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PRAĆENJE STANJA REDUKTORA TRAMVAJA TIP 901 ANALIZOM ULJA

Sažetak

Želja za stalnim praćenjem i uvidom u stanje opreme, uvjetovala je razvoj i primjenu analize ulja. Ovakva analiza osim stanja maziva daje sliku stanja opreme tijekom cijelog procesa korištenja, bez nepotrebnih gubitaka zbog zaustavljanja opreme.

U radu je prikazana mogućnost praćenja stanja reduktora tramvajskih kola tip 901 pomoću analize ulja.

1. UVOD

Zagrebački električni tramvaj-ZET u proteklih je 5-6 godina kupio desetak rabljenih tramvajskih kola u Njemačkoj, koja nose oznaku 901 i stara su tridesetak godina. Karakteristike tramvajskih kola tip 901 su:

Proizvođač:	Duwag
Snaga motora:	2x95 KW
Broj okretaja e.m.:	1200 min^{-1}
Broj reduktora:	4
Masa vozila:	31,4 t

Proizvođač i prijašnji vlasnik propisivali su vrste i intervale zamjene maziva. U želji da se prijeđe na maziva domaćeg proizvođača, napravljeno je ispitivanje primjene polusintetičkog višegradacijskog ulja INA Hipenol GTL HD 75W-90 za podmazivanje zupčanika reduktora.

Ispitivanje svojstava i parametara ulja tijekom eksploatacije provedena su u laboratoriju INA-Maziva u Zagrebu. Drugi dio ispitivanja, koji se odnosio na praćenje trošenja reduktora, proveden je u laboratoriju za tribologiju Fakulteta strojarstva i brodogradnje u Zagrebu.

2. SVOJSTVA I ANALIZA ULJA ZA REDUKTORE

INA Hipenol GTL HD 75W-90 je polusintetičko višegradacijsko ulje za zupčaničke prijenosnike klase API GL-5. Sastoji se od mineralnog ulja, sintetičke komponente (polialfaolefini) i različitih aditiva. Ti aditivi poboljšavaju svojstva podmazivanja, smanjuju trošenje i koroziju te služe za poboljšanje niskotemperaturnih svojstava i svojstava smične stabilnosti.

Tijekom analize ulja u laboratoriju INA-Maziva praćeni su podaci koji su prikupljani na vozilima u razdoblju od kolovoza 1998. do lipnja 1999. Prikaz praćenih podataka kao i dobivene vrijednosti tijekom ispitivanja dani su u tablici 1.

Ispitivanjem fizikalno-kemijskih svojstava kao i mehaničkih svojstava dolazi se do vrijednih podataka o stanju i kvaliteti ulja nakon određenog vremenskog intervala primjene. U ovom ispitivanju zadnji uzorak uzet je nakon približno 86.000 kilometara.

Viskoznost kao jedna od najvažnijih osobina maziva predstavlja mjeru unutrašnjeg trenja, koja djeluje kao otpor na promjenu položaja molekula maziva pod utjecajem smičnog naprezanja. Ovisna je o temperaturi i tlaku. Odnos viskoznosti i gustoće naziva se kinematička viskoznost (ISO 3104). Promjena kinematičke viskoznosti tijekom primjenskog ispitivanja ne bi trebala prelaziti više od 10% u usporedbi sa svježim mazivom.

Kiselinski broj se tijekom primjenskog ispitivanja nije značajnije mijenjao, što nam pokazuje da je aditivacija ulja zadovoljavajuća. Malo povećanje kiselinskog broja javlja se zbog očekivane oksidacije ulja (ISO 6618).

Sadržaj sumpora (X-ray) također je bitan pokazatelj aditiviranosti maziva. Uporabom maziva dolazi do pada sadržaja sumpora.

Povećanjem broja prijeđenih kilometara raste sadržaj olova i željeza zbog trošenja bokova zuba. Međutim, količine izražene u ppm (ICP metoda) su unutar definiranih granica za hipoidna ulja, odnosno ispod 1500 ppm.

Uzorci maziva bili su podvrgnuti i mehaničkim ispitivanjima svojstava nosivosti opterećenja mazivog sloja, tj. ispitivanju graničnih opterećenja – ispitivanje EP svojstava (extreme pressure). U aparatu sa 4 kugle (ASTM D 2783) nalazi se u obliku tetraedra jedna rotirajuća i 3 nepokretne kugle istog materijala i dimenzija. Sustav kugli nalazi se u držaču, koji se može opteretiti, a napunjen je ispitnim uljem. Kugle se opterećuju dok se ne zavare i to optrećenje izraženo u N (Newton) označava se kao točka zavarivanja.

Na wear stroju sa 4 kugle mjeri se srednji dijametar istrošenja (ASTM D 4172). Kod tog ispitivanja opterećenje je standardizirano, kao i trajanje pokusa (1200 o/min, 392 N, 75^{0}C, 1h). Nakon provedenog ispitivanja mjeri se promjer istrošenja kuglica. Što je čvršći mazivi sloj, dolazi pri višem opterećenju do zavarivanja kuglica, a i trošenje kuglica je manje.

Temeljem prikazanih rezultata možemo zaključiti da polusintetičko ulje za zupčaničke prijenosnike osigurava produženi vijek izmjene ulja i preko 80.000 prijeđenih kilometara. Ulje je zbog toga prihvatljivije za okoliš, a i ekonomska ušteda je veća. Dobra niskotemperaturna svojstva osiguravaju primjenu i tijekom cijele godine. Primjensko ispitivanje pokazalo je da se INA Hipenol GTL HD 75W-90 može primjenjivati u daljnjoj eksploataciji tramvaja tip 901.

Tablica 1: Pregled rezultata ispitivanja
Table 1: Test results overview

Uzorak, DOB	➢POS 110/98	198/98	1/99	49/99	102/99	128/99	168/99	180/99
Datum uzorkovanja	-	28.08.1998.	10.12.1998.	08.02.1999.	16.03.1999.	21.04.1999.	31.05.1999.	23.06.1999.
Kin. viskoznost pri 40^{0}C, mm^2/s, ISO 3104	122.81	124.95	123.81	123.64	125.26	124.86	124.97	123.57
Promj. viskoznosti pri 40^{0}C	-	1.74	0.81	0.68	1.99	1.67	1.76	0.62
Kin. viskoznost pri 100^{0}C, mm^2/s, ISO 3104	13.40	13.28	13.21	13.23	13.24	13.28	13.25	14.09
Promj. viskoznosti pri 100^{0}C	-	-0.9	-1.42	-0.01	-1.19	-0.9	-1.12	-5.15
Indeks viskoznosti	104	101	101	101	99	101	100	113
Korozivnost na bakru, 3h, 120 ^{0}C, ISO 2160	1a	3a	3a	3b	3b	3b	3a	1b
Sadržaj sumpora (X-Ray), %	2.37	2.35	2.22	2.25	2.33	2.32	2.32	2.37
Sadržaj željeza (ICP), ppm	6.70	251	281	291	280	264	231	207
Sadržaj olova (ICP), ppm	8.50	75	71	71	56	59	54	53
Kiselinski broj. mgKOH/g ISO 6618	3.07	4.48	4.95	3.90	3.67	3.56	4.39	4.28
Dinam. viskoznost pri -40 ^{0}C. mPas, ASTM D 2983	110000	102000	–	119400	114000	122000	148000	–
Točka zavarivanja, N ASTM D 2783	3500	3600	–	4000	3500	4000	3500	4000
Početak svarivanja, N ASTM D 2783	1100	1500	–	1500	1500	1300	1400	1200
Srednji dijametar istrošenja, mm, ASTM D 4172	0.33	0.33	0.40	0.49	0.49	0.50	0.36	0.44

➢svježi uzorak maziva = fresh lubicant sample

Sample, AGE	Kin. viscosity at	Sulphur content	Dynamic viscosity at
Sampling date	Viscosity change at	Iron content	Welding point
Kin. viscosity at	Viscosity index	Lead content	Welding start
Viscosity change at	Copper corrosion	Acid number	Average wear scar

3. PRAĆENJE TROŠENJA REDUKTORA FEROGRAFSKOM ANALIZOM

Paralelno s ispitivanjem svojstava ulja tijekom eksploatacije u laboratoriju za tribologiju Fakulteta strojarstva i brodogradnje u Zagrebu provedena je ferografska analiza uzoraka ulja iz reduktora tramvaja.

3.1. Ferografija

Ferografija je metoda kojom se izdvajaju čestice trošenja iz uzorka ulja za podmazivanje, te slažu prema veličini na prozirni supstrat za proučavanje ili u vrlo glatku cijev za procjenu [2]. Prvi put je opisana 1972. godine [3] kao metoda za izdvajanje i proučavanje čestica materijala otkinutih s radnih površina dijelova tribosustava kao rezultat djelovanja procesa trošenja. Čestice trošenja treba najprije izdvojiti iz medija kojim su nošene, a to je najčešće ulje za podmazivanje, ispušni plinovi dizelovog motora, rashladni mediji kod obradbe odvajanjem čestica, mlaz mlaznog motora i sl. To odvajanje čestica se provodi putem magnetskog privlačenja odgovarajućim permanentnim magnetima. Ferografska metoda se potvrdila kao uspješna tehnika za nadgledanje stanja zatvorenih sustava (motora, reduktora i sl.).

3.2. Oprema za ispitivanje

Sva potrebna ispitivanja provedena su na uređajima koji se nalaze u laboratoriju za tribologiju Zavoda za materijale Fakulteta strojarstva i brodogradnje u Zagrebu. Korišteni uređaji su:

- ferograf s direktnim učitanjem - **PMA 90 S**
- uređaj za mjerenje ukupnog sadržaja zagađujućih tvari u ulju-**TCM-U**

Slika 1. Ferograf PMA 90 S
Figure 1: Ferrograph PMA 90 S

Slika 2. Mjerni uređaj TCM-U
Figure 2: TCM-U measurement device

4. REZULTATI ISPITIVANJA

Zbog kratkoće ovog rada dani su rezultati samo za jedan reduktor tramvaja. U tablici 2 dan je prikaz svih rezultata mjerenja slijedećih veličina:

- TCM –sadržaj svih zagađenja
- WPC- koncentracija čestica trošenja

Tablica 2: Rezultati mjerenja
Table 2: Measurement results

Datum uzorkovanja/Sampl. date	Šifra uzorka/Sample code	WPC (ppm)	TCM (%)
28.08.1998.	DOB 198/98	35	0.173
10.12.1998.	DOB 1/99	57	0.218
08.02.1999.	DOB 49/99	68	0.274
16.03.1999.	DOB 102/99	56	0.181
21.04.1999.	DOB 128/99	79	0.37
31.05.1999.	DOB 168/99	97	0.66
23.06.1999.	DOB 180/99	111	0.511

Slika 3: Dijagramski prikaz podataka iz tablice 2
Figure 3: Plotted data from table 2

Na osnovi prikupljenih podataka (WPC i TCM) izrađen je nomogram koji je prikazan na slici 4. Ovaj nomogram ima svrhu za brzo i lako određivanje stanja opreme (reduktora) i ulja, prilikom redovitih analiza ulja ferografskom analizom. Potrebno je napomenuti da je svrha uporabe nomograma dobivanje informacije o stanju opreme i ulja na temelju koje se donosi odluka o potrebitosti daljnjih zahvata.

Nomogram sačinjava 6 polja koje smo označili velikim slovima i to:

A – ulje i reduktor u optimalnom stanju
B – reduktor u dobrom stanju, ulje u zadovoljavajućem
C – preporuča se kontrola reduktora, ulje u zadovoljavajućem stanju
D – reduktor u optimalnom stanju, preporuča se zamjena ulja
E – reduktor u dobrom stanju, preporuča se zamjena ulja
F – preporuča se pregled redukora i zamjena ulja

Slika 4: Nomogram stanja reduktora i ulja.
Figure 4: Gear reduction unit and oil condition nomogram

5. ZAKLJUČAK

Analizirajući postignute rezultate ispitivanja prikupljenih uzoraka ulja i provedene ferografske analize na reduktorima tramvaja tip 901 uz pretpostavku pouzdanosti mjernih uređaja i rezultata mjerenja, može se zaključiti da se ukupno dobivene vrijednosti kreću u granicama koje slijede očekivanu sliku promjene stanja reduktora.

Nomogram prikazan na slici 4 pruža mogućnost brzog određivanja stanja reduktora i ulja koje se nalazi u njemu, te tako olakšava donošenje odluke o potrebitosti zahvata održavanja.

Uspješnost provođenja ferografske analize temelji se na pravilnom i pravodobnom uzimanju uzoraka pa pogreška učinjena u ovom dijelu ispitivanja dovodi u pitanje cijelu metodu. Stoga uzimanju uzoraka treba posvetiti posebnu i najveću pozornost kako bi rezultati ispitivanja i ferografske analize bili što pouzdaniji.

Na kraju se može zaključiti da ferografska analiza može dati pouzdanu sliku stanja reduktora ako se poštuju pravila uzimanja uzoraka i njihova obradba. Sve to omogućilo bi uočavanje pojave prekomjernog trošenja u reduktoru koja prethodi kvaru. Zahvaljujući tome moguće je na vrijeme obaviti zahvat održavanja i time smanjiti troškove koji bi nastali bilo zbog zastoja u radu ili troškova kvara.

CONDITION MONITORING OF TRAM TYPE 901 GEAR REDUCTION UNIT BY OIL ANALYSIS

Abstract

A need for machinery condition monitoring without dismounting the components has initiated the development and use of oil analysis. A possibility of condition monitoring of a tram type 901 gear reduction unit by means of oil analysis is discussed in this paper.

1. INTRODUCTION

The Zagreb Electric Tram - ZET has over the past 5-6 years purchased around a dozen used tram cars in Germany, that bear the mark 901 being around 30 years old. The properties of the trams type 901 are as follows:

Manufacturer: Duwag
Engine power: 2x95 KW
Rotations e.m.: 1,200 min^{-1}
Number of gear reduction units: 4
Vehicle weight: 31.4 t

The manufacturer and the previous owner were determining the lubricant fill intervals and brands. In the desire to pass to the use of locally produced lubricants, a test was performed using the semi-synthetic multigrade oil INA Hipenol GTL HD 75W-90 for the lubrication of gear reduction units.

The testing of oil properties and parameters during exploitation was conducted at the INA-Lubricants' laboratory in Zagreb. The second part of the test, referring to the monitoring of the gear reduction unit wear, was performed at the Laboratory for Tribology of the Faculty of Mechanical Engineering and Naval Construction in Zagreb.

2. THE GEAR REDUCTION UNIT OIL PROPERTIES AND ANALYSIS

INA Hipenol GTL HD 75W-90 is a semi-synthetic multigrade oil for gears of the API GL-5 class. It consists of mineral oil, synthetic component (polyalphaolefins), and various additives. These additives improve lubrication, low temperature, and shear stability properties, while reducing corrosion and wear. During the oil analysis at INA-Lubricants' laboratory, the data collected in the August, 1998-June, 1999 period were monitored. The review of the data monitored, as well as of the values obtained during the tests are given in Table 1.

The testing of physico-chemical, as well as of mechanical properties, provides valuable information on the condition and quality of oil after a given application interval. In this particular test, the last sample was taken after approximately 86,000 km covered.

Viscosity, being one among the most significant lubricant properties, constitutes the measure of inner friction acting as resistance to the change of the lubricant molecules position under the influence of shear stress. It is temperature and pressure dependent. The relation between viscosity and density is called kinematic viscosity (ISO 3104). The change of kinematic viscosity during field test should not exceed 10% in comparison with the fresh lubricant.

The acid number did not change significantly during the field test, showing that the oil's additive content is satisfactory. A slight acid number increase occurs due to the expected oil oxidation (ISO 6618).

The sulphur content (x-ray) is also an important indicator of the lubricant's additive content. Lubricant use leads to sulphur content reduction.

The increase of the mileage covered is accompanied by lead and iron content increase due to the tooth flank wear. However, the volume expressed in ppm is within the limits set for hypoid oils i.e. below 1,500 ppm.

Lubricant samples were subjected also to the mechanical testing of the film load carrying capacity i.e. the testing of limit loads - EP (extreme pressure) properties' testing. The 4-ball machine (ASTM D 2783) contains one rotating and 3 immobile balls of the same material and dimensions distributed in the shape of a tetrahedron. The ball system is located within a holder filled with test oil, which may be subjected to load. The balls are subjected to load until they weld together. The said load, expressed in N (Newtons), is marked as the welding point.

The 4-ball wear machine measures average wear diameter (ASTM D 4172). In this test, the load is standardized, as well as the test's duration (1,200 r/min, 392 N, 75^{0}C, 1h). After the test has been performed, the ball wear scar is measured. The greater the film strength, the greater the load under which the balls become welded, and the smaller the ball wear.

Based on the results presented we may conclude that the semi-synthetic gear oil ensures extended oil fill interval of over 80,000 km covered. The oil is therefore more environmentally tolerable, while the savings are higher.

Good low temperature properties ensure application throughout the year. The field test has shown that INA Hipenol GTL HD 75W-90 may safely be applied in further exploitation of the tram type 901.

3. MONITORING GEAR REDUCTION UNIT WEAR THROUGH FERROGRAPHIC ANALYSIS

Parallely with the oil properties' field testing, a ferrographic analysis of oil samples from the tram gear reduction units has been performed at the Laboratory for Tribology of the Faculty of Mechanical Engineering and Naval Construction in Zagreb.

3.1. Ferrography

Ferrography is the method through which wear particles are isolated from lubricating oil samples and placed according to their size on a transparent substrate for inspection or a very smooth tube for evaluation /2/. It was described for the first time in 1972 /3/ as the method for isolating and inspecting material particles chipped off from the tribological systems' operating surfaces as a result of wear.

The wear particles must first be isolated from the media carrying them, most frequently being lubricating oils, diesel engine exhaust gases, cooling media at working through particle separation, jet engine spurt, and the like. Particle separation is conducted through their magnetic attraction using appropriate permanent magnets. The ferrographic method has proven to be a successful technique for the condition monitoring of closed systems (engines, gear reduction units, and the like).

3.2. Test Equipment

All the necessary tests were performed on devices located at the Laboratory for Tribology of the Institute for Materials at the Faculty of Mechanical Engineering and Naval Construction in Zagreb. The devices used were as follows:

- ferrograph with direct loading - PMA 90 S
- device for measuring total pollutants oil content - TCM-U

4. TEST RESULTS

Due to the size of the paper, we are here bringing the results for only one tram gear reduction unit. Table 2 provides a review of all measurement results for the following values:

- TCM - total content of particles
- WPC - wear particle concentration

Based on the data collected (WPC and TCM), a nomogram has been made, shown in Figure 4. The purpose of the nomogram is to enable speedy and easy determination of the equipment (gear reduction unit) and oil condition during regular oil analyses performed through ferrographic analysis. We should mention that the purpose of the nomogram is in fact to provide information on the condition of equipment and oil based on which decision is made on the possible need for further interventions.

The nomogram consists of 6 fields that we have marked by capital letters, as follows:

A - oil and gear reduction unit are in optimal condition

B - gear reduction unit is in a good condition, while oil is in a satisfactory condition

C - gear reduction unit control is recommended, while oil is in a satisfactory condition

D - gear reduction unit is in optimal condition, while oil fill is recommended

E - gear reduction unit is in a good condition, while oil fill is recommended

F - both gear reduction unit inspection and oil fill are recommended

5. CONCLUSION

By analizing the results obtained through the testing of collected oil samples and the ferrographic analysis performed on the tram type 901 gear reduction units, assuming the accuracy of the measurement instruments and results, we may conclude that the total values obtained are within the limits following the expected picture of the gear reduction unit change.

The nomogram shown in Figure 4 offers the possibility for a fast determination of the condition of the gear reduction unit and the oil it contains, thus facilitating the making of decision on the need for maintenance interventions.

Successful performance of ferrographic analysis is based on a proper and timely taking of samples, which means that a mistake made in this part of the test questions the entire method. That is why sample taking deserves a special, even the greatest attention, in order for the test and ferrographic analysis results to be as accurate as possible.

In the end, we may conclude that ferrographic analysis may offer a reliable picture of the gear reduction unit condition, provided that the sample taking rules and their processing are respected. All this should enable the spotting of excessive wear in the gear reduction unit preceding failure. Owing to this, it is possible to undertake maintenance interventions on time, thus reducing costs that would be incurred by standstill or failure.

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