of the gearbox with modified oil.

At the end of the tests, modified oils were used in gearboxes until the end of the sugar production campaign without replacement.

TEST RESULTS

The results are presented in both tabular and graphic forms below.

Figure 4 shows the results of the friction tests. In the first row in the graph, the values of unmodified oils are shown in the five columns.

Columns 1 through 4 correspond to consecutive numbers of Flender gearboxes. Column 5 is a test result of fresh oil, which was taken directly from the original packaging. The second row refers to the results obtained when friction testing oil with low friction additives. Metaltec 1213, 2% by volume, was admixed to the Flender 1 gearbox oil, and Metaltec 1213, 5% by volume, was admixed to the Flender 2 gearbox oil. Molly SP1, 2% and 5% by volume, was admixed to oils in gearboxes Flender 3 and Flender 4, respectively.

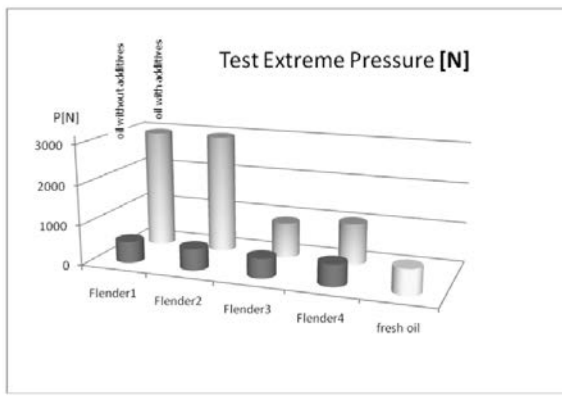

Fig. 4. Graphical presentation of the results of friction tests

Rys. 4. Graficzne przedstawienie wyników badań zatarciowych

The results of the tests are shown in **Table 2**.

Table 2. Results of friction tests

Tabela 2. Wyniki badań zatarciowych

No.	Gearbox	Additive	Weld load [N]	Value increase
1	Flender1-0	-	540.00	-
2	Flender2-0	-	540.00	-
3	Flender3-0	-	490.00	-
4	Flender4-0	-	540.00	-
5	Fresh oil	-	640.00	-
6	Flender1	2% Metaltec	2950.00	445%
7	Flender2	5% Metaltec	2950.00	445%
8	Flender3	2% Molly SP1	880.00	80%
9	Flender4	5% Molly SP1	1030.00	91%

The readings of the values given in **Table 2** indicate the level of lubricity of the oils from the individual gearboxes before admixing the additives (**Tab. 2**, items 1-4), and oils modified with low friction additives (**Tab. 2**, items 6–9). The value of fresh oil's lubricity parameter was also measured (**Tab. 2**, item 5).

The last column of **Table 2** shows the percentage increase of the oil lubricity parameter for each gearbox. An increase by 445% compared to unmodified oil was observed in Flender 1 and Flender 2 gearboxes with oil modified with additive Metaltec 1213 in the amounts of 2% and 5% by volume. The value of the lubrication parameter increased by 80% in gearbox Flender 3 with oil modified with Molly SP1, 2% by volume. In the last gearbox, Flender 4, oil was admixed with 5% of Molly SP2 by volume. This resulted in an increase in the value of the lubricity parameter by 91% relative to the oil prior to modification. It should be emphasised that the oil in the Flender 3 gearbox had the lowest lubricity value measured before adding the additive. In the other gearboxes – Flender 1, 2, 4 – the measured value of the lubricity parameter before modification of low friction additives was at the same level.

The oils used in all tested gearboxes were characterized by a lower lubricity value compared to fresh oil. At the start of the test, the gearbox oil change interval was estimated at 1300 hours.

In order to visualise the correlation of the durability of oil's boundary layer to the vibration level of noise emitting gearboxes, the noise level of the individual gearboxes was measured. A detailed graph of changes in noise emission is shown in **Figure 5**. Please note that the scale is not retained in the timeline of the gearbox's operation, the spacing of the markers indicates the next moment of testing expressed in hours after the additive has been applied.

In gearboxes Flender 1 and Flender 2, additive Metaltec 1213 made noticeable changes in noise emissions within 6 hours of application. After another 60 hours, there was a further decrease in the noise level in both gearboxes. Noise emission stabilised after 54 hours in the case of gearbox Flender 2 and after 90 hours in the case of Flender 1.

In gearboxes Flender 3 and Flender 4 where Molly SP1 was added to the oil, there was no sudden change in noise emission. During the 154 hours of noise level tests, changes in the value of the noise emission parameter were observed in these gearboxes. **Figure 5** shows temporary trends in noise reduction. At the end of the graph, after 154 hours of the gearbox's operation with oils modified with Molly SP1, a return to the initial level can be noticed.

Figure 6 shows screens from the SoundMeter application during testing. Figure 6a shows the noise level of the gearbox with unmodified oil, and Figure 6b shows the noise emission of the gearbox modified with Metaltec 1213.

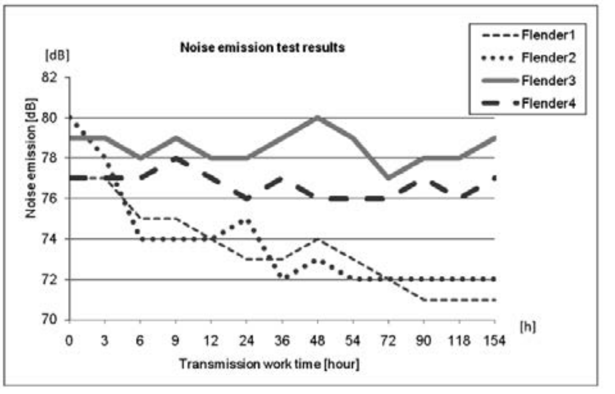

Fig. 5. Graphical presentation of noise emission test results

Rys. 5. Graficzne przedstawienie wyników badań emisji hałasu

a) b)

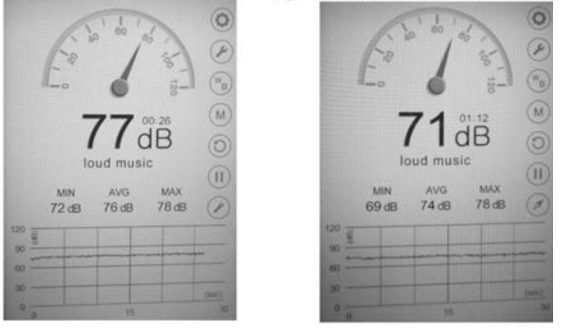

Fig. 6. Sound emission level gearbox: a) with unmodified oil, b) with oil modified Metaltec 1213 additive

Rys. 6. Poziom emisji dźwięku przekładni: a) z olejem niemodyfikowanym, b) z olejem modyfikowanym dodatkiem Metaltec 1213

ANALYSIS OF TEST RESULTS

There was a significant increase in load values for oils modified with Metaltec1213 (**Table 2**). The addition of Metaltec in the amount of 2% by volume increased the value of the oil lubricity parameter comparable to the 5% addition. Changes in noise levels for the 2% and 5% admixtures are comparable. This is due to the high efficiency of Metaltec 1213. When this modifier was already mixed in 2% by volume, it initiates the process of creating a pressure-resistant boundary layer.

In the case of an additive based on mollybdenum disulphide – Molly SP1, there was a noticeable increase in the lubricity parameter. The noise level of the gearboxes operated with oil modified with Molly SP1 during the test was varied. After a period of 154 hours in which noise emission measurements were carried out, the measured noise values of the gearboxes with oils modified with Molly SP1 stabilized to a level comparable to the noise emission values before modifying the oils in the gearboxes. The use of Molly

SP1 reduced the noise emission by a small value – close to the measurement error. This relationship was noted for both concentrations.

CONCLUSIONS

The following final conclusions can be formulated on the basis of the operational tests of gear oils.

According to the results of the tests, it is concluded that advanced low-friction additives for oils have a significant multiple effect on the increase in the lubricity parameter, since they increased lubricity at a level of 445%.

On the basis of the final results of the tests shown in Section Test results of this paper, it is stated that, as the lubricity increases, the noise level emitted by the working gearbox decreases several times (from 80 dB to 72dB). According to the author's information, the decrease in noise emissions is related to the formation of an extremely pressure-resistant boundary layer. The boundary layer created eliminates dry and boundary friction in the existing mixed friction, occurring in the contact places of friction pair surfaces in the analysed gearbox.

The tests conducted have shown that any modification of the oil with a low friction additive requires a separate test of lubricity and of the effects on the noise level. Further studies of the impact of low-friction additives should be carried out to find out the nature of the correlation of boundary layer formation and noise emission changes.

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