DOI: http://doi.org/10.52651/sam.j.2023.1

SCIENCE & MILITARY

No 1 | Volume 18 | 2023

SCIENCE & MILITARY

The rationale for publishing this periodical by the Armed Forces Academy of General Milan Rastislav Štefánik is to enable the authors to publish their articles focused on particular scientific issues in the following areas: Military science, Natural Sciences, Engineering and Technology. Original scientific articles will be published twice a year.

Published by: Armed Forces Academy of General Milan Rastislav Štefánik, Demänová 393, 031 01 Liptovský Mikuláš, Slovak Republic. IČO 37 910 337. Registered No: EV 2061/08. ISSN 1336-8885 (print). ISSN 2453-7632 (online).
DOI: http://doi.org/10.52651/sam.j.2023.1

Printed by: Armed Forces Academy of General Milan Rastislav Štefánik, Demänová 393, 031 01 Liptovský Mikuláš, Slovak Republic. Published biannually. The subscription rate for one year is 7,30 €.

The Journal Science & Military is included in following multiple databases: EBSCO. ProQuest Central: PQ Science Journals; PQ Military Collection; PQ Computing; PQ Telecommunications; Illustrata; Forthcoming Technology; Research Database (TRD) full text packages.

Address of the editorial office

Armed Forces Academy of General Milan Rastislav Štefánik, Demänová 393, 031 01 Liptovský Mikuláš, Slovak Republic

Phone: +421-960-423065 E-mail: redakcia@aos.sk http://sm.aos.sk/index.php/en/

DOI: https://doi.org/10.52651/sam.j.2023.1

SCIENCE & MILITARY

No 1 | Volume 18 | 2023

Dear Readers,

You are just holding the latest issue of the Science & Military journal. It has been already eighteen years, during which we have managed to publish the only scientific peer-reviewed journal focused on military science in Slovakia. Its new volume brings several changes we decided to introduce in order to make the journal more attractive and accessible to our devoted as well as new readers and authors.

Firstly, we decided to increase the number of editorial board members by recruiting several acknowledged experts with the aim of enhancing the quality of the journal.

The second change, equally important, is that the Science & Military has become an open-access journal, which means that its entire content is accessible to readers or institutions for free. Its readers can read, download, copy, print, link to full texts of papers or use them for any other lawful purposes without asking prior permission from publishers or authors. The authors share their publications under the Creative Commons Attribution-NoDerivatives license (CC BY-ND 4.0). We implemented this change in order to make our journal more accessible to a wider public in Slovakia and abroad.

Dear readers, let me express my appreciation for your interest in reading the Science & Military journal. I sincerely believe that you will remain devoted to it not just as readers but also as authors. We will be pleased to accept scientific papers written by experts in the following fields: Military Science, Natural Sciences, and Technical Sciences. We will be grateful for all suggestions that might improve the quality of the Science & Military journal.

Let me briefly introduce the papers that the latest issue of the journal contains. I believe that they will inspire you and that they will initiate scientific debates.

The first among the peer-reviewed articles in this issue is the article titled ***"Tribotechnical Diagnostics - Motor Oil (MO) Castrol Edge SAE 5W30 Characteristics Control on Škoda Octavia II"*** *written by Martin Haluška and Miroslav Marko. This article deals with tribotechnical diagnostics, more specifically checking the properties of the motor oil used in the Škoda Octavia II during regular use of the vehicle and after a certain number of kilometres. The diagnostic measurements were performed in the diagnostics laboratory of the Department of Mechanical Engineering at the Armed Forces Academy of General Milan Rastislav Štefánik in Liptovský Mikuláš.*

The following article written by Miroslav Matejček and Mikuláš Šostronek titled ***"The Ground Based Air Defence Solutions"*** *deals with air defence, focusing on the use of Ground Based Air Defence (GBAD) systems. This article contains descriptions of modern GBADs solutions as well as the main advantages and disadvantages of their composition.*

Among the articles in this issue, you can find the paper written by Peter Droppa, Pavol Lukášik, Radovan Stephany and Vladimír Kadlub titled ***„Current Status of the Quality of Oil Fillings in the Technology of the Armed Forces of the Slovak Republic".*** *The article provides not only information about the most fragile parameters of motor oils (AW Additive, TBN, kinematic viscosity) and their causes, but also a statistical overview of the current condition of motor oils on military equipment in the Armed Forces of the Slovak Republic for the year 2022.*

Another paper titled ***„Evaluation of Engine Oil Degradation (MO) Shell Helix HX-8 SAE 5W-30 ON BMW 330D XDRIVE"*** *was written by Miroslav Marko and Jindřich Stehlík. This paper deals with the description of the used technology and the monitored degradation parameters of engine oils. In the practical part, the authors performed tribodiagnostic measurements of oil level during downtime of the BMW 330d Xdrive in order to determine the current quality status of engine oil and the degree of its degradation.*

The authors Jozef Bača and Ivan Pemčák wrote the article titled ***"Measurement of Crosshair Shift on Magnification Change in Field-Conditions"*** *This article presents the issue of crosshair shift with the change of magnification. The article deals with crosshair shift with change of magnification on VIS camera. It shows possible ways of crosshair shift measurement. The theoretical solution to the problem is demonstrated through experimental measurement.*

The series of articles is closed with the paper titled ***„Relevant Tasks for UAV Protection Systems in Relation to the Aerial Scenario of Nuclear Facilities"*** *written by Zoltán Bebesi and Zsolt Jurás. The goal of this paper is to present the risks that Unmanned Aerial Vehicles (also called Drones) pose for nuclear facilities. The paper includes a technological overview of the UAVs, their use-cases and a discussion of the security risks they represent.*

In conclusion, I would like to express my gratitude to the authors for their quality papers, without which our journal could not exist. My big thanks also go to the reviewers, who help improve the quality of the journal through their expertise and constructive feedback.

Enjoy your reading!

Brig. Gen. (ret.) Assoc. Prof. Eng. Boris ĎURKECH, CSc.
Chairman of the Editorial Board

Reviewers

Assoc. Prof. Dipl. Eng. Marián **BABJAK**, PhD.
Armed Forces Academy of General Milan Rastislav Štefánik, Liptovský Mikuláš, SK

Dipl. Eng. Ján **BLATA**, PhD.
VSB - Technical University of Ostrava, CZ

Prof. Dipl. Eng. Štefan **ČORŇÁK**, Dr.
University of Defence, Brno, CZ

Col. Assoc. Prof. Dipl. Eng. Laurian **GHERMAN**, PhD.
„Henri Coanda“ Air Force Academy Brasov, RO

Assoc. Prof. Dipl. Eng. František **HELEBRANT**, CSc.
VSB - Technical University of Ostrava, CZ

Assoc. Prof. Dipl. Eng. Miroslav **KRÁTKÝ**, Ph.D.
University of Defence, Brno, CZ

prof. Dipl. Eng. Daniela **MARASOVÁ**, CSc.
Technical University of Košice, SK

Col. Gšt. Assoc. Prof. Dipl. Eng. Jan **MAZAL**, Ph.D.
University of Defence, Brno, CZ

Dr. h. c. Prof. Dipl. Eng. Jiří **STODOLA**, DrSc.
University of Defence, Brno, CZ

DOI: https://doi.org/10.52651/sam.a.2023.1.5-12

TRIBOTECHNICAL DIAGNOSTICS – MOTOR OIL (MO) CASTROL EDGE SAE 5W30 CHARACTERISTICS CONTROL ON ŠKODA OCTAVIA II

Martin HALUŠKA, Miroslav MARKO

Abstract: This work deals with tribotechnical diagnostics, more specifically checking the properties of the motor oil used in the Škoda Octavia II during regular use of the vehicle and after a certain number of kilometers. The work consists of a brief theoretical basis of measuring instruments, their operation as well as the theoretical basis of the measured liquid for the very beginning of the measurement. The practical part of this work will consist of measuring the properties of oil and monitoring its gradual degradation with the help of individual devices. Diagnostic measurements were performed in the diagnostics laboratory of the Department of Mechanical Engineering at the Armed Forces Academy of General Milan Rastislav Štefánik (hereinafter „AOS") in Liptovský Mikuláš.

Keywords: Motor oil; ACEA; API; SAE; VW 501 01; 505 00504.00; 507.00/MB-Approval 229.31/229.5; Kinematic viscosity.

1 INTRODUCTION

The measurement of motor oil properties was performed on a škoda octavia II vehicle. this vehicle is regularly used with a range of approximately 301,000 kilometers. it is a 1.6 liter engine (cayc) 77kw TDI [5-6]with direct injection common rail system. For this reason, the vehicle is used in the vast majority of cases for long-distance transport, mainly on the route Liptovský Mikuláš - Lučenec (153 km), Lučenec - Banská Bystrica - Lučenec (140 km), Lučenec - Zvolen (110 km). The motor oil in this vehicle is changed regularly at the intervals recommended by the manufacturer (castrol), i. interval 12,000 km or 2 years. [10] Approximately 11,000 km have been driven to the vehicle's current oil level, and at the time of writing, the original oil level has been agreed to be replaced along with further vehicle Maintenance. Measurements were performed at the department of mechanical engineering in the laboratory of tribodiagnostics AOS, using 3 measuring instruments. To measure the kinematic properties of Spectrovisc - Q3050, which will be provided in more detail in a separate chapter in this work. The Fluidscan Q1000 instrument was used to measure the oil content properties and the Ferrocheck 2000 series instrument was used to measure the ferrous particles contained in the oil. [4,5,11] Measurements were performed on these devices in accordance with the rules and safety principles associated with working on these devices. [1-3]

2 MEANS OF MEASUREMENT MO-CASTROL EDGE 5W-30 LL TITANIUM FST IN THE LABORATORY OF TRIBODIAGNOSTICS AOS

The measurements were carried out in the laboratory of tribodiagnostics at the Armed Forces Academy of General Milan Rastislav Štefánik (AOS) and at the workplace of the Department of Mechanical Engineering – workshop where the samples were taken. The laboratory is equipped with various means suitable for performing measurements. The instruments used in this work includes SpectroVisc Q3050, FluidScan Q1000 and SpectroCube, these instruments will be closer examined in later chapters of this work.

Fig. 1 Tribodiagnostics Laboratory
Source: author.

SpectroVisc Q3050 model (fig.1 extends from 1 [cSt] to 680 [cSt] at 40°C; the functionality is the result of a new polished cell that provides the range and performance enhancements. The unit can calculate 100°C viscosity values with the input of the vi index. [14] The Fluidscan Q1000 series is infrared motor oil analyzer that provides a direct quantitative measurement of a lubricant's condition. The FluidScan is compliant with ASTM D7889 "Standard test method for field determination of in-service fluid properties using infrared spectroscopy. [15]

3 MOTOR OIL CASTROL EDGE 5W-30 LL TITANIUM FST

Castrol Edge LL Titanium motor oil is a synthetic motor oil with Titanium technology specially developed to meet the more demanding tests of motor oils from leading car manufacturers. It provides protection by the current complex emission system throughout the extended exchange interval. The ACEA has included the C3 (catalyst & GPF / DPF compatible motor oils for gasoline & diesel engines) viscosity group SAE 5W-30, which means that it is suitable for use on high-speed direct-injection petrol and diesel engines (Common Rail) of passenger cars and vans.

The advantages of this oil are:

- Maximize short-term and long-term engine performance.
- Reducting deposits and maximizing engine response.
- Maintaining maximum performance even under high loads and pressures.
- Improves engine efficiency according to independent tests.
- Provides exceptional protection in a variety of driving styles and temperatures.

Table 1 Manufacturer specified oil Castrol EDGE 5W-30 LL Titanium FST

Name	Method	Units	Castrol EDGE 5W-30
Density @ 15C, Relative	ASTM D4052	g/ml	0.851
Viscosity, Kinematic 100C	ASTM D445	mm²/s	12.0
Viscosity, CCS -30C	ASTM D5293	mPa.s (cP)	5800
Viscosity, Kinematic 40C	ASTM D445	mm²/s	70
Viscosity Index	ASTM D2270	None	169
Pour Point	ASTM D97	°C	-42
Flash Point, PMCC	ASTM D93	°C	202
Ash, Sulphated	ASTM D874	% wt	0.64

Source: author.

4 SPECTROVISC Q3000 SERIES MEASURING STATION

The SpectroVisc Q3000 Series viscometer is a portable device used to measure the kinematic viscosity of oils and other lubricating fluids. The Q3000 series viscometer is created in two versions, Q3000 and Q3050, which was used in the measurements in this work.

Package contents:

- Viscometer;
- Disposable pipettes;
- Disposable, non-abrasive cleaning protectors;
- Bottle of verification standard fluid for calibration and correction;
- Power cord (varies by region of purchase);
- AC adapter.

Sampling - we collect samples using a pipette. Both types, whether disposable or point-exchanged, are used in a similar way. After taking the sample, we place the pipette in the pouring tunnel and apply it at a suitable speed. [7, 8, 14]

5 MEASUREMENT OF SAMPLES

In the practical part of this work, we performed measurements on the SpectroVisc Q3000 instrument, examining changes in mileage and comparing changes between the test sample, which was taken from the measured object Škoda Octavia II 1.6 TDi (Facelift).

5.1 Criteria for Applicability and Evaluation of Motor Oil Parameters

- Appearance (comparison of clarity, gloss, odor and turbidity). Determine whether or not it satisfies according to its own methodology (practical and professional experience). Do not allow turbidity - matt surface with light reflection.
- Kinematic viscosity (primary and basic property for the usability of motor oil in the vehicle engine) motor oil may only be operated within a viscosity range of ± 20 % of the reference sample and diesel engine manufacturer's data.
- Viscosity index Temperature dependence of oil fluidity. The degree of viscosity index determines the guarantee of sufficient lubrication under operating conditions.
- Sulphation products. Sulphates are products containing salts of sulfuric acid, sulphates. They cause the breakdown of the base oil components and additives in the motor oil. It is a negative parameter in motor oil.
- The glycol content (Ethylene Glycol-$C_2H_6O_2$ or Propylene Glycol-$C_3H_8O_2$) is not permitted in the motor oil. Glycol causes the additive to separate from the base oil in the motor oil and to cause overall viscosity and concentration of the motor oil.
- TBN - alkalinity number (parameter for the dispersion of acid sludge, its condition expresses the life of the oil). Do not allow the operation of motor oil when the TBN value is reduced by more than 50 % of the value of the reference sample and the motor oil manufacturer's data.

- Antioxidant content (durability and foaming, ...). Do not allow the operation of motor oil when the value of the antioxidant content is reduced by more than 50 % of the value of the reference sample and the motor oil manufacturer's data.
- Total motor oil additive. The motor oil must be usable in the working parts of the engine in all conditions. Adding Additives to the base oil improves the performance of motor oils, slows down their aging and degradation. Do not allow the operation of motor oil when the value of the total additive is reduced by more than 50 %.
- Water content affects the initiation of chemical reactions. The limit value of water content in motor oil is 0.5 % w / w / 5,000 ppm (concentrations of 0.1 - 0.3 % w / w / 1,000-3,000 ppm are already a risk factor).

5.2 Sampling from the Measured Object (Škoda Octavia II)

It is important that the engine is warm enough before sampling the engine of the vehicle. The main reason is the change in the viscosity of the oil when the oil becomes thinner due to the temperature, which ensures easier oil removal.

We performed the collection using:

- Compressor / syringe;
- Hose of suitable diameter;
- Technical gasoline;
- Container for storing the collected oil sample.

Fig. 2 Sampling devices
Source: author.

Fig. 3 Engine of Škoda Octavia
Source: author.

Fig. 4 Sampling MO – Castrol Edge 5W -30
Source: author.

Fig. 5 Sampling with syringe
Source: author.

5.3 Measurement of Reference and Test Oil Sample on Spectrovisc Q3000 Instrument

After starting the instrument and its initial cleaning before the start of the measurement, we prepared a suitable amount of cleaning agent (non-abrasive cloth), a pipette and a reference / test sample. The first measurements were performed on a reference oil sample. At the beginning of the measurement, we needed to find out the viscosity index given by the manufacturer, which in our case was 169 [index].

Subsequently, we selected the required amount of oil from the reference sample using a pipette and applied the volume of pipette to the instrument on the pad. [10,14,15]

Fig. 6 Pipetting the sample
Source: author.

After analyzing the oil sample, we wrote down the values in a table (table 2,3). We performed this measurement three times. After performing the measurement on the reference sample, we performed the same measurements in the same number on the test sample of motor oil.

5.4 Evaluation of Motor Oil (MO) Properties of Sample NO.1-NO.3; 1. MEASUREMENT SERIES

SAE 5W-30 [**Castrol Edge LL Titanium FST 5W-30**], in Škoda Octavia, samples taken - 01.03.2022. [8] The results of individual measurements were recorded in Table 2.

Table 2 Evaluation of vehicle sample measurements in the Tribodiagnostic Laboratory AOS

Č.	Property	Unit	Reference sample - Castrol Edge 5W-30	Test sample - Castrol Edge 5W-30 Measurement No.1	Test sample - Castrol Edge 5W-30 Measurement No.2	Test sample - Castrol Edge 5W-30 Measurement no.3	Test sample - Castrol Edge 5W-30 Measurement average 1-3
1	Kinematic viscosity at 40 ° C	[cSt]	+20% 78,32 65,27 -20% 52,21	73,9 +8,63/13,22%	78,4 +13,13/20,12%	74,2 +8,93/13,68%	75,5 +10,23/15,67%
2	Kinematic viscosity 100 ° C	[cSt]	+20% 13,72 11,43 -20% 9,14	12,6 +1,17/10,24%	13,2 +1,77/15,49%	12,7 +1,27/11,11%	12,83 +1,4/12,25%
3	Viscosity index	-	169	-	-	-	

Source: author.

5.4.1 Reference sample no. R AOS showed the status of:

March 2022 / measured 03. 03. 2022:

Kinematic viscosity at 40 ° C: COMPLIES [65.27 cSt. ± 20 %].

Kinematic viscosity at 100 ° C: COMPLIES [11.43 cSt. ± 20 %].

Water contamination 0 [ppm], additive 101 %, glycol content 0 %, degradation by sulphation 25,01 [abs / 0,1], probably by atmospheric O2, oxidation 16,15 [abs / 01], measured alkalinity number TBN 4, 1 [mg KOH / g].

5.4.2 Used sample No. 1 MO Castrol Edge Titanium FST 5W-30

- COMPLIANT kinematic viscosity / 40 ° C: 75.5 [cSt], increase in MO viscosity is 10.23 [cSt] - increase in Mo viscosity by 15.67 [%]. The allowable tolerance is derived from a reference sample of 65.27 [cSt], ± 20 % (+ 20 % = 78.32; - 20 % = 52.21cSt), cf. Table no. 2.
- COMPLIANT kinematic viscosity / 100 %: 12.83 [cSt], increase in viscosity Mo is 1.40 [cSt] - increase in viscosity MO by +12.25 [%]. The allowable tolerance is derived from a reference sample of 11.43 [cSt], ± 20 % (+ 20 % = 13.72 [cSt]; -20 % = 9.14 [cSt]), cf. Table no. 2.
- Other parameters of the monitored properties, measured in the Laboratory of Tribodiagnostics AOS, are within the tolerances of the usability of the MoD, valid for the used MoD No. 1 (see table). [9]
- **Alkalinity number** [mg KOH / g] - **0,0** - if the value decreases by more than 50% of the value of the reference sample, MO operation is not permitted – **COMPLIES.**
- **Soot** [% w / t] - **0,61** - increase compared to the reference sample by 0,61 [% w / t], maximum value is up to 2 % w / t – **COMPLIES.**
- **Oxidation** [abs / 0,1] - **23,43**- increase compared to the reference sample by 4,83 abs / 0,1 - do not allow MO operation if the value of antioxidant content decreases by more than 50 % of the value of the reference sample – **COMPLIES**
- **Nitration - Nitritation** [abs / cm] - **62.22** - increase compared to the reference sample by 53.47 abs / cm.
- **Sulfation** [abs / 01] - **26,33** - process in MO causing decomposition of base oil components and additive by starter water is present in MO in proportion to the presence of water – **COMPLIES**.
- **Water content** [ppm] - **183** - reference sample was not contaminated with water - monitored and limit values of water content in MO are 0.1-0.3 % w / w / 1000-3000ppm – **SUITABLE.**
- **Glycols** [%] **-0,0-** value the same as in the reference sample / the presence of glycols in the MO is not allowed – **COMPLIES.**
- **Addivation** [%] - **75.33** - decrease compared to the reference sample by 26 [%] - do not allow MO
- operation if the value of the total additive is reduced by more than 50 % - **SUITABLE.**

Table 3 Evaluation of vehicle sample measurements in the Tribodiagnostic Laboratory

Č.	Property	Unit	Castrol Edge reference sample 5W-30	Castrol Edge test sample 5W-30 Measurement No.1	Castrol Edge test sample 5W-30 Measurement No.2	Castrol Edge test sample 5W-30 Measurement No.3	Castrol Edge test sample 5W-30 Measurement average
1.	Additives	[%]	101	79	75	72	75,3
2.	Glycols	[%]	0,0	0,0	0,0	0,0	0,0
3.	Nitritation	[abs/cm]	6,2	20,7	20,8	20,7	20,73
4.	Oxidation	[abs/0,1]	18,6	24,9	24,7	24,8	24,8
5.	Soot	[% wt]	0,0	0,61	0,61	0,61	0,61
6.	Sulfation	[abs/0,1]	25,0	26,4	26,3	26,3	26,33
7.	TBN	[mg KOH]	4,1	0,0	0,0	0,0	0,0
8.	Water content	[ppm]	0	160	194	196	183

Source: author.

6 TRIBODIAGNOSTIC CONTROL OF PROPERTIES ON SPECTRO CUBE, MO CASTROL EDGE LL TITANIUM FST; SAE 5W-30, VZ. NO.1

SPECTRO CUBE ED XRF-X-ray analyzer, measuring column with MO Castrol Edge SAE 5W-30 sample. The analyzer ensures reliable, easy and accurate analysis. It determines with very high accuracy what elements are in a given sample and in what concentration. When measuring the contained elements, those elements were detected which were contained in the lubricant during friction processes and wear of the contact surfaces of the combustion chamber. The main elements of the above wear are: ^{13}Aluminium, ^{14}Silicon, ^{15}Phosphorus, ^{16}Sulfur, ^{20}Calcium, ^{29}Copper, ^{30}Zinc, ^{26}Iron ... [4]

6.1 Measured parameters of the REFERENCE SAMPLE Castrol Edge SAE 5W-30

After evaluating the total content of elements in the reference oil, it is possible by using the table of elements to select those that interest us. The reference sample does not have any trace of ferroparticles since they are a product of abrasive effect of the friction parts in contact with each other such as piston and cylinder contact in the engine of vehicle.

So for the reference oil the main elements that interest us are occurrences of the elements used in production of the base motor oil and additives. Those elemts are Phosphorus, Sulfur, Calcium Zinc, Titanium and other trace elements.

Occurrence : ^{26}Fe, ^{20}Ca, ^{28}Ni, ^{24}Cr, ^{30}Zn, ^{42}Mo, ^{47}Ag, ^{48}Cd, ^{81}Ti
Trace occurrence :^{34} Se, ^{33}As,^{50} Sn, ^{51}Sb, ^{24}Cr, ^{25}

27	Co	Kobalt	< 1,0	-	ppm	6	CH₂	Oil	-	-	ppm
28	Ni	Nikel	< 0,3	-	ppm	12	Mg	Horčík	< 6,5	-	ppm
29	Cu	Meď	< 0,2	-	ppm	13	Al	Hliník	< 1,5	-	ppm
30	Zn	Zinok	860,0	0,8	ppm	14	Si	Kremík	1,3	0,1	ppm
33	As	Arzén	0,07	0,03	ppm	15	P	Fosfor	917,6	1,3	ppm
34	Se	Selén	< 0,1	-	ppm	16	S	Síra	2501	1	ppm
35	Br	Bróm	0,40	0,02	ppm	17	Cl	Chlór	8,2	0,1	ppm
38	Sr	Stroncium	0,7	0,1	ppm	19	K	Draslík	2,6	0,3	ppm
40	Zr	Zirkónium	< 0,2	-	ppm	20	Ca	Vápnik	1811	2	ppm
42	Mo	Molybdén	1,2	0,1	ppm	22	Ti	Titán	27,8	0,2	ppm
47	Ag	Striebro	< 0,4	-	ppm	23	V	Vanád	< 0,0	-	ppm
48	Cd	Kadmium	< 0,6	-	ppm	24	Cr	Chróm	< 0,3	-	ppm
50	Sn	Cín	< 0,2	-	ppm	25	Mn	Mangán	< 0,4	-	ppm
51	Sb	Antimón	< 0,2	-	ppm	26	Fe	Železo	< 0,4	-	ppm
53	I	Jód	4,8	1,8	ppm	27	Co	Kobalt	< 1,0	-	ppm
56	Ba	Bárium	< 0,3	-	ppm	28	Ni	Nikel	< 0,3	-	ppm
74	W	Wolfrám	< 0,1	-	ppm	29	Cu	Meď	< 0,2	-	ppm
80	Hg	Ortuť	< 0,2	-	ppm	30	Zn	Zinok	860,0	0,8	ppm
81	Tl	Tálium	< 0,1	-	ppm	33	As	Arzén	0,07	0,03	ppm
82	Pb	Olovo	< 0,3	-	ppm	34	Se	Selén	< 0,1	-	ppm
83	Bi	Bizmut	< 0,3	-	ppm	35	Br	Bróm	0,40	0,02	ppm

Fig.7 Measured values of elements on the SPECTROCUBE device
Source: author.

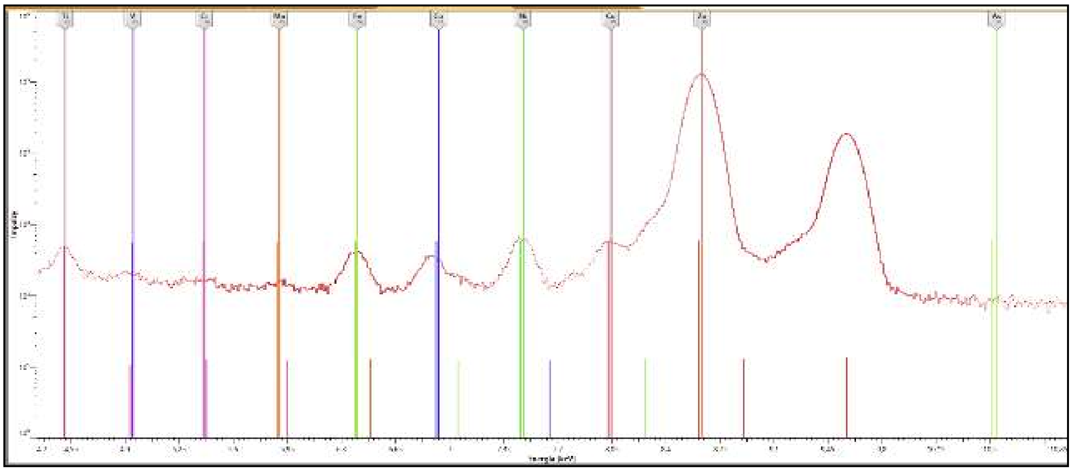


Fig. 8 Measured values of elements on the SPECTROCUBE device
Source: author.

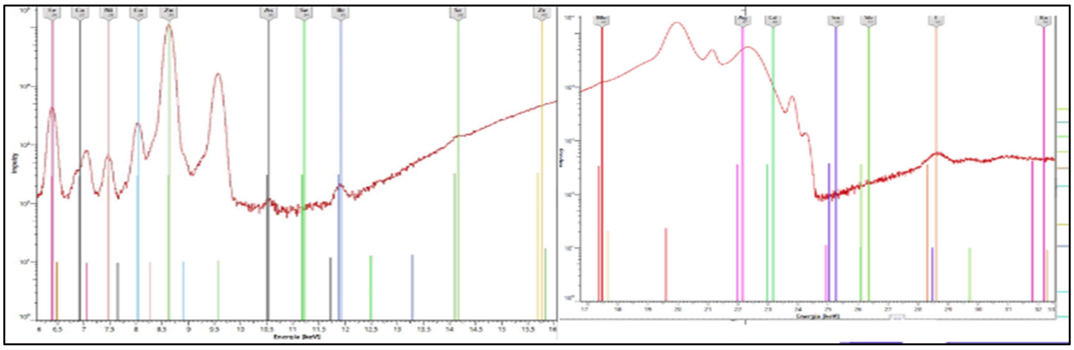


Fig. 9 Graphic course of monitored elements
Source: author.

6.2 Measured parameters of USED SAMPLE Castrol Edge SAE 5W-30

Change of monitored parameters : ^{13}Al –increase; ^{14}Si - increase; ^{17}Cl - increase; ^{29}Cu - increase; ^{42}Mo - increase;
Occurrence without change : ^{26}Fe, ^{20}Ca, ^{28}Ni, ^{24}Cr, ^{30}Zn, ^{42}Mo, ^{47}Ag, ^{48}Cd, ^{81}Ti

12	Mg	Horčík	< 6,3	-	ppm
13	Al	Hliník	47,0	0,7	ppm
14	Si	Kremík	26,0	0,5	ppm
15	P	Fosfor	793,7	1,2	ppm
16	S	Síra	2086	1	ppm
17	Cl	Chlór	13,4	0,1	ppm
19	K	Draslík	13,3	0,4	ppm
20	Ca	Vápnik	1733	2	ppm
22	Ti	Titán	22,6	0,2	ppm
23	V	Vanád	< 0,0	-	ppm
24	Cr	Chróm	2,8	0,2	ppm
25	Mn	Mangán	< 0,1	-	ppm
26	Fe	Železo	79,7	0,5	ppm
27	Co	Kobalt	< 1,0	-	ppm
28	Ni	Nikel	< 0,3	-	ppm
29	Cu	Meď	17,2	0,2	ppm
30	Zn	Zinok	746,8	0,8	ppm
33	As	Arzén	0,08	0,03	ppm
34	Se	Selén	< 0,1	-	ppm
35	Br	Bróm	0,34	0,02	ppm

27	Co	Kobalt	< 1,0	-	ppm
28	Ni	Nikel	< 0,3	-	ppm
29	Cu	Meď	17,2	0,2	ppm
30	Zn	Zinok	746,8	0,8	ppm
33	As	Arzén	0,08	0,03	ppm
34	Se	Selén	< 0,1	-	ppm
35	Br	Bróm	0,34	0,02	ppm
38	Sr	Stroncium	0,62	0,05	ppm
40	Zr	Zirkónium	< 0,2	-	ppm
42	Mo	Molybdén	2,6	0,1	ppm
47	Ag	Striebro	< 0,4	-	ppm
48	Cd	Kadmium	< 0,5	-	ppm
50	Sn	Cín	< 0,2	-	ppm
51	Sb	Antimón	< 1,6	-	ppm
53	I	Jód	8,6	1,8	ppm
56	Ba	Bárium	< 0,3	-	ppm
74	W	Wolfrám	< 0,1	-	ppm
80	Hg	Ortuť	< 0,2	-	ppm
81	Tl	Tálium	< 0,2	-	ppm
82	Pb	Olovo	0,25	0,05	ppm
83	Bi	Bizmut	< 0,3	-	ppm

Fig. 10 Graphic course of monitored elements
Source: author.

In the used sample, the main monitored elements, are those that figure as the undesirable effect of mutual contact of friction surfaces or foreign substances. They are occurring in the system due to leak or age of the vehicle which is causing that vehicle's systems are not sealed properly. Other reasons for vehicle leakage could be weather conditions as well as the environment in which the vehicle is operated. In the partial conclusion of the observation of used sample of motor oil, we found that there was an increase elements that may appear as particles contained as a result of abrasive effect due to movement of surfaces of the engine. Elements found in the used sample were mainly aluminium, chrome, copper, ferrum and molybdenum. Occurrence of an element such as silicium could be caused by the already mentioned leakage of the lubrication system, into which gets silicon from the environment such as dust, that occurs during vehicle operation in the summer season. Depletion of elements that are characteristic of base oil components as well as additives like phosphorus, sulphur, calcium or Titanium could decrease due to operation of the vehicle in the long term interval that is causing motor oil to slowly decrease by negative effects like the presence of water, that accelerates the sulfation and nitritation, process of oxidation or gradual decrease of additivity due to age etc.

7 CONCLUSION

Measured values in the laboratory of tribodiagnostics from 1.3.2022 MO Castrol Edge LL Titanium FST SAE 5W-30 taken at the extended workplace of the Department of Mechanical Engineering from the measured object Škoda octavia II despite the number of kilometers driven (13,000 km) SUITABLE.

Tendency of increase or decrease of properties with respect to time as well as regular use of a motor vehicle. The overall sample No. 1 MO Castrol Edge LL Titanium FST SAE 5W-30 as well as the measured vehicle should be considered ADEQUATE and from the overall point of view, given the above measurements, we can say that the measured object is in GOOD CONDITION.

From the point of view of the recommendation for the future, it would be appropriate (and it will be) to continue to operate the vehicle only on long distances in order to avoid significant degradation of the MoD as well as consequent engine wear.

References

[1] MARKO, M. *Tribotechnical diagnostics.* Projekt VV1 (VV4). 70 s.

[2] MARKO, M. *Checking parameters of motor oils (MO) PETRONAS URANIA FE LS, SAE 5W-30, (O-1178) vo vozidlách IVECO CROSSWAY.* Liptovský Mikuláš: Akadémia ozbrojených síl generála M. R. Štefánika, 2020.

[3] MARKO, M. *Comparation of motor oils (MO) SAE 20W-50, (O-239), API CG4/CF, v T-72 M1*. Liptovský Mikuláš: Akadémia ozbrojených síl generála M. R. Štefánika, 2020. 41 s.

[4] *SPECTROCUBE XRF analyzator Pro.* Príručka. AMETEK, 2019.

[5] *SpectroVisc Q3000 Series.* Používateľská príručka: Spectro Scientific. One Executive Drive. Chelmsford, 2014.

[6] REIF, K. *Diesel Engine Management.* Berlin: Springer Viewerg, 2014. 359 s. ISBN 978-3-658-03981-3.

[7] MOLLENHAUER, K. and TSCHOEKE, H. *Handbook of Diesel Engines*. Berlin: Springer-Verlag, 2010. 621 s. e-ISBN 978-3-540-89083-6.

[8] *SlovnaftprimeDiesel.* (Online). Available at: https://slovnaft.sk/images/slovnaft/pdf/o_nas/trvalo_udrzatelny_rozvoj/zdravie_a_bezpecnost/reach/karty_bezpecnostnych_udajov/Xylen_verz.11.0_SK.pdf.

[9] MARKO, M. *Bulletin č. 4 storage, transportation and properties of fuels*. Trenčín.

[10] Author's sources: fotodokumentácia voj.1.st. Martin Haluška.

[11] *FluidScan 1000 User's Guide: Spectro Scientific*. One Executive Drive. Chelmsford, 2014.

[12] ILERI, E. *Experimental study of 2-ethylhexyl nitrate effects on engine performance and exhaust emissions of a diesel engine fueled with n-butanol or 1- pentanol diesel–sunflower oil blends.* Energy Conversion and Management. 2016 (volume 118). ISSN 0196-8904. (Online). Available at: https://doi.org/10.1016/j.enconman.2016.04.015

[13] MAGDI, K. and JAASKELAINEN, H. *Diesel fuel injection 2020.* (Online). Available at: https://dieselnet.com/tech/diesel_fi.php

[14] *SpectroVisc Q3050: portable kinematic viscometer.* (Online). 2013. Available at: https://www.spectrosci.com/news/news/2021/08/19/13/46/spectro-scientific-introduces-spectrovisc-q3050-portable-kinematic-viscometer-featuring-extended-measurement-range.

[15] *FluidScan 1000 Series: Handheld infrared oil analyzer.* (Online). Available at: https://www.spectrosci.com/product/fluidscan-1000-series---handheld-infrared-oil-analyzer [cit. 2023-05-19].

Bc. Martin **HALUŠKA**
Armed Forces Academy of General M. R. Štefánik
Department of Mechanical Engineering
Demänová 393
031 01 Liptovský Mikuláš
Slovak Republic
E-mail: martin.haluska@aos.sk

Dipl. Eng. Miroslav **MARKO**, PhD.
Armed Forces Academy of General M. R. Štefánik
Department of Mechanical Engineering
Demänová 393
031 01 Liptovský Mikuláš
Slovak Republic
E-mail: mikro_makro@pobox.sk
Miroslav.marko@aos.sk

Martin HALUŠKA was born on April 7,1999 in Lučenec, Slovakia. Between 2005 to 2014 received basic education at a school in Lučenec. In the years 2014 to 2018 received secondary education at the Grammar School in Lučenec. In the years 2018 to 2021, he received a bachelors degree from the Armed Forces Academy of General M. R. Štefánik in Liptovský Mikuláš.

Miroslav MARKO was born on September 25, 1954 in Myjava, Slovakia. Between 1961 to 1970, he received his basic education in Stará Turá. Between 1970 to 1974, he received secondary education at the Grammar School in Nové Mesto and Váhom. From 1974 to 1978 VVŠ PV, university education in the field of „Operation and repair of the tank and automotive technology". From 1991 to 1993 VŠPe, additional pedagogical study, Faculty of Education Nitra. In 1997 House of Technology ZSVTS, Slovak Society for Tribology and Tribotechnics, postgraduate one-year study in Tribotechnik, Bratislava. From 1999 to 2004 Military Academy doctoral study – external. 91-06-9 Armament and ground forces technology, Liptovský Mikuláš in the field 20. May 2011 Tribotechnik II Certification – This is to certify that is qualified for activities in technical diagnostics.

DOI: https://doi.org/10.52651/sam.a.2023.1.13-20

CURRENT STATUS OF THE QUALITY OF OIL FILLINGS IN THE HEAVY TECHNOLOGY OF THE ARMED FORCES OF THE SLOVAK REPUBLIC

Peter DROPPA, Pavol LUKÁŠIK, Radovan STEPHANY, Vladimír KADLUB

Abstract: Monitoring of oil fillings in internal combustion engines was focused on heavy military equipment (Tatra 815, Praga PV3S, BVP, BRDM) on which operation was stopped due to a malfunction. The equipment, which was handed over to the 3rd level military service, was also subjected to an oil sample. The tribodiagnostic analysis was focused on the basic chemical and physical properties of engine oil using the most modern devices (optical and FTIR analysys). The article provides not only information about the most fragile parameters of motor oils (AW Additive, TBN, kinematic viscosity) and their cause, but also a statistical overview of the current condition of motor oils on military equipment in the Armed Forces of the Slovak Republic for the year 2022.

Keywords: Motor oil; Motor oil qualitative parameters; AW aditives; TBN; Kinematic viscosity; Engine oil degradation.

1 INTRODUCTION

The combat capability of military vehicle and tank equipment is very closely related to the reliability of the vehicle's drive motor unit. The condition of the engine oil with reliable lubrication is the primary factor for guaranteed operation and long life of the engine.

In the conditions of the Slovak Armed Forces, a planned - predictive system of maintenance of military equipment is introduced, where the replacement of oil fillings is preferably included. This system guarantees reliable operation of the technology, but with a strict tribodiagnostic view, deficiencies may also occur. Among the most common problems are occasional abnormal degradation indicators of oil fillings. Tribodiagnostic monitoring of oil fillings also revealed interesting results in this case, which provide important information to the operator of military equipment.

2 EXPERIMENT

Monitoring of oil fillings in internal combustion engines was focused on heavy military equipment Tatra 815, Praga PV3S, BVP, BRDM (Fig. 1., Fig. 2., Fig. 3., Fig. 4.) on which operation was stopped due to a malfunction. The equipment, which was handed over to the 3rd level military service, was also subjected to an oil sample. The oil samples were subsequently evaluated in the tribodiagnostics laboratory at the Department of Mechanical Engineering A.O.S. Gen. M.R. Štefánik in L. Mikuláš (Fig. 6.). The tribodiagnostic analysis was focused on the basic chemical and physical properties of engine oil using the most modern devices (optical and FTIR analysis) (Fig. 7.).

The collection and evaluation of oil samples from damaged military equipment at the service station is actually also connected with the spot check of the condition of the oil fillings in heavy military vehicles. These laboratory tests also proved whether the technical failure was caused by the inadequate quality of the engine oil.

Fig. 1 Tatra – 815
Source: authors.

Fig. 2 Praga PV3
Source: authors.

The tribodiagnostic analysis provided an overview of the real condition of motor oils in basic chemical and physical parameters (Table 1.). In the article, increased attention is paid to the most fragile parameters (AW additives, TBN, kinematic viscosity) and all limit values for the given type of oil filling are listed. The achieved laboratory results should be further used in the field of planned and predictive maintenance of technology in practice, or in mathematical predictive models on a theoretical basis.

Fig. 3 BVP-2
Source: authors.

3 RESULTS AND DISCUSSION

13 oil samples from equipment awaiting repair were subjected to tribodiagnostic monitoring. In the case of broken equipment, the cause of the failure was not an inadequate oil filling, but the effect of the operation itself.

Fig. 4 BRDM-2
Source: authors.

The chemical properties of the oil samples indicate the excellent condition of almost all oil fillings, with the exception of 1 x Tatra-815 in the AW additives parameter and marginally 1 x Tatra-815 in the TBN parameter (Tab. 2).

However, the permitted values were approached and exceeded in the area of physical properties of the oil (Tab. 2., Tab. 3., Tab. 4.), i.e. in the parameter of kinematic viscosity for wheeled and tracked.

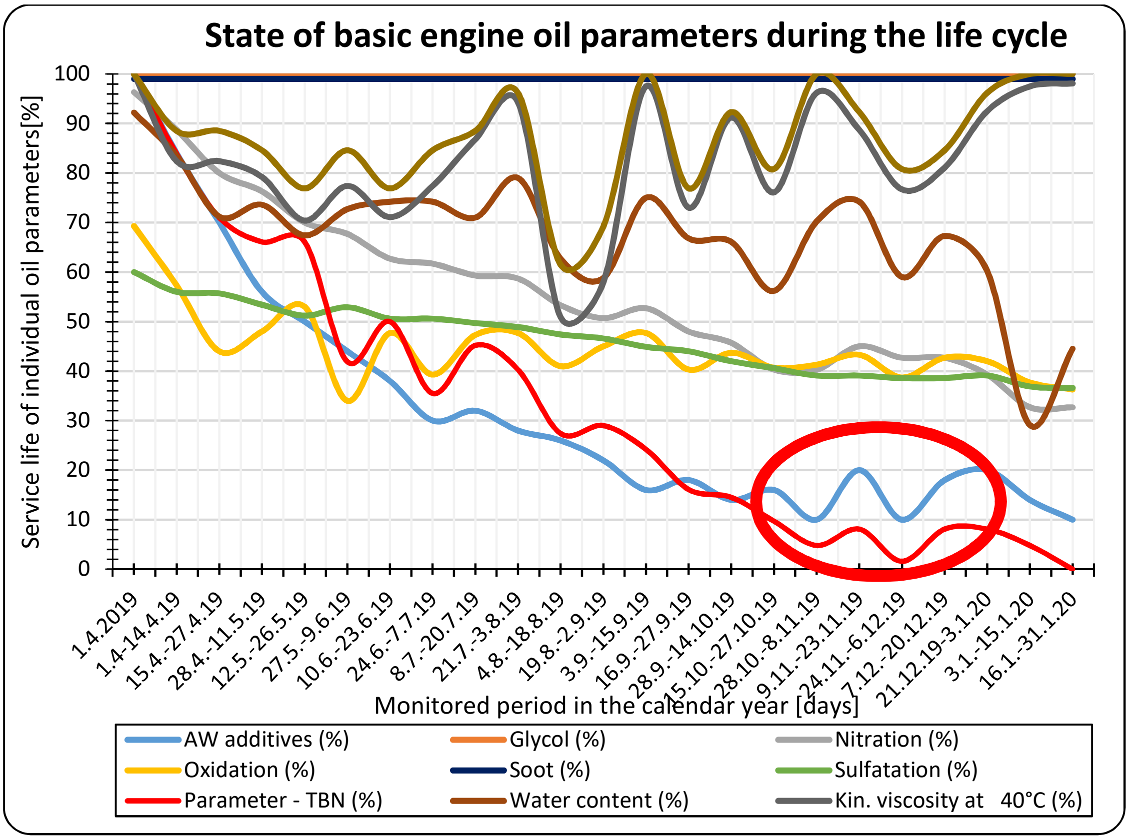


Fig. 5 Illustrative example service life of engine oil in an internal combustion engine and the most fragile parameters (parameter TBN, AW additives) [1]
Source: authors.

Table 2 Measured values of wheeled vehicle

P.č.	Physical property / Physics unit	MEASURED VALUES															
		REFERENCE SAMPLE		Sample No.1		Sample No.2		Sample No.3		Sample No.4		Sample No.5		Sample No.6		Sample No.7	
		23.10.2018 164/18; 29.01.2019 4/19		165/18		165/18		165/18		165/18		165/18		165/18		165/18	
		SAE 15W-40		SAE 15W-40		SAE 15W-40		SAE 15W-40		SAE 15W-40		SAE 15W-40		SAE 15W-40		SAE 15W-40	
		Type of the vehicle		T-815 8×8		T-815 6×6		T-815 RM		T-815.12VV		AV-15		PV3S		T-815 8×8	
		COMBO-AOS		COMBO-AOS		COMBO-AOS		COMBO-AOS		COMBO-AOS		COMBO-AOS		COMBO-AOS		COMBO-AOS	
		23.10.**2018** / 21.01.**2019**		5.5.2022		5.5.2022		5.5.2022		5.5.2022		5.5.2022		6.5.2022		19.5.2022	
x1.	Total mileage of the vehicle [km/Mh]	xx	xx	**95 958**		**42 507**		**13 004**		**27 823**		**36 416**		**9 820**		**40 431**	
x2.	Mileage of the engine oil filling	xx	xx	**18.7.2021**		**29.3.2021**		**13.11.2019**		**11.2.2020**		**28.22019**		**12.3.2019**		**23.5.2019**	
	[km/Mh]			**94667**	**1 291**	**39 549**	**2 958**	**10 963**	**2 041**	**24 322**	**3 501**	**33 121**	**3 295**	**8 734**	**1 086**	**31 154**	**9 277**
x3.	Oil change interval [km/Mh]	xx	xx	**15.000/ 2 years**		**15.000/ 2 years**		**15.000/ 2 years**		**15.000/ 2 years**		**15.000/ 2 years**		**15.000/ 2 years**		**15.000/ 2 years**	
1		+20% +126	+20% 127,20	-37,92	-40,20	-12,66	-13,42	-17,69	-18,75	-18,14	-19,23	19,81	21,00	16,98	18,00	0,28	0,30
	Kinematic viscosity at 40°C	105,0	106,0	**65,80**		**92,58**		**87,25**		**86,77**		**127,00**		**124,00**		**106,30**	
	% [mm2.s-1]	- 20 % -84	-20% 84,80	-37,92	-40,20	-12,66	-13,42	-17,69	-18,75	-18,14	-19,23	19,81	21,00	16,98	18,00	0,28	0,30
		+20% +16,86	+20% +17,55	-8,20	-1,20	-5,67	-0,83	-9,64	-1,41	-8,75	-1,28	19,34	2,83	17,02	2,49	4,58	0,67
	Kinematic viscosity at 100°C	14,05	14,63	**13,43**		**13,80**		**13,22**		**13,35**		**17,46**		**17,12**		**15,30**	
	% [mm2.s-1]	- 20 % 11,24	-20% 11,71	8,20	1,20	-5,67	0,37	-9,64	-1,41	-8,75	-1,28	19,34	2,83	17,02	2,49	4,58	0,67
2.	AW additives [%]	97,00	95	**46,00**	-54,00	**76,00**	-24,00	**83,00**	-17,00	**74,00**	-26,00	**76,00**	-24,00	**86,00**	-14,00	**92,00**	-8,00
3.	Glycol [%]	0	-0,2	**6,00**	6,20	**0,00**	0,20	**0,00**	0,20	**0,00**	-0,20	**0,00**	-0,20	**0**	-0,20	**0**	6,00
4.	Nitration [A/cm]	0,00	-2,0	**0**	35,00	**0,80**	34,20	**0,30**	34,70	**0,40**	34,60	**6,00**	29,00	**0**	35,00	**0**	35,00
5.	Oxidation [A/cm]	8,65	8,5	**10,10**	24,90	**13,50**	21,50	**14,50**	20,50	**14,50**	20,50	**17,30**	17,70	**9,1**	25,90	**12,3**	22,70
6.	Soot [%/w/w]	0,00	0	**0,10**	2,90	**0,16**	2,84	**0,20**	2,80	**0,17**	2,83	**0,22**	2,78	**0,23**	2,77	**0,06**	2,94
7.	Sulfation [A/cm]	14,15 !	14,20 !	**17,90**	22,10	**19,40**	20,60	**19,50**	20,50	**19,60**	20,40	**21,70**	18,30	**18**	22,00	**18,2**	21,80
8.	TBN parameter [mg.KOH/g]	9,85	9,7	**5,00**	2,50	**5,70**	3,20	**5,50**	3,00	**5,00**	2,50	**2,30**	-0,20	**5,5**	3,00	**6,9**	4,40
9.	Water content [ppm]	105,00 !	105,00 !	**789**	2211,00	**797,00**	2203,00	**660,00**	2340,00	**430,00**	2570,00	**1046,00**	1954,00	**683**	2317,00	**853**	2147,00
	Results			**fails**		**passes**		**still passes**		**still passes**		**still passes**		**passes**		**passes**	

Source: authors.

T**able 3** Measured values of wheeled vehicle

L.N.	Physical property / Physicals unit		MEASURED VALUES							
			REFERENE SAMPLE		Sample No.1		Sample No.2		Sample No.3	
			Date		3.5.12022		3.5.2022		3.5.2022	
			SAE W-15W40		SAE W-15W40		SAE W-15W40		SAE W-15W40	
			Type of the vehicle		T-815 6×6		T-815 8×8		T-815	
x1.	Total mileage of the vehicle	[km/Mh]	km	Mh	**36 430**	**0,00**	**22 106**	**0,00**	**51 955**	**0,00**
x2.	Milage of the engine oil filing		Dátum							
	last mileage status km/Mh to MO		km	Mh	**35035**	**0,00**	**21543**	**0,00**	**51545**	**0,00**
	worked km/Mh to MO		km	Mh	**1 395**	**0,00**	**563**	**0,00**	**410**	**0,00**
x3.	Oil change interval	[km/Mh]	**15000/ 2 roky**		**15000/ 2 roky**		**15000/ 2 roky**		**15000/ 2 roky**	
1	%	[mm2.s-1]	+20%	170,40	-38,83	-55,13	-56,78	-80,63	-47,04	-66,80
	Kinematic viskozity 40°C		142,00		**86,87**		**61,37**		**75,20**	
	%	[mm2.s-1]	-20%	122,00	-38,83	-55,13	-56,78	-80,63	-47,04	-66,80
	%	[mm2.s-1]	+20%	16,80	-9,29	-1,30	-30,12	-4,22	-18,81	-2,63
	Kinematic viskozity 100°C		14,00		**12,70**		**9,78**		**11,37**	
	%	[mm2.s-1]	-20%	11,20	-9,29	-1,30	-30,12	-4,22	-18,81	-2,63
2.	AV additives	[%]	99	-1,00	**41,00**	-9,00	**77,00**	27,00	**81,00**	31,00
3.	Glykol	[%]	0	0,00	**0,00**	0,00	**0,00**	0,00	**0,00**	0,00
4.	Nitration	[A/cm]	1,05	33,95	**0,00**	35,00	**0,10**	34,90	**0,00**	35,00
5.	Oxidation	[A/cm]	1,05	33,95	**12,90**	22,10	**10,60**	24,40	**12,90**	22,10
6.	Soot	CCT) (%/w/w)	0	3,00	**0,00**	3,00	**0,00**	3,00	**0,09**	2,91
7.	Sulfation	[A/cm]	0,5	39,50	**15,30**	24,70	**17,80**	22,20	**18,40**	98,00
8.	TBN parameter	[mg KOH/g]	7,8	5,30	**4,40**	1,90	**4,00**	1,50	**5,60**	3,10
9.	Water content	[ppm]	258	2742,00	**653,00**	2347,00	**583,00**	2417,00	**717,00**	2283,00
	Results				**fails**		**fails**		**fails**	

Source: authors.

Table 4 Measured values of wheeled and tracked vehicle

L.N.	Physical property / Physicals unit		REFERENE SAMPLE		MEASURED VALUES					
			09.09.2020		Sample No.1		Sample No.2		Sample No.3	
			SAE 20W-50		6.5.2022		6.5.2022		6.5.2022	
					SAE 20W-50		SAE 20W-50		SAE 20W-50	
			Type of the vehicle		BVP-2		OT-90		BRDM2	
x1.	Total mileage of the vehicle	[km/Mh]	km	Mh	8 102		1 348	579,00	2 065	
x2.	Milage of the engine oil filing		Dátum		30.5.2014		24.1.2019		10.8.2016	
	last mileage status km/Mh to MO		km	Mh	6478		907,60	486,00	1635,00	
	worked km/Mh to MO		km	Mh	1 624	0	440,40	579,00	430,00	0,00
x3.	Oil change interval	[km/Mh]	3000/ 6 rokov		3000/ 6 rokov		3000/ 6 rokov		3000/ 6 rokov	
1	%	[mm2.s-1]	+20%	196,80	-25,98	-42,60	-53,94	-88,46	-37,40	-61,34
	Kinematic viskozity 40°C		164,00		121,40		75,54		102,66	
	%	[mm2.s-1]	-20%	131,20	-25,98	-42,60	-53,94	-88,45	-37,40	-61,34
	%	[mm2.s-1]	+20%	22,44	-17,33	-3,24	-40,64	-7,60	-20,11	-3,76
	Kinematic viskozity 100°C		18,70		15,46		11,10		14,94	
	%	[mm2.s-1]	-20%	14,96	17,33	3,24	-40,64	-4,36	-20,11	-3,76
2.	AV additives	[%]	100		130,00	30,00	74,00	-26,00	92,00	-8,00
3.	Glykol	[%]	0,0		0,00	0,00	0,00	0,00	0,00	0,00
4.	Nitration	[A/cm]	-2,0		0,00	35,00	0,00	35,00	0,00	35,00
5.	Oxidation	[A/cm]	0		9,80	25,20	10,10	24,90	10,90	24,10
6.	Soot	CCT) (%/w/w)	0,05		1,14	1,86	0,10	2,90	0,00	3,00
7.	Sulfation	[A/cm]	16,6		19,10	20,90	17,90	22,10	17,40	22,60
8.	TBN parameter	[mg KOH/g]	7,0		64,00	57,00	5,00	-2,00	9,40	2,40
9.	Water content	[ppm]	3000		483,00	2517,00	789,00	2211,00	1167,00	1833,00
	Results				fails		fails		fails	

Source: authors.

equipment (7 x Tatra 815, 1 x BVP 2, 1 x OT-90, 1 x BRDM-2), while kinematic viscosity is the most important parameter of engine oil.

However, the permitted values were approached and exceeded in the area of physical properties of the oil (Tab. 2., Tab. 3., Tab. 4.), i.e. in the parameter of kinematic viscosity for wheeled and tracked equipment (7 x Tatra 815, 1 x BVP 2, 1 x OT-90, 1 x BRDM-2), while kinematic viscosity is the most important parameter of engine oil.

This adverse phenomenon is not a modern problem, but has persisted in the operation of military equipment for many years. It is not caused by the chemical composition of modern motor oils, nor by the wrong choice of oil for the given technology. The primary cause is mainly in the operation of military equipment over short distances with a high number of cold starts. Another factor is the very design of mostly older large-volume internal combustion engines, where there are large structural clearances in the compression part of the combustion chamber of an unheated internal combustion engine. The combination of the above causes an increased leakage of unburned fuel and condensed water vapor into the oil filling in the combustion engine. According to available sources, up to 0.36% of the fuel from the total consumption reaches the oil filling. This results in an increase in consumption of approximately 2%. Unburnt fuel that gets into the oil fill is one of the most harmful degradation factors. [1]

From the above, it follows that diesel for the oil filling is a much bigger problem than gasoline. If the oil temperature of an overheated engine reaches 110-130 °C, diesel with a distillation range of 180-360 °C cannot evaporate from the oil at all, even its lightest components, and diesel gradually accumulates in the oil. On the other hand, gasoline can evaporate considerably at operating temperatures and only the heaviest components remain in the oil. The concentration of gasoline in the oil filling can be significantly eliminated by driving the vehicle over long distances. [2]

When taking a more detailed look at fuel leakage into the oil filling, it should be emphasized that this is a natural process caused by exhaust gases leaking into the crankcase through the piston rings due to the ovality of the working space, or non-locked piston rings. Exhausts always contain unburned fuel, especially when it comes to a cold start and working with an undercooled engine. Depending on the temperature of the engine, condensation of fuel vapors in the oil filling also occurs. [2]

Fig. 6 Tribodiagnostics laboratory
Source: authors.

In most cases, fuel leakage into the oil causes undesirable chemical changes in the oil. There is a decrease in kinematic viscosity and an increased risk of pressure drop in the lubrication system. The stability of the lubricating film is also at risk, especially in parts with marginal friction, since the fuel has a degreasing and cleaning effect.

Due to the dilution of oil with fuel, the following problems can generally arise: [3]

- risk of paraffin residue formation in diesel engines,
- decrease in TBN, AW additive (Fig. 5.), loss of corrosion protection and reduction of the oxidation layer,
- decrease in engine oil viscosity, decrease in pressure in the lubrication system, reduction in the thickness of the lubrication film, risk of exceeding the friction limit [3].

Fig. 7 Devices for optical and FTIR analysis
Source: authors.

The figure (Fig. 5.) shows that some of the most fragile chemical parameters of engine oil have a significant correlation. Specifically, the parameter TBN and AW additives have an unevenly decreasing trend during the operation of the oil filling.

Their significant correlation is expressed in the picture (Fig. 8), where the three life stages of the oil filling of a vehicle with an internal combustion engine are shown. TBN (Total Base Number) is a parameter that characterizes the property of the oil associated with the neutralization of the acidic environment, which is created mainly during the arising products of combustion and by the oxidation.

During operation, this ability decreases, i.e. the alkaline reserve decreases and the acidity (TAN-Total Acid Number) increases. The measured TBN should not fall below 50 % of the original value. The decrease in this oil parameter is mainly related to the quality of the fuel (sulfur content in the diesel) and the water content in the oil. Acidic substances are not desirable in engine oil and in the worst case they can cause serious engine corrosion. This is also the reason why every motor oil contains alkaline compounds (detergents) that neutralize the action of acidic substances. These alkaline substances create a basic oil reserve. The higher the oil's TBN value, the longer the oil can neutralize acidic substances. [1], [4], [5] Anti-wear additives (AW additives) are most often based on zinc dialkyldithiophosphates (ZDDP) and ashless phosphoric acid dialkyldithiophosphates, bismuth carboxylates and nano-particle potassium borates. [6] The most commonly used additives based on ZDDP are sensitive to the presence of water in the oil. In the presence of water, salts break down, i.e. hydrolysis of ZDDP to acids and bases. [7]

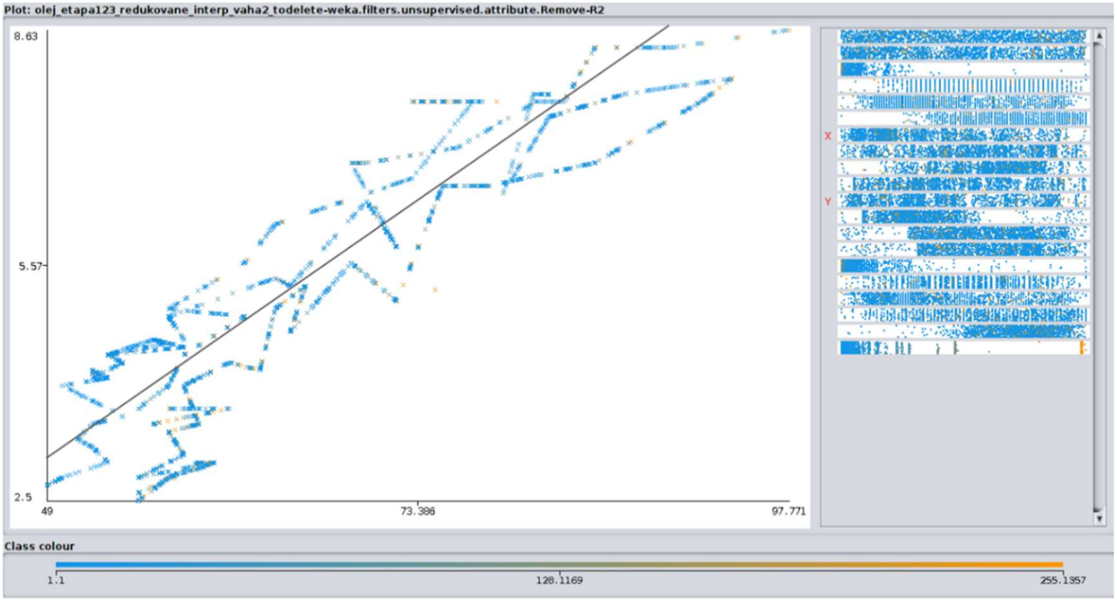


Fig. 8 Correlation of TBN parameter and AW additives displayed in WEKA software [3]
Source: autors.

4 CONCLUSION

It follows from the measured values (Tab. 2.) that the chemical parameters of the oil fillings are in very good condition. However, physical properties (kinematic viscosity) are a persistent problem from the past, as well as today. This phenomenon often occurs already at low mileage (on the order of hundreds of km for tracked vehicles) and represents a major problem in operation. The most common cause is fuel leakage into the oil filling due to cold starts, the operation of vehicles over short distances and the very construction of high-volume engines. This problem can only be solved by an early preventive replacement of the oil filling, which, however, is complicated and unprofitable in the system of operation of equipment in the Slovak Armed Forces. Basically, this problem remains open and tolerated, because many factors in the operation of the vehicle cannot be influenced. Despite this, it follows from random control measurements that service inspections in the Slovak Armed Forces are carried out regularly, honestly and in full.

References

[1] STOPKA, J. *Technická informácia č. 4/2011 - Nežiadúce nečistoty v motorovom oleji pre naftové motory.* Bratislava: TRIBEX s. r. o., 2011. s. 1-4.

[2] ČERNÝ, J. Palivo v oleji. In *AutoExpert 5/2006.* Praha: Autopress, s. r. o., s. 40 – 42. ISSN 1211-2380.

[3] LUKÁŠIK, P. *Analýza parametrov motorových olejov a ich optimalizácia pre mobilnú techniku.* Dizertačná práca. Liptovský Mikuláš: Akadémia ozbrojených síl generála M. R. Štefánika, 2022. p. 73 – 76.

[4] MARKO, M. *Aplikovaná chémia I. Vybrané aspekty tribotechniky, tribochémie a úvod do petrochémie.* Liptovský Mikuláš: Akadémia ozbrojených síl generála M. R. Štefánika, 2012. s. 56 – 60. ISBN 978-80-8040-451-2.

[5] POŠTA, J. a kol. *Opravárenství a diagnostika III.* (2. vyd.) Praha: Nakladatelství Informatorium, 2010. s. 28. ISBN 978-80-7333-073-6.

[6] TRIISO, Lubricant Antiwear (AW) Additives. 2020. Available at: https://www.tri-iso.com /lubricants-antiwear-additives.html

[7] STOPKA, J. *Tribotechnické listy II.* Bratislava: TRIBEX s.r.o., TechPark, 2018. 129 s. ISBN 978-80-972716-1-9.

Prof. Dipl. Eng. Peter **DROPPA**, PhD.
Armed Forces Academy of General M. R. Štefánik
Department of Mechanical Engineering
Demänová 393
031 01 Liptovský Mikuláš
Slovak Republic
E-mail: peter.droppa@aos.sk

Dipl. Eng. Pavol **LUKÁŠIK**, PhD.
Armed Forces Academy of General M. R Štefánik
Department of Mechanical Engineering
Demänová 393
031 01 Liptovský Mikuláš
Slovak Republic
E-mail: pavol.lukasik@aos.sk

Dipl. Eng. Radovan **STEPHANY**
Armed Forces Academy of General M. R. Štefánik
Department of Mechanical Engineering,
Demänová 393
031 01 Liptovský Mikuláš
Slovak Republic
E-mail: radovan.stephany@aos.sk

Dipl. Eng. Vladimir **KADLUB**
Armed Forces Academy of General M. R. Štefánik
Department of Mechanical Engineering,
Demänová 393
031 01 Liptovský Mikuláš
Slovak Republic
E-mail: vladimir.kadlub@aos.sk

Peter DROPPA was born in Liptovský Mikuláš, Slovakia in 1960. He works as an Professor at the Department of Mechanical Engineering, Armed Forces Academy of General M. R. Štefánik in Liptovský Mikuláš. In 1984 he graduated (Eng.) at the Military University in Brno in branch Mechanical technology. He received a PhD. degree in Armament and Technics of Land Forces from the Military Academy in Liptovský Mikuláš in 2003. Since 2007, he has been become the associate professor at the Transport Machines and Equipment, Faculty of Military Technology, University of Defence in Brno and in 2013 he was appointed a professor. His research interests include combat and special vehicles, experimental measurement and simulations and their development trends.

Pavol LUKÁŠIK was born in Liptovský Mikuláš, Slovakia in 1980. He received his M. Sc (Eng.) at the Armed Forces Academy in Liptovský Mikuláš in 2004. He received his PhD. degree in Tribology in 2022. His research interests are focused on tribology and technical diagnostics. He is currently working as an assistant professor at the Department of Mechanical Engineering, Armed Forces Academy of General M. R. Štefánik in Liptovský Mikuláš. He is a member of the Slovak Society for Tribology and Tribotechnics (SSTT).

Radovan STEPHANY was born in Sobrance, Slovakia in 1973. He received his M. Sc (Eng.) at the Armed Forces Academy in Liptovský Mikuláš in 2004. He started his dissertation studies in 2022. His research interests are focused on repairs and maintenance. He is currently working as an assistant professor at the Department of Mechanical Engineering, Armed Forces Academy of General M. R. Štefánik in Liptovský Mikuláš.

Vladimir KADLUB was born in Trstená, Slovakia in 1981. He received his M. Sc (Eng.) at the Armed Forces Academy in Liptovský Mikuláš in 2004. He started his dissertation studies in 2019. His research interests are focused on repairs and maintenance. He is currently working as an assistant professor at the Department of Mechanical Engineering, Armed Forces Academy of General M. R. Štefánik in Liptovský Mikuláš.

DOI: https://doi.org/10.52651/sam.a.2023.1.21-28

THE GROUND BASED AIR DEFENCE SOLUTIONS

Miroslav MATEJČEK, Mikuláš ŠOSTRONEK

Abstract: The article deals with air defence, focusing on the use of Ground Based Air Defence (GBAD) systems. GABDs are complex systems consists of different types of radars, sensors, launchers, command, control, communication, intelligence information subsystems. GBADs parameters and subsystems features can influence overall GBAD systems characteristics and range of GBADs usage. In this article are described modern GBADs solutions, main advantages, and disadvantages of their composition.

Keywords: Ground based air defence system (GBAD); Air defence; Launcher; Radar; Missile.

1 INTRODUCTION

An air defence (AD) is realized by two category of weapon systems, by aviation systems and by Ground Based Air Defence systems (GBADs).

GBADs are complex systems consists of sensors, radars, command, control, communication, information, and intelligence systems (C2, C3, C4I[2]), launchers, missiles, and special power supplies.

GBADs systems are divided into following groups [1]:

- VSHORAD (Very Short Range Air Defence) systems.
- SHORAD (Short Range Air Defence) systems.
- MRAD (Medium Range Air Defence) systems.
- LRAD (Long Range Air Defence) systems.

Engagement ranges of above-mentioned systems are up to 5 km for VSHORAD, up to 15 km for SHORAD, up to 50 km for MRAD and more than 50 km for LRAD systems. Range of GBADs are mainly determined by the missile characteristics.

Different categories of above mentioned GBAD systems can be used against different types of aerial threats. Aerial threats are tactical aviation, bombers, fighters, helicopters, unguided/guided missiles especially cruise missiles, tactical ballistic missiles (TBMs), unmanned aerial vehicles (UAVs), precise guided munition (PGM) and others [2]. Commonly, characteristics of GBADs are divided into the technical, tactical characteristics, maintenance characteristics and economic characteristics [2].

Different categories and types of GBADs create cluster. A cluster creates multi-height and omnidirectional air defence element layered air defence, where the large range GBADs covers GBADs of lower layers (ranges). For example, VSHORAD (SHORAD) GBADs cover LRADs and fill in noncovered zones in an AD. This type of AD is called multi-layered AD.

Each of GBADs can be characterized by its combat features. Combat features are divided into categories of reconnaissance features, firing features a manoeuvring feature [1].

GBADs reconnaissance features define reconnaissance features of sensors (e.g. passive, active radars) which are responsible for aerial reconnaissance and RAP (Recognized Air Picture) creation.

Desired GBADs radar range is defined by the equation [3]:

$$d_{ZP} = d_d + v_C\left(\tau_{PS} + \tau_{rd}\right), \qquad (1)$$

where d_{ZP} is desired GBADs radar range, d_d is horizontal maximal range of GBADs engagement zone, v_c is target speed, τ_{PS} is time of GBADs direct preparation of fire and, τ_{rd} is time of missile flight into the maximal engagement zone border.

An engagement zone – is a zone around the GBADs, where surface-to-air missile (SAM) missiles (hereafter just missiles) destroy aerial targets. An engagement zone is described by parameters like ranges in distance or ranges in heights, where aerial targets can be engaged and other parameters mentioned in this article.

Engagement zone is defined in connection with probability of target destruction *P.* Probability *P* is dimensionless number obviously defined according firing results against aerial target in conditions specified by a GBADs producer. Probability P_n is defined when multiple (salvo) missiles are firing against one aerial target [3]:

$$\mathrm{P}_n = 1 - \left(\sum_{n=1}^{n}(1 - P_1^n)\right), \qquad (2)$$

where *n* defines number of fired missiles to one target and P_1 is probability of target destruction by one missile. Probability of aerial target destruction is dimensionless value, that is different for different types of targets or for different firing conditions or for conditions created by a jamming.

The target engagement zone with firing characteristics defines range of distances, heights, azimuths, and elevation angles of destroyed aerial targets, their speeds, and types. Firing features define number of simultaneously destroyed targets and number of simultaneously guided missiles.

Manoeuvring features influence the readiness of GBADs for combat operations. These features are defined by the time characteristics, for example time for set up GBADs into firing position, a deployment time GBAD, etc.

2 A CURRENT STATE OF GBADS

The current state in an area of GBADs has been formed by the past development of GBADs, where one-channel GBADs were replaced by the multiple-channel GBADs. Multichannel GBADs can engage multiple targets at the same time.

A development of modern GBADs is still influenced by following facts:

- Spectrum of aerial threats is still increasing (new tactical aviation, UAVs, PGMs, TBMs and hypersonic missiles).
- Technical and tactical characteristics of aerial threats (ranges, their speed, manoeuvrability, operating time etc.) are increasing too.
- A utilization of an integrated inertial navigation systems and global position systems (INS/GPS) leads to increasing the guidance accuracy of threats and guided missile in terminal flight phase.
- Low-cost UAVs can be equipped with 3D full HD cameras, targeting or weapon systems and can be used for reconnaissance or combat operations.
- An operation of low-cost aerial threats is very simple (user-friendly).
- Spectrum of aerial threats fired out of GBADs range (carrying missiles, anti-radiation missiles, cruise missiles) is still increasing.
- Aerial threats use STEALTH technology, that is the fact which leads to decreasing GBADs radar ranges etc.

Thanks to above mentioned facts requirements for GBAD system capabilities are still increasing too.

A lot of armies are so far equipped with legacy GBADs produced by Russia. After start of Russian – Ukraine war conflict, the international security situation and international relationships were changed. It affects the operation of GBADs – it is impossible to service, repair, and supply of spare parts.

Some older GBADs types were developed in 1970’s and produced in 1980’s (SA-6 Gainful) and those systems don’t fulfil current requirements for modern GBADs:

- High effective engagement of wide spectrum of aerial threats.
- Resistance to various types of interference or jamming.
- Operation 24 hours/7 day per week with low level of failures occurrence, in different operational conditions.
- Interoperability of GBADs and their subsystems.
- Economic and logistical aspects of GBADs operation.

3 MODERN GBADS SOLUTION

Modern GBADs in the same way as legacy systems consists of firing units (FUs), sensors – radars, C2, C3, C4I2 systems, launchers, and special power supplies for GBADs subsystems.

An AD effectiveness of the European airspace (or in combat operation) can be increased by centralized commanding. NATINAMDS (NATO Integrated Air and Missile Defence Systems) represents means of Integrated Air and Missile Defense (IAMD) of European airspace.

Firing units (clusters) and their GBADs are commanded and controlled from Joint Force Air Component (JFAC)/Combined Air Operation Centre (CAOC) that represents international commanding level (HQ - Headquarters) as in Fig. 1. CAOCs are superior to national Air Operation Centres (AOC) and Command Reporting Centres (CRC).

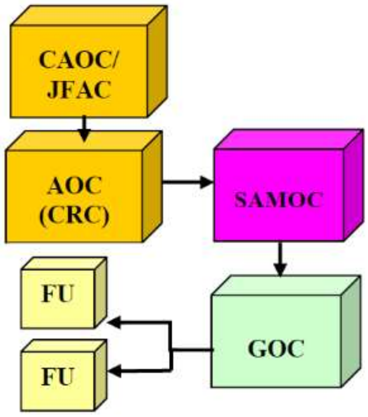


Fig. 1 Structure of commanding levels
Source: authors.

The CRC (at the operational level) commands tactical level units (brigade level), where the Surface to Air Missile Operation Centre (SAMOC) is C4I element. The SAMOC is commanding element for Group Operation Centres (GOC) which control subordinate FUs. Main advantages are:

- Airspace information sharing.
- Early warning and quick reaction.

Main advantages of modern GBADs are:

- GBADs radars uses Active Electronically Scanned Array (AESA), allowing quick reconnaissance and control of operation modes of GBADs radar.
- Radar transmitters can use frequency hopping mode.
- Radar receivers use low noise amplifiers and advantages of high-speed digital signal processing (DSP).
- Radars use set of countermeasures against the current sources of jamming.
- GBADs subsystems use high level of modularity (modules and blocks are backed up).

- FUs can be created according to user (national and NATO) requirements. It means, user can select suitable number of launchers per one FU, suitable numbers of missiles with different guidance systems, suitable levels and types of support devices and maintenance services.
- GBADs subsystems use Built-In-Test-Equipment (BITE) diagnostics which simplify user service operations.
- GBADs use Low Level Air Picture Information (LLAPI) defined in [4], datalinks LINK-11, LINK-16, and Joint Range Application Protocol (JREAP) defined in [5, 6].
- Requirements for operating the of GBADs are lower. It means the range of technical, diagnostic operations and their depth were relatively reduced.

The range of aerial targets speeds are still increasing, therefore ranges of the GBADs radars must be increased too. For example, if the missile speed is v_r = 600 m.s^{-1} and t_{PS} = 20 sec, the computed radar range defined according to (2) for different target speeds is shown in Fig. 2.

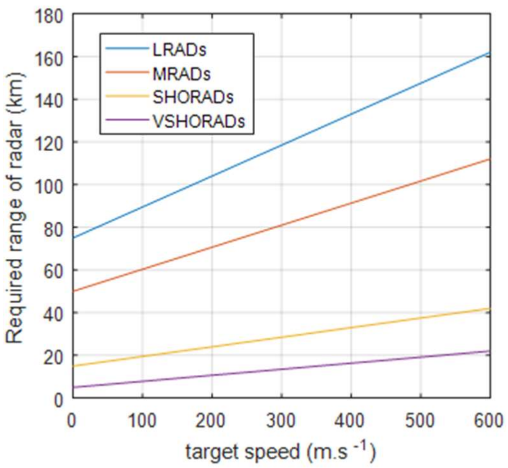


Fig. 2 Required radar ranges vs. target speed.
Source: authors.

3.1 Solutions in the VSHORAD category

The VSHORAD category of GBADs (range up to 5 km) is used for AD of small objects, military bases, land forces units against the enemy aviation, fighters, or helicopters.

Man Portable Air Defence Systems (MANPADS) is category of VSHORAD GBADs. For example, MISTRAL system is according to producer [8] MANPADS.

Modern solutions of VSHORAD systems are for example:
- RBS-70 NG (Saab, Sweden, Fig. 3).
- MISTRAL (MBDA, France, Fig. 4).
- LFK NG (Diehl, Germany, Fig. 5).

The RBS-70 NG is an improved version of the RBS set developed by SAAB (Sweden). The current generation of this set allows to use the original missiles generations as well as the BOLIDE missiles. Basic characteristics of the system are (depending on the missile type) engagement range 250 – 8 000 m, height range 0 – 5 000 m, use of a contact fuse with an adaptive delay, guidance of the missile in a laser beam, and Mach 2 (approx. 600 m/s) missile flight speed.

The RBS-70 NG set consists of:
- RBS-70MK1, MK2 or BOLIDE missiles.
- Aiming system with a tripod.
- IFF and C3I interface.

The system allows to engage air and ground targets, using a system of thermal imaging and automatic target tracking with the option of manual control. It records the combat situation, and it enables its playback.

Fig. 3 RBS-70 NG (Saab, Sweden)
Source: [7].

The advantages are:
- Increased range and probability of target destruction.
- The ability to engage of various target types.
- The ability to engage targets under countermeasures conditions.
- Integrated night reconnaissance system.

The disadvantage of the RBS-70NG is sensitivity of laser guidance in bad weather conditions (smoke, battlefield dust, fog, etc.).

MISTRAL is MANPADS system with following characteristics:
- Range of Mistral Coordination Post (MCP) radar: 30 km distance, 4 km height.
- IFF MODE 4.
- Missile max. range 6 km (M-2 version).
- Missile height range 3 km.

Basic elements (of a platoon) are:
- MCP SHORAR (radar).
- ATLAS launcher 5 pcs.
- MISTRAL-2, and M-3 missile.

Fig. 4 Mistral (MBDA, France)
Source: [8].

LFK NG is a set developed by the company MBDA (Germany) and Diehl BHGT Defence (Germany). The system uses direct guidance method of the missile through the up-link, and it uses vertical launch. Subsequently, it uses a passive homing warhead to terminal guidance. The basic characteristics of the set are:
- Range in the distance 500 – 10 000 meters.
- Height range is 15 – 5 000 m.
- combined fuse (contact and non-contact).

Fig. 5 LFK NG (MBDA, Diehl, Germany)
Source: [8, 10].

LFK NG advantages are increased range, probability of target engagement, the ability to destroy various types of targets on arrival and departure, and the ability to engage targets in the various countermeasures conditions. The disadvantages are longer deployment time, greater number of personnel.

GROM and PIORUN (Poland), STINGER (USA) and Starstreak (UK) are possible solutions in VSHORADs category too.

3.2 Solutions in the SHORADs - MRADs category

SHORAD and MRADs categories of GBADs (range up to 15 km and range up to 50 km) are used for AD of large objects, military bases, land forces, units and terrestrial areas against the enemy aviation, for example fighters, or helicopters.

Nowadays SHORAD-MRADs systems solutions are for example:
- MICA VL (MBDA, France).
- SPYDER-MR (Rafael, Israel).
- NASAM 2 (Norway/USA).
- IRIS-SL (Diehl, Germany).

MICA VL is a system (Fig. 6) using vertical launch missiles in two versions, either MICA RF with active homing or MICA IR with infrared homing in the terminal phase.

For the initial missile flight phase, both versions of the missile are guided to the target using initial information about the target transmitted by radio link. The missiles can capture the target during the flight. Missiles use the advantages of a vertical launch from the container placed on the launcher. It means, there is a possibility to guide a missile in full circle from firing position (launcher). There is not limited firing sector.

MICA VL is composed of:
- ICMP (Improved Command Missile Post).
- Launchers (from 3 to 6 launchers, each equipped with 4 missiles).
- Tactical Operations Center (TOC).
- Integrated logistic support.

MICA VL is characterized by the following characteristics:
- Engagement range of 1500 – 20 000 m.
- Height range 10 – 10 000 m.
- Contact and contactless fuse.
- Deployment time up to 10 minutes.

The advantages of the system are the possibility of simultaneous shooting of several targets. The distance between the launcher and the TOC can be from 0.5 km up to 10 km. The disadvantage is significantly dropping of missile's manoeuvrability, for increasing target distance.

Fig. 6 MICA VL (MBDA, France)
Source: [8].

SPYDER MR is a system (Fig. 7) developed by Israeli companies Rafael Advanced Defense Systems and Israel Aerospace Industries. It uses PYTHON-5 and DERBY missiles. A typical FUs consist of:
- Unit for command and control.
- Usually 6 launchers (each equipped with 4 missiles).
- Loading vehicle.
- EL/M-2106 ATAR radar.

Fig. 7 SPYDER (IAI, Rafael, Israel)
Source: [12, 14].

The EL/M-2106 ATAR radar can track and engage several targets at the same time and control fire units at distance up to 10 km. The system is characterized:

- Engagement ranges from 1 000 m to 35 000 m (PYTHON-5 to 20 km, DERBY 35 km).
- Height ranges from 20 m to 16 000 m.
- Combined fuse.
- Active homing system (DERBY missile) and infrared homing system (PYTHON-5 missile).

The GBADs advantages have possibility of simultaneous shooting of several targets and high rate of fire. GBADs is not intended to destroy the TBM, and missiles are launched at a non-vertical angle.

NASAMS 2 is a system developed by Norwegian Kongsberg companies (Norway) and Raytheon (USA) based on the original NASAM system. System is equipped with AIM-120C AMRAAM missiles (Fig. 8). The NASAMS 2 system has the following typical structure:

- Fire Distribution Centre (FDC).
- 3-D radar type MPQ-64F1 Sentinel.
- Passive electro-optical and infrared sensor.
- Towed launchers with AIM 120A (120C) AMRAAM missiles in containers.

One FUs platoon consists of 3 launchers with 18 missiles, and the battery contains 3 platoons. Radars are connected to the FDC as sources of a radar information.

The NASAMS 2 system is characterized by the following characteristics:

- Engagement range of 2 500 – 40 000 m.
- Height range 30 – 14 000 m.
- Maximum target speed 1000 m.s^{-1}.
- Contact and contactless fuse.
- Radio command guidance with active guidance in the terminal phase.

The launchers are located within 25 km radius from FDC, and they can communicate using cable, optical, or radio communication channels.

Fig. 8 NASAMS II missiles
Source: [9].

The multifunctional radar AN/TPQ-64 is pulsed Doppler radar with AESA and IFF Mark XII. It ensures all-round scanning of area with a range of 75 km. The NASAM 2 system obviously uses launchers with a missile launch angle approximately 30°. The advantages of the system are the possibility of simultaneous shooting of several targets, a high rate of fire. Missile uses an optical guidance method.

The disadvantages are follows: missiles are not placed into the containers and missiles have to be manually loaded.

IRIS-SL is a system developed by Diehl BGT Defense (Germany). Missiles IRIS-T SL were developed from the IRIS-T air missile. The system is designed for two variants of the IRIS-T SLS (short range) and IRIS-T SLM (medium range) missiles. The missiles use up-link for the initial guidance phase and an infrared homing in the terminal flight phase.

The system consists of:

- CEAFAR Active Phased Array Radar.
- IRIS-T SL launchers (Fig. 9).
- BMD-FLEX C3 system.
- Oerlikon Skymaster battlefield C2 system.

Fig. 9 IRIS SL subsystems
Source: [10].

The system has the following characteristics:

- Engagement range 1 000 m – 40 000 m.
- Height range 20 m – 20 000 m.

The advantages of the system are the possibility of simultaneous shooting of several targets, high rate of fire, vertical launch of missiles, modularity of the system. The disadvantage is impossibility to engage the TBMs.

3.3 Solutions in the LRADS category

LRADs category of GBADs (range more than 50 km) is used for AD of strategic objects, military bases, land forces, units and large terrestrial areas against the enemy aviation, fighters, helicopters, guided and unguided missiles, cruise missiles and TBMs.

Modern LRADs systems solutions are follows:
- MEADS (France, USA, Italy).
- BARAK 8 (Israel, India).
- SAMP-T (France, Italy).

MEADS is a system in Fig. 10 that gradually replace the PATRIOT and NIKE-Hercules systems.

The MEADS system includes:
- Multifunctional Fire Control Radar (MFCR) using an AESA for precise search, tracking and identification of targets. It uses an AESA to creation Missile Control Fire Radio (MCFR) link.
- Reconnaissance radar is a radar operating in the UHF band with an AESA.
- TOC is the system performing BMC4I (Battle Management, Command, Control, Communication, Computational and Intelligence) tasks.
- Launchers (up to 6 pieces) equipped with ASTER 30 missiles located in containers or PAC-3 MSE missiles.

The MEADS system is characterized by:
- Engagement range 3 000 – 120 000 m,
- Ability to destroy TBM.
- Using several types of missiles.
- Command guidance method and active self-guidance method in the terminal missile flight phase.

The advantages of the system are the possibility of simultaneous shooting of several targets with several missiles, the possibility of firing at the same time in different azimuths, high rate of fire, high resistance to countermeasures, the possibility of using several types of missiles with different ranges and Hit-To-Kill technology. The system is compatible according to NATO requirements. System is not combat proved or a lot of information about its characteristics and next development are missing.

Fig. 10 MEADS subsystems
Source: [8, 11].

BARAK 8 system is the LRAD system defending against aircrafts, helicopters, and guided missiles (Fig. 11). The system was developed in cooperation with the Israeli company Israel Aerospace Industries (IAI) and the Indian Defense Research and Development Organisation.

Fig. 11 BARAK 8 elements
Source: [12, 13].

The missile is guided by a radar EL/M-2248 [7] during the initial flight phase. In the terminal phase of the missile's flight, the main engine is jettisoned (first stage), and the missile it is guided by using an on-board radar.

BARAK 8 consists of:
- Command and control unit (CP).
- Radar EL/M-2248 [7].
- Launchers (4 pieces) each equipped with 8 missiles.
- Loading vehicles.
- Multifunctional (support) vehicle MV.
- Power supply generators.
- The main advantages of BARAK 8 system are:
- Resistance to all kinds of interference.
- Possibility of combination with SPYDER MR elements.
- Compatibility with the EL/M-2084 radar.
- Containerized missiles - long storage period.

The main disadvantages are:
- The problematic interoperability according to NATO standards.
- Deployment time is approx. 45 minutes.

SAMP-T system developed by the companies MBDA, THALES, EUROSAM (France, Italy). The system (in the Fig. 12) is intended for the destruction of a wide range of targets, missiles, UAVs and TBMs.

SAMP-T unit is composed of:
- Multifunctional radar (ARABEL).
- Command module (C2).
- Launchers (up to 6, each equipped with 8 missiles).
- Missile ASTER 30 or ASTER 15.
- Integrated logistic support.

The multifunctional radar ARABEL is intended for the detection and tracking of aerial targets with a range up to 150 km. The X-band radar uses AESA, which allows it to track and identify (IFF) up to 100 air targets simultaneously and guide up to 16 missiles to targets. Missiles are guided over the radio link. Missile launchers can be up to 10 km away from the multifunctional radar.

Fig. 12 SAMPT with ASTER-30 missile
Source: [8].

The system is further characterized by:
- Engagement range 3 000 m – 120 000 m (ASTER-30) or 1 700 – 30 000 m (ASTER-15).
- Engagement of TBMs up to 30 000 m.
- Height range is 0 – 20 000 meters.
- Deployment time within 10 minutes.
- Missile uses active non-contact radio fuse.

Both types of ASTER missiles use an inertial navigation system with control via a radio link from the ARABEL radar. In the terminal flight phase, the missiles use an active homing system.

The advantages of the GBADs are the possibility of simultaneous shooting of several targets with several missiles, high rate of fire, high resistance to countermeasures (jamming), the possibility of using several types of missiles with different ranges. A lot of information about its characteristics and combat operation are missing.

4 CONCLUSION

Legacy or older types GBADs are characterized by their original conception and composition. Those systems are still used in several Armed forces of NATO countries. Their characteristics and capabilities in this time are not enough for creation of the modern IAMD. Service and operation of those systems are not long-term sustainable and cost effective. From this reason is necessary to create IAMD based on current GBADs.

The aim of this paper was to show basic characteristics of current GBADs in all range categories (VSHORAD, SHORAD, MRAD, and LRAD), which can be used for the replacement of legacy systems.

In each category are summarized the composition of GBADs, their basic characteristics (radars, missiles, launchers, etc.), advantages and some disadvantages. Article provides a comprehensive overview in GBADs area focusing on GBADs which can be used in Integrated Air Missile Defense (IAMD) for NATO environment.

References

[1] PTÁČNIK, R., ROVŇAN, R., KOŽLEJ, P. OSTRADECKÝ, L., LÍŠKA, T., KALINA, M. a LOHYŇA, V. *Vojenský predpis o zásadách plánovania a riadenia bojovej činnosti palebných prostriedkov protivzdušnej obrany – PVO-1-32.* Bratislava: GŠ OS SR, 2020.

[2] MATEJČEK, M., ŠOSTRONEK, M., BARÁNI, Z. a KOŽLEJ, P. *Analytická štúdia PVO krajín V4.* Záverečná správa štúdie CREPC_ID: 428638. Liptovský Mikuláš: Akadémia ozbrojených síl generála M. R. Štefánika, 2020. 152 s.

[3] LAKOTA, B., ŠOSTRONEK, M., MATEJČEK, M., OCHODNICKÝ, J., MATOUŠEK, Z., SZARVAŠ, J. a BÁLINT, J. *Návrh obmeny prostriedkov na komplexné zabezpečenie PVO Slovenskej republiky*: analytická štúdia CREPC_ID: 289989. Liptovský Mikuláš: Akadémia ozbrojených síl generála M. R. Štefánika, 2015.

[4] NATO-STANAG 4312, *Interoperability of Ground-Based Air Defence Surveillance, Command and Control Systems.* NATO, 2012.

[5] NATO-STANAG 5518, *Joint Range Extenson Application Protocol (JREAP) – ATDLP-5.18 Edition B Version 2.* NATO, 2019.

[6] NATO - STANAG 5516, *Tactical Data Exchange – Link 16 - ATDLP-5.16 EDITION B.* NATO, 2019.

[7] *Producer datasheets.* (Online). Available at: https://www.saab.com [cit. 2023-01-25].

[8] *Producer datasheets.* (Online). Available at: https://www.mbda-systems.com/ [cit. 2023-01-25].

[9] *Producer datasheets.* (Online). Available at: https://www.kongsberg.com [cit. 2023-01-25].

[10] *Producer datasheets.* (Online). Available at: https://www.diehl.com [cit. 2023-01-25].

[11] *Producer datasheets.* (Online). Available at: https://www.raytheonmissilesanddefense.com/ [cit. 2023-01-25].

[12] *Producer datasheets.* (Online). Available at: https://www.iai.co.il [cit. 2023-01-25].

[13] *Producer datasheets.* (Online). Available at: https://www.drdo.gov.in/ [cit. 2023-01-25].

[14] *Producer datasheets.* (Online). Available at: https://www.rafael.co.il/ [cit. 2023-01-25].

Dipl. Eng. Miroslav **MATEJČEK**, PhD.
Armed Forces Academy of General M. R. Štefánik
Department of Electronics
Demänová 393
031 01 Liptovský Mikuláš
Slovak Republic
E-mail: miroslav.matejcek@aos.sk

Assoc. Prof. Dipl. Eng. Mikuláš **ŠOSTRONEK**, PhD.
Armed Forces Academy of General M. R. Štefánik
Department of Electronics
Demänová 393
031 01 Liptovský Mikuláš
Slovak Republic
E-mail: mikulas.sostronek@aos.sk

Miroslav MATEJČEK was born in 1979 in Liptovsky Mikulas (Slovak Republic). He received his engineer degree in 2002 and PhD. degree in 2018, at Department of Air Defense, Military Academy in Liptovsky Mikulas. He works as an assistant professor at Department of Electronics, Armed Forces Academy in Liptovsky Mikulas. His research area mainly includes guided weapon systems and control systems.

Mikuláš ŠOSTRONEK was born in 1972 in Bojnice (Slovak Republic). He received his engineer degree in 1996 at Air Defense Faculty, Military Academy in Liptovsky Mikulas, PhD. degree in 2001 at Department of Electronics, Military Academy in Liptovsky Mikulas. He works as associated professor at Department of Electronics, Armed Forces Academy in Liptovsky Mikulas. His research area mainly includes control systems and microwave engineering.

DOI: https://doi.org/10.52651/sam.a.2023.1.29-32

MEASUREMENT OF CROSSHAIR SHIFT ON MAGNIFICATION CHANGE IN FIELD-CONDITIONS

Josef BAČA, Ivan PEMČÁK

Abstract: Crosshair shift with changing magnification of VIS camera is investigated in this article. The shift is a real problem that can significantly worsen fire-control system performance. The main condition of this measurement is ability to perform it on mounted devices in real fire-control system in field condition, it means that the measurement is adjusted to be done with accessible equipment. To measure this shift it is important to design target image which enables the shift measurement. Inaccuracy of this measurement is also discussed. The theoretical solution of the problem is demonstrated on experimental measurement.

Keywords: Hit probability; Crosshair shift; Aiming, Optics; Fire-control system; Optical measurement.

1 INTRODUCTION

Today, light reconnaissance battle vehicles are parts of every modern armed forces. They are equipped with remote controlled weapon station (RCWS) with a equivalent of 12.7 mm or 7.62 mm machinegun, laser rangefinder (LRF), VIS cameras, and IR cameras. (1)

Information from all these sources is combined in fire-control unit (FCU) which provides output to operator display and then enables operator to shoot on the target. (2)

Reconnaissance cameras have two main tasks- to find a target, and to identify it to allow operator to lead the fire on it. Therefore, the camera needs to have great zoom interval on the one hand with a wide field of view (FOV) and low magnification and on the other hand with narrow FOV and great magnification.

To find a target it is needed to have wide field of view. To identify a target, you need to have a great zoom to be able lead a fire on an effective weapon range.

With a great zoom interval, there is difficult to stabilize real boresight with crosshair provided by FCU. This difference can negatively affect LRF, or weapon hit probability.

It is needed to be able to measure this shift on a real mounted weapon station in field conditions.

2 DETERMINATION OF BASICS PARAMETERS

To measure crosshair shift, there was chosen daylight camera from a reconnaissance vehicle used by armed forces. RCWS uses heavy machinegun .50 BMG M2 QCB, it has a day CCD camera, IRC and LRF, information from these sources is displayed on a FCU unit display. The FCU display limits the resolution of a camera to 0.05 mrad at a maximum magnification. (3)

Rectification of the RCWS is done with rectification target with set maximal magnification on distance l=15 m.

Table 1 Camera properties

Spectrum	FOV	Magnification	Display resolution
VIS/NIR	1.7-45°	1.2-30x	640x480 px

Source: author.

FCU uses 4 different types of crosshairs, the crosshair is displayed over the final image with exact width of line of 1 px. This property is used when measured its shift in the image.

Crosshair midpoint when rectified lies on the optical axis of the day camera. When the elevation of the camera is 0° the crosshair midpoint aims on the same point in the target independently on a magnification.

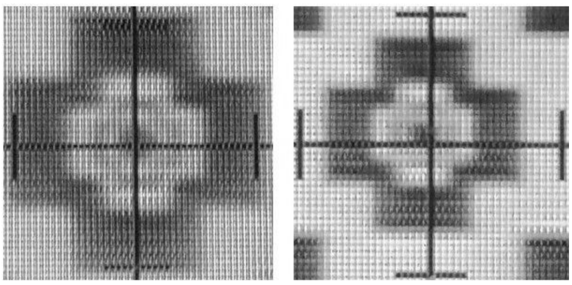


Fig. 1 Crosshair shift with change of magnification
Source: author.

Due to various influences, there is recognizable crosshair shift when magnification is changed. This shift can cause targeting error when LRF or weapon is used. To measure this shift in field conditions it is needed to use target image suiTab. for the RCWS.

The final image is captured by frame grabber or camera and then the shift is measured in the picture.

3 TARGET DESIGN

In the beginning of a target design, it is needed to know the distance to the target. Then there is important to know the magnification steps. It is not possible to have a target for every possible magnification because of unclarity of the final target image. On the other hand, the target image must be detailed enough to enable shift measurement on a camera resolution level, that means 1 px on the screen.

It is favoured to be able to measure shift in both axes at once, that can be done when the target shape consists of isosceles crosses lying within each other. Their size corresponds to 3 px on each side to enable shift measurement in x and y axes.

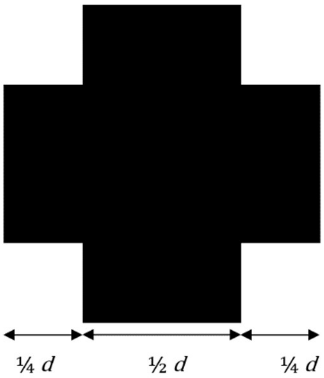


Fig. 2 Cross element from a target image
Source: author.

$$\frac{d}{2} = n \cdot \tan\left(2\omega \cdot \frac{\Gamma_{max}}{\Gamma}\right) \cdot l \text{ [mm]}, \quad (1)$$

where d is cross element width, n is number of pixels on the screen, 2ω is maximal pixel resolution in mrad, $\frac{\Gamma_{max}}{\Gamma}$ is ratio of maximal magnification and corresponding magnification, and l is the distance to the target. (3) Final example of a target image is shown in the Fig. 3

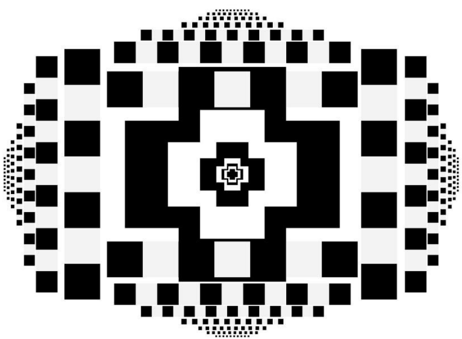


Fig. 3 Final target image with side rulers
Source: author.

For rough estimation of the shift in field conditions it is possible to add sidebar rulers.

4 CROSSHAIR SHIFT MEASUREMENT

To determine shift it is needed to set the starting point of the crosshair. Consider that elevation must be set to 0, maximal magnification and crosshair must aim to the middle of the target. Capture the displayed image to have starting condition image. Then zoom out to the next designed magnification, capture the image, and continue till the maximal zoom out.

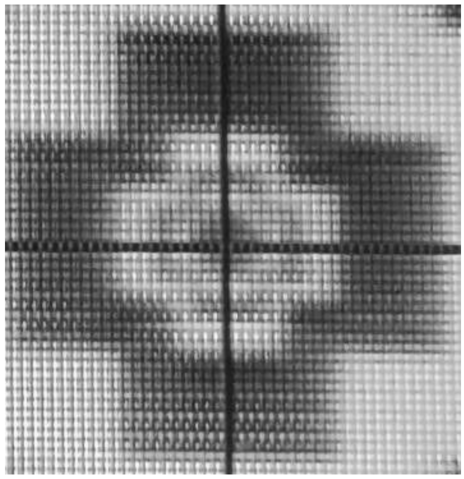


Fig. 4 Default condition image
Source author.

Captured images are analysed with ImageJ program (4) that enables to perform measurement in the image with known distances. There is determined crosshair midpoint on each captured image which is confronted with starting position crosshair midpoint. Distance of these two midpoints is the wanted crosshair shift.

Measurement example is shown in the Fig. 5, where the distance is the red segment nr. 1.

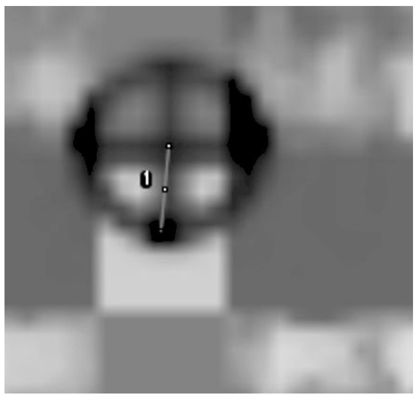


Fig. 5 Measured shift distance
Source: author

Measured distances across zooming out shows the crosshair shift in both axes of target plane.

5 DEMONSTRATION EXPERIMENT

5.1 Experimental measurement

To demonstrate shift measurement in real conditions it was used target situation with following properties, l = 17 m, magnification interval Γ∈<1.2:30>, zoom out step is irregular because of autofocus properties of used camera.

Camera was rectified according to standard instructions. Elevation was set to 0°, the middle point of crosshair was set to the middle of the target image (Fig. 4).

Then the camera zoomed out in steps and then the image was autofocused. No change in elevation and traverse was made. After each step the autofocused image was captured.

Measurement of the shift is done in ImageJ program (4), measured data are processed in Matlab environment.

In the captured image it was measured the distance from the crosshair to the default crosshair point. Measured distances are shown in the Tab. below. Angular shift is determinated as an angle of shift on the distance l.

$$\Delta\varphi = \frac{\Delta x}{l}; \Delta\theta = \frac{\Delta y}{l} \text{ [mrad]}, \quad (2)$$

Table 2 Measured crosshair shift

Magn. Γ	FOV [°]	shift Δx [mm]	shift Δy [mm]	shift Δφ [mrad]	shift Δθ [mrad]
1,2	44,2	-32,50	21,31	-1,91	1,25
1,9	27,4	-18,04	30,68	-1,06	1,80
2,9	17,4	-9,94	18,36	-0,58	1,08
4,4	11,5	-8,44	15,76	-0,50	0,93
9,4	5,4	-3,92	7,18	-0,23	0,42
18,9	2,7	-1,50	1,53	-0,09	0,09
23,2	2,2	-0,96	1,17	-0,06	0,07
30,0	1,7	0,00	0,00	0,00	0,00

Source: author.

Magnification 30 is the default condition with 0 shift. Measured shift is approximated by Smoothing spline. (5)

$$p \cdot \sum_i w_i \cdot (y_i - s(x_i))^2 + (1-p) \cdot \int \left(\frac{d^2 s}{dx^2}\right)^2 dx, \quad (3)$$

where graph smoothness p=0.9 and weight w=1 is chosen.

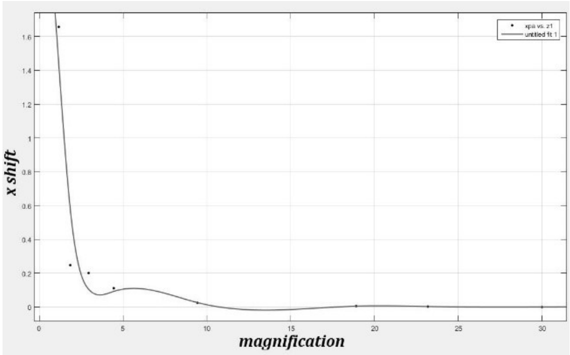


Fig. 6 Measured angle shift in x axis
Source: author.

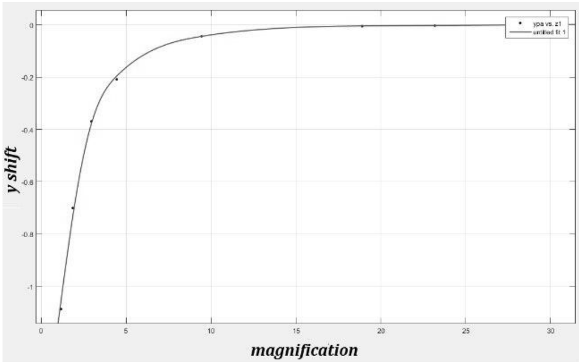


Fig. 7 Measured angle shift in y axis
Source: author.

For the lowest magnification the shift is the greatest, it can be caused by stopping mechanism of the zooming element of the camera.

6 MEASUREMENT ACCURACY

This field-condition measurement is affected by several conditions. The biggest source of inaccuracies is the fire-control unit and its display, which shows the target image and creates the crosshair. It has low resolution display which makes the main part of the inaccuracy. It is possible to determine the distance with accuracy of $u_2 = 2$ px in the display (1 px for each edge).

Second significant part of the inaccuracy is the in-image measurement of crosshair middle point. It is possible to identify the midpoint with accuracy of $u_1 = 0{,}5$ px.

Resolution of the capturing system is order of magnitude higher than the display, so it can be omitted, also measurement of the distance l and accuracy of the printed target is negligible.

Inaccuracy of the measurement for both axes is then

$$u_x = u_y = \sqrt{\left(2\omega \cdot \frac{\Gamma_{max}}{\Gamma} \cdot u_1 \cdot l\right)^2 + \left(x_{min/px} \cdot u_2 \cdot \frac{\Gamma_{max}}{\Gamma}\right)^2} \quad (3)$$

where $x_{min/px}$ is width of 1 px in the target image. (3)

Inaccuracy for the maximal magnification is then determined with $\Gamma_{max} = \Gamma$ and $x_{min/px} = \frac{0,001}{12}$ as

$$u_x = \sqrt{\left(0,00005 \cdot \frac{30}{30} \cdot 0,5 \cdot 17\right)^2 + \left(\frac{0,001}{12} \cdot 2 \cdot \frac{30}{30}\right)^2} = 0,46 \text{ mm} \approx 0.27 \text{ mrad} \qquad (4)$$

To decrease measurement inaccuracy, it is needed to have higher resolution display. In-image measurement accuracy depends on precision of the program and operator.

7 CONCLUSION

This article presents problematic of crosshair shift with change of magnification. This problem can be crucial in combat situation when the fast and accurate hit is needed.

It shows possible way of crosshair shift measurement. It can be stated that crosshair shift is a real problem that can leads to fire-control system inaccuracy or aiming failure. Crosshair shift about the size of 1 mrad can transfer the impact area of fire up to 1 m on the 1 km distance.

Next important part of the article shows the way of tailoring target image to camera system which can be used not only for day cameras but also for image intensifiers-based night vision devices.

This article presents measurement of this shift in field-conditions enabling to perform measurement of mounted devices in real fire-control system. It is possible to measure this shift with accuracy better than 0.3 mrad.

This problematic can be developed further by comparing crosshair shift on different types of vehicles. Evaluation of the shift from the image could be performed by machine learning to decrease measurement inaccuracy. For the exact influence of this shift, it is needed to experimentally compare it to real shooting experiment.

References

[1] CHRZANOWSKI, K. *Testing Passive Surveillance Terahertz Imagers.* Warsaw: Military University of Technology, 2013. DOI: 10.5277/oa130215.

[2] CHRZANOWSKI, K. *Configurable Modular System for Testing All Types.* Warsaw: Military University of Technology, 2016. OPTRO-2016-076.

[3] BALÁŽ, T. a ŘEHOŘ, Z. *Dosahy OE přístrojů v reálných podmínkách.* (Online). Available at: https://docplayer.cz/68745505-Dosahy-oe-pristroju-v-realnych-podminkach.html [cit. 2022-09-05].

[4] Schneider CA, Rasband WS, Eliceiri KW. NIH IMAGE TO IMAGEJ: 25 YEARS OF IMAGE ANALYSIS. Nature methods. 9(7), 2012, Sv. 671–675, Available at. https://doi.org/10.1038/nmeth.2089

[5] The MathWorks, Inc. Mathworks. Mathworks. [Online] https://uk.mathworks.com/, 2022. Available at: https://uk.mathworks.com/help/curvefit/smoothing-splines.html [cit. 2022-09-05]

[6] CHRZANOWSKI, K. *Inframent Education.* (Online). Inframet, 2021. Available at: https://www.inframet.com/education.htm [cit. 2022-08-01].

Dipl. Eng. Ivan **PEMČÁK**
University of Defence
Kounicova 65
662 10 Brno
Czech Republic
E-mail: ivan.pemcak@unob.cz

Dipl. Eng. Josef **BAČA**
University of Defence
Kounicova 65
662 10 Brno
Czech Republic
E-mail: josef.baca@unob.cz

Ivan PEMČÁK graduated in Weapons and ammunition engineering from University of Defense, Czech Republic in 2018. After two-year as an ordnance officer in a light infantry battalion of Czech armed forces, he returned to the University of Defense as Ph.D. candidate. His field of research is fire control systems, target hit probability and weapon design.

Josef BAČA graduated in Weapons and ammunition engineering from University of Defense, Czech Republic in 2017. He serves in the military repair facility in Jaroměř, where he specializes in the repair of fire control systems. His field of research is fire control systems, target acquisition and optical system design.

DOI: https://doi.org/10.52651/sam.a.2023.1.33-38

EVALUATION OF ENGINE OIL DEGRADATION (MO) SHELL HELIX HX-8, SAE 5W-30 ON BMW 330D XDRIVE

Miroslav MARKO, Jindřich STEHLÍK

Abstract: Work deals with the description of the used technology and motor oil used in my work. The next section describes the engine oils and the monitored degradation parameters of engine oils. In the practical were performed tribodiagnostic measurements of oil level during downtime of the BMW 330d Xdrive in order to determine the current quality status of engine oil and the degree of its degradation.

Keywords: Oil; Degradation; Kinematic viscosity; TAN; TBN; Soot; Nitritation.

1 INTRODUCTION

Oils are technologically very complex products with a number of parameters that must meet performance requirements under various load conditions. Despite the time and mileage declaration of the service life interval from the manufacturer, there may be cases where there is an accelerated degradation action and the associated risk of premature wear or engine failure. In my work, I focused on measuring the quality indicators of engine oil during operation and to determine the degree of degradation. Sampling was performed from a BMW 330d Xdrive. We performed measurements of the reference sample and 2 measurements of the oil filling. Sampling took place in the workshop premises of the Department of Mechanical Engineering and measurements were performed in the tribodiagnostics laboratory also belonging to the Department of Mechanical Engineering. The work consists of theoretical and practical part.

2 VEAHICLE BMW 330d Xdrive

The BMW 330d Xdrive, equipped with the M-package and the F30 generation, is a vehicle equipped with an in-line diesel 6-cylinder, which has an output of 190 kW at 4000 rpm and a torque of 560 Nm at 1500-3000 rpm At the beginning of the measurements, the vehicle had a mileage of 193 256 kilometers and at the last measurement it had 200 396 kilometers. [1,4]

3 N57 ENGINE

In 2008, the in-line 6-cylinder turbo diesel N57 was launched, which was to replace the popular BMW M57 engine. The new engine consists of a closed aluminum cylinder block with cast iron inserts and a forged crankshaft. Engine capacity is 2997 cm^3. The block is covered by an aluminum cylinder head, which is slightly lower than the M57 predecessor. To increase the distance between the engine and the hood, the wiring has moved to the rear of the engine. The timing chain on the N57 is single-row and will last longer than on the 4-cylinder sibling N47. The service life of the timing chain exceeds 200,000 km. The N57 uses the 3rd version of the Common Rail injection system. [6]

4 MOTOR OIL SHELL HELIX HX-8 SAE 5W-30

It is a fully synthetic motor oil, providing high performance, cleaning and protection.

Table 1 Parameters of used motor oil Shell HX-8 5W-30

Viscosity grade SAE	**5W-30**
ACEA	**C3**
API	**SN**
VW	**504.00/507.00**
Viscosity index	**171**
Viscosity at -30°C (mPa.s)	**4640**
Kinematic viscosity at 40° C (mm^2/s)	**67,8**
Freezing point	**-48° C**

Source: authors.

The sampling shown below in the images was carried out after the engine had warmed up to operating temperature. After opening the front hood, we took an undefined small amount of engine oil through the channel of the oil dipstick of the lubrication system. Samples were collected using a syringe with an infusion set. [11]

5 USED TRIBODIAGNOSTIC DEVICES

From the point of view of maintaining competitiveness on the market, very high demands are placed on today's high-performance motor oils. They are technologically very complex products with a number of parameters that must fulfill performance parameters in various load conditions. Despite the time and kilometer declaration of the service life interval by the manufacturer, there may be cases where accelerated degradation occurs and the associated risk of premature wear or engine failure.

A set of operating factors (e.g. cold starts and their frequency, the operator's approach to gradually warming the engine up to operating temperature, technical condition of the engine, operating load of the vehicle, length of operating distances, operation in difficult terrain, operation in a dusty environment) has a decisive influence on the service life of the engine oil. etc.). It is precisely the operation of technology in the Slovak Armed Forces that is significantly characterized by the above-mentioned factors. In order to maintain the combat capability and reliability of military equipment, it is therefore necessary to pay increased attention to the monitoring and evaluation of engine oil degradation.

The service life of the lubricating oil is negatively affected mainly by various unsuitable and unforeseen operating conditions. We check the lubricating oil according to three criteria, which also determine the time to change the oil filling. This is mainly the deterioration of the base oil, the decrease in the content of additives in the engine oil and various impurities. Degradation of engine oil is mainly accelerated by thermal degradation and oxidation processes in engine oil. [3]

Additives are added to base oils to reduce destructive processes and improve beneficial properties. For example, antioxidant additives help slow the rate of oxidation. Detergent additives help prevent deposits and sludge. Anti-wear additives are added to some motor oils to form a coating on metal components to prevent wear. Exhaustion of additives is one of the main reasons why engine oil loses its effectiveness and needs to be changed. Although all motor oils deteriorate over time, synthetic oils last longer than conventional oils and provide improved protection against wear and deposits. [3]

6 USED TRIBODIAGNOSTIC DEVICES

6.1 SpectroVisc Q3000

It is a portable viscosimeter which is used to measure the kinematic viscosity at 40 ° C and then calculates the kinematic viscosity at 100 ° C on the basis of the viscosity index of the engine oil. [12]

Fig. 1 SpectroVisc Q3000
Source: authors.

Before the actual measurement, we turn on the SpectroVisc Q3050 device and pull out the metal sampler at the instruction of the imaging unit. The internal surfaces of the device must be thoroughly cleaned.

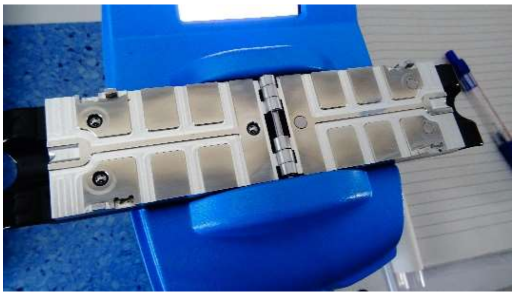


Fig. 2 Sampler with prismatic slot
Source: authors.

Subsequently, the sampler with the prismatic slot is inserted into the device and the device is allowed to heat up to an operating temperature of 40 °C.

Fig. 3 Warming up the SpectroVisc Q3000
Source: authors.

After heating, the device will give us an instruction to insert the sample: „Load the sample".

Fig. 4 Device prompt to insert oil sample
Source: authors.

Using a special applicator, we insert a sample of 60 microliters into the device.

Fig. 5 Inserting a sample
Source: authors.

6.2 Fluidscan 1000

This instrument analyzes the qualitative properties of motor oils on the basis of infrared spectrometry. The device provides comprehensive information on the status of engine oils through individual monitored parameters. After inserting the sample, the device analyzes it, provides us with the required data via the user interface and saves the measurement results in its memory, where it is able to store up to 5000 measurement results. [7, 10]

Fig. 6 Fluidscan 1000
Source: author.

Before measuring, it is necessary to clean the measuring surfaces when prompted by the device.

Subsequently, in the system, we select the vehicle from which the engine oil sample is to be evaluated by the device. The vehicle is predefined in the device by the user of the device in the form of a directory. Individual measurements are stored in the directory in the form of files. The system includes the new measurement in the database of previous measurements for the given vehicle. Subsequently, we apply an unspecified volume (drop) of engine oil through a sampling syringe with a connected tube. The volume of the sample must be sufficient to cover the surface of the slide. When inserting the sample, we ensure that bubbles do not form, which could negatively affect the accuracy of the measurement. The images show the actual application of the sample to the slide.

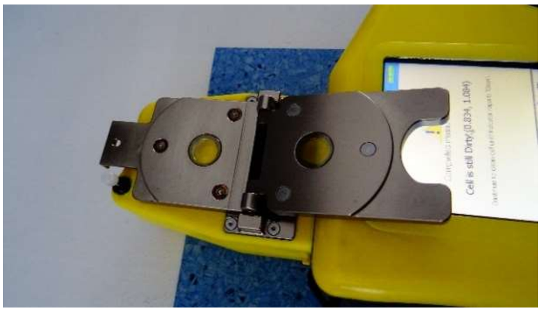


Fig. 7 Cell
Source: authors.

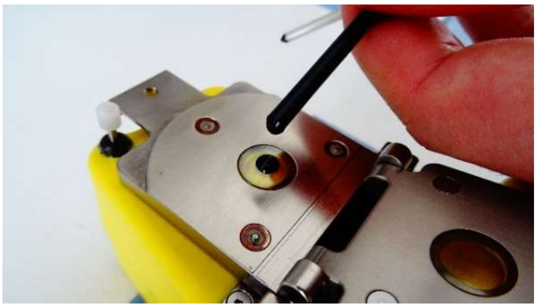


Fig. 8 Inserting the sample on the sample slide 1
Source: authors.

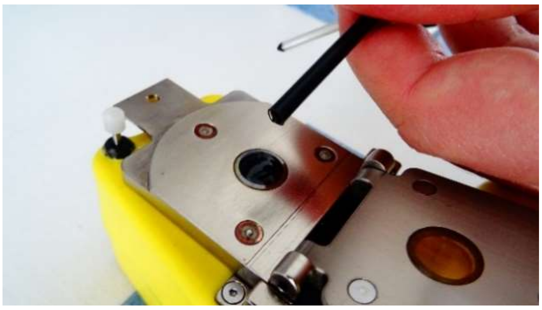


Fig. 9 Inserting the sample on the sample slide 2
Source: authors.

The output of the device is the measured parameters in numerical form and a graphic display, which compares the state of the new oil (reference sample) and the current state of the oil filling in the engine. In the graphic display, the red curve represents the new oil (reference sample). The black curve represents the worn (current) sample of engine oil. A large distance between the curves indicates a high degree of oil degradation. In this case, it is a relatively large degree of degradation in the monitored chemical parameters.

7 CRITERIA FOR USABILITY AND EVALUATION OF ENGINE OIPARAMETERS

- **Appearance.** Do not allow turbidity - matt surface with light reflection.
- **Kinematic viscosity.** Engine oil may only be operated within a viscosity range of ± 20% of the reference sample and diesel engine oil manufacturer's data.
- **Viscosity index**. Temperature dependence of oil fluidity.
- **Sulfation products**. Sulfates are products containing sulfuric acid salts, sulfates. They cause the breakdown of the base oil components and additives in the engine oil.
- **The glycol content.** (Ethylene Glycol-C2H6O2, or Propylene Glycol-C3H8O2) in engine oil is not permitted.
- **TBN - alkalinity number.** Do not allow the operation of engine oil when the TBN value is reduced by more than 50% of the value of the reference sample and the engine oil manufacturer's data.
- **Total engine oil additive.** Do not allow the operation of engine oil when the value of the total additive is reduced by more than 50 %.
- **Water content**. The limit value of the water content in motor oil is 0.5% w / w / 5,000 ppm (concentrations of 0.1 - 0.3% w / w / 1,000-3,000 ppm are already a risk factor). [4] [12]

Table 2 Parameters of used motor oil Shell HX-8 5W-30

Measured samples	**4.12.2021 (reference sample)**	23.02.2022 (first used sample)	**27.4.2022 (second used sample)**
Kilometres worked	**0**	3940	**7140**
Veahicle approach	**193256**	197196	**200396**
Aditives [%]	**100**	80	**69,3**
Glycols [%]	**0**	0	**0**
Nitritation [abs/cm]	**6,3**	7,3	**12,2**
Oxidation [abs/0,1]	**14,6**	20,5	**22,8**
Soot [% wt]	**0**	0,05	**0,14**
Sulfatation [abs/0,1]	**17,8**	34	**33,5**
TBN [mg/KOH]	**7,75**	4,4	**2,8**
Water content [ppm]	**37,5**	207	**264**
Kinematic viscosity at 40° C [cSt]	**+20% 81,4 67,7 -20% 54,16**	**66,9 -0,8/-1,18%**	**67,2 -0,6/-0,88%**

Source: authors.

8 MEASURMENT RESULTS

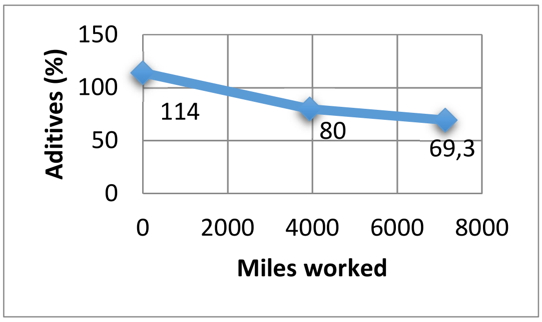
- **SUITABLE** kinematic viscosity / 40 ° C: 67.2 [cSt], MO viscosity reduction is 0.5 [cSt] - Mo viscosity reduction by -0.88 [%]. The allowable tolerance is derived from a reference sample of 67.7 [cSt], ± 20% (+ 20% = 81.4; -20% = 54.16cSt), cf. Table.

Other parameters of the monitored properties, measured in the Laboratory of Tribodiagnostics AFA are within the tolerances of the usability of the MoD, valid for the used MoD No. 1 (see table).

- **Alkalinity number (TBN)** [mg KOH / g] - 2.8 - if the TBN value decreases by more than 50% of the value of the reference sample, MO operation is not permitted - **NOT SUITABLE.**
- **Carbon black [% w / t]** - 0,14 - increase compared to the reference sample by 0,14 [% w / t], maximum value is up to 2% w / t – **SUITABLE.**
- **Oxidation [abs / 0,1]** - 22,8- increase compared to the reference sample by 7,4 abs / 0,1 - do not allow MO operation if the value of antioxidant content decreases by more than 50% of the value of the reference sample – **SUITABLE.**
- **Nitration - Nitritation [abs / cm]** - 12.2 - increase compared to the reference sample by 5.9 abs / cm.
- **Sulfation [abs / 01]** - 33.5 - process in MO causing decomposition of base oil components and additive by starter water is present in MO in proportion to the presence of water - **SUITABLE.**
- **Water content [ppm]** - 264 - reference sample was not contaminated with water - monitored and limit values of water content in MO are 0.1-0.3% w / w / 1000-3000ppm – **SUITABLE.**

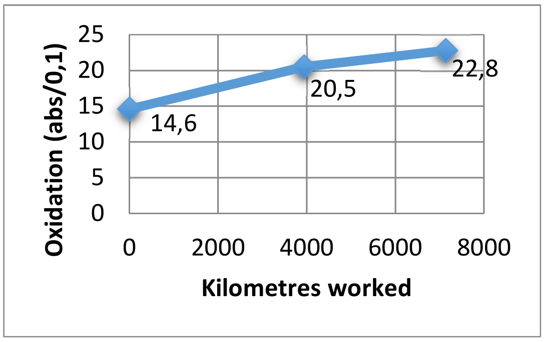
- **Glycols [%]** -0,0- value the same as in the reference sample / the presence of glycols in the MO is not allowed - **SUITABLE.**
- **Addivation [%]** - 69.3 - decrease compared to the reference sample by 39,2 [%] - do not allow MO operation if the value of the total additive is reduced by more than 50% - **SUITABLE**

Appearance (comparison of clarity, gloss, odor and turbidity) Determine whether or not it satisfies according to its own methodology (practical and professional experience). Do not allow turbidity - matt surface with light reflection



Graph 1 The level of motor oil addition depending on the mileage of the oil level
Source: authors.

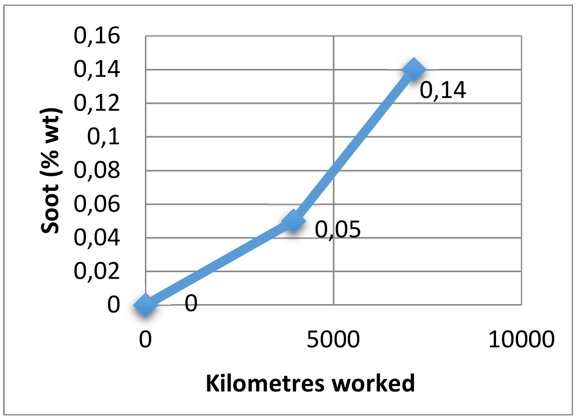
As the mileage of the oil fill increases, the concentration of the additives in the engine oil decreases due to chemical reactions during operation.



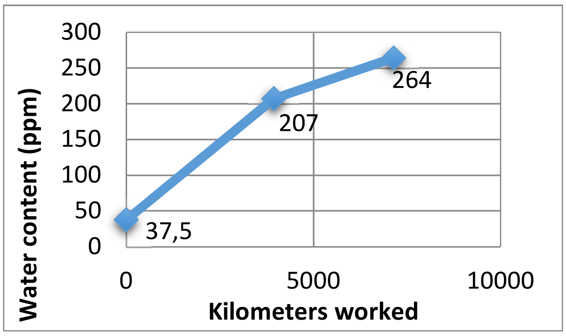
Graph 2 The level of oxidation of the engine oil depending on the kilometers of oil filled
Source: authors.

The measurements showed a gradual slight increase in the oxidation of the engine oil. However, the increase in oxidation was minimal. We can say that the oil is characterized by good oxidative stability.

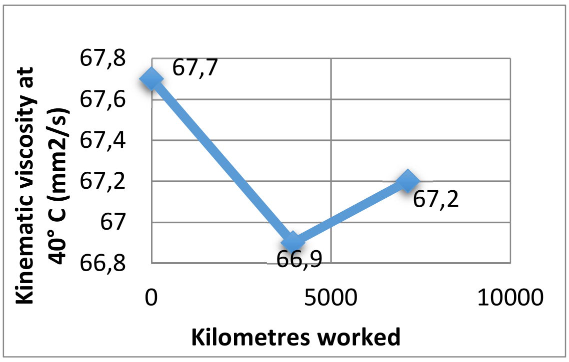
The carbon black content was expected to increase during the period under review. This increase is due to the penetration of combustion products into the oil charge.



Graph 3 Soot content in the engine oil depending on the mileage of the oil level
Source: authors.



Graph 4 Water content of engine oil depending on the mileage of the oil
Source: authors.



Graph 5 Change in kinematic viscosity of the engine oil at 40 ° C depending on the kilometers of oil filled
Source: authors.

During the monitored period of operation, the water content of the engine oil increased, but it was within the permitted values. Water causes additives to fall out because it triggers the sulfation process. Water also has a corrosive effect on steel surfaces.

Kinematic viscosity values remained stable during the observed period. Viscosity values were within the allowable range. Kinematic viscosity is the primary physical parameter monitored for engine oil.

9 CONCLUSION

This work consisted of tribodiagnostic measurements and their evaluation. The measured values show that the new oil filling during the first ones showed a significant decrease in the TBN parameter. Measurements showed unsatisfactory TBN parameter. We recommend to measure sample of the motor oil after driving next 2 000 km and then is possible to decice about the further operation of the MO.

References

[1] *Bmw 3*. (Online). Available at: https://edukr.ru/en/avtoyurist---free-consultation/bmv-dvigatel-3-litra-dizel-osobennosti-ekspluatacii-dizelnye-dvigateli-bmv/

[2] *Classification SAE*. (Online). [cit. 2021-5-5]. Available at: https://www.motorove-oleje.sk/dokumenty/klasifikacia-sae/

[3] LUKÁŠIK P. and MARKO, M. *Deterioration dependability diagnostics. Monitoring of motor oils degradation by the operation of the vechiles 155mm ShKH Zuzana type 2000, 2017.* ISBN 978-80-7582-009-9.

[4] *Engine cooling and lubrication systems.* (Online). Available at: https://www.cedengineering.com/userfiles

[5] *Engine lubrication system, diagnostics and distribution of oils.* (Online). Available at: http://www.autorubik.sk/clanky/ mazaci-system-motora-diagnostika-a-rozdelenie-olejov/

[6] *Engine N57.* (Online). Available at: http://australiancar.reviews/bmw_N57.php

[7] FluidScan 1000 User´s Guide: Spectro Scientific. One Executive Drive Chelmsford, 2014.

[8] *Principles of lubrication.* (Online). Available at: https://blog.emersonbearing.com/blog/principles-of-lubrication

[9] MARKO, M. a kol. BULL-12-6, *Properties and tribodiagnosis of lubricants in the operation of motor vehicles.* Trenčín.

[10] ČERNÝ, J. *Properties of motor oils-Oxidation stability, nitration of oils.* (Online). Available at: https://www.oleje.cz/clanek/Vlastnosti-motorovych-oleju---Oxidacni-stabilita--nitrace-oleje/ [cit: 2021-05-05].

[11] *Shell Helix HX-8 5W-30.* Available at: https://www.shell.co.id/in_id/motorists/oil-and-lubricant/helix/helix-hx8/_jcr_content/par/contentblock/link.stream/1587444518076/71a934067d799f774bcbd632722a86fc3ae5fd24/hx8-x-5w30.pdf

[12] SpectroVisc Q3000 Series User´s guide: Spectro Scientific. One Executive Drive Chelmsford, 2014

[13] STOPKA, J. *Technical information č. 4/2011.* Undesirable impurities in engine oil for diesel engines, 2011. [online]. Available at: http://www.tribex.sk/info/info.pdf/

Dipl. Eng. Miroslav **MARKO**, PhD.
Armed Forces Academy of General M. R. Štefánik
Department of Mechanical Engineering
Demänová 393
031 01 Liptovský Mikuláš
Slovak Republic
E-mail: miroslav.marko@aos.sk

Bc. Jindřich **STEHLÍK**
Armed Forces Academy of General M. R. Štefánik
Department of Mechanical Engineering
Demänová 393
031 01 Liptovský Mikuláš
Slovak Republic
E-mail: jindrich.stehlik@aos.sk

Miroslav MARKO was born on September 25, 1954 in Myjava, Slovakia. Between 1961 to 1970, he received secondary education at the Grammar School in Nové Mesto nad Váhom. From 1974 to 1978 VVŠ PV, university education in the field of "Operation and repair of the tank and automotive technology". From 1991 to 1993 VŠPe, additional pedagogical study, Faculty of Education in Nitra. In 1997 House of Technology and Tribotechnics, postgraduate one-year study in Tribotechnik, Bratislava. From 1999 to 2004 Military Academy, doctoral study – external, 91-06-9 Armament and Ground forces technology. Liptovský Mikuláš in the field 20. May 2011 Tribotechnik Certification – This is to certify that is qualified for activities in technical diagnostics.

Jindřich STEHLÍK was born in Levice, Slovakia in 1999. In the years 2014 to 2018 heI received a secondary education in Levice. In the year 2021 he received a bachelor's degree from the Academy of the Armed Forces gen.M.R. Štefánik in Liptovský Mikuláš.

DOI: https://doi.org/10.52651/sam.a.2023.1.39-44

RELEVANT TASKS FOR UAV PROTECTION SYSTEMS IN RELATION TO THE AERIAL SCENARIO OF NUCLEAR FACILITIES

Zoltán BEBESI, Zsolt JURÁS

Abstract: The goal of this paper is to present the risks that Unmanned Aerial Vehicles (also called Drones) pose for nuclear facilities. The technologic advancements of these unmanned aerial vehicles are one of the most dynamically evolving industries currently; which while through the growing widespread and numerical increase represent many advantageous usability, are also starting to pose an ever-increasing threat. An increasing number of cases get reported when UAVs violated the airspace and security of critical infrastructure facilities. The paper includes a technological overview of the UAVs, their use-cases and a discussion of the security risks they represent. In order to present the actuality of the topic, the recent nuclear power plant endangerment incidents committed by drones and the properties of drones that represent a potential source of danger are detailed. Additionally, the physical protection technologies of nuclear power plants are discussed; also, the importance of capabilities for the detection, delay and neutralisation of drones. In the final chapters we present our conclusions and suggestions.

Keywords: Umanned aerial vehicle; Nuclear facility; Anti-drone systems; Risk; Defences tasks.

1 INTRODUCTION

The global threat of terrorism has elevated to new levels after the 9/11 terror attacks on the U.S., and it gave rise to new concerns about the risks of a terror attacks on nuclear facilities. If we take into consideration the significant effect they have on national moral, economy and power safety - these facilities can be a very tempting target for terrorist groups. Though the paramount objective a terrorists group can achieve with an attack on a nuclear facility which makes it even more tempting is global new coverage. Attacks on nuclear power plants (NPP) not only have the potential for nuclear endangerement of the general population, but can also greatly damage the power supply and the economy with it (49,2 % of Hungary's power generation is realized in the NPP of Paks for example) [1]. The fact that there were more then one occassion of airspace violation of airs spaces of NPPs by drones in France in recent years shows us, that the risks are all too real and the threat is serious. Not only does it gives reason for worry that these drones could perform this act, but the fact that the competent authorities could not find an answer on how these incidents could happen or prevent them from happening is even more worrisome. Political leaders around the globe have noticed these problems. In spring 2016 there was an international nuclear security meeting in Washington D.C. where David Cameron british prime minister have said that in his opinion the terrorists will utilise any tools and equipment they can get their hands on to achieve their goals. [2] Trusted sources have confirmed, that two terrorists organizations – the Al-Queda and the AumShinrikyo (Japan) have already attempted to acquire nuclear or radioactive material or weapons. Other sources have confirmed that Chechen terrorists groups have performed reconassiance missions on russian nuclear weapons depots, and as part of the nuclear arms initiative of the Al Queda they have tried to purchase nuclear material and recruit nuclear expertise to their ranks. Amongst the plans for the 9/11 terror attacks was the plan to attack a NPP also. In the databases of the Interpol counter-terrorism unit one could find 167 cases which involved nuclear material in the three decades between 1970 and 1999. Between 1966 and 1977 there was 10 attacks in Europe which were performed against power plants or related infrastructure. Based on reports of the russian intelligence services 50 of such cases were registered in the Russian Federation. In the October of 2005, chechen insurgents have attempted to hijack airplanes and planned on attacking russian targets with them - and amongst the targets was one NPP as well. 240 cases of attacks were registered in the U.S. in the time period of 1967 – 1975. In a report published in 2005 January 40 cases were published of endangerement of the safety of NPPs in the United Kingdom. The sabotage action committed against the Belgian Doel 4 reactor in 2014 was performed by an insider who have – by opening a simple valve – released all the machinery oil from the turbine of a reactor, which lead to it overheating and becoming irreversibly inoperable. Even though there was no risk of radiactive endangering, the losses of the forced downttime and repairs were 100-200 million U.S. dollars. In 2016 both the identity of the saboteur, and possible motivations were still mistery for the authorities.

Based on these cases it can be concluded, that the threat of terrorism targeting nuclear facilities is real and be verifyed. One emerging tool for these attacks are the utilization of drone technology. The evolution of drone technologies gives rise to the need for the evolution of counter-measure technologies. The drones are usually flying equipment, that can either be autonomous or remotely controlled (or combination of these), there is no need for an on board pilot. The reason behind drones becoming a more competent equipment for threat actors can be traced back to more then one reason. Firstly the price of commercial drones have plummeted in recent years and are easily accessible for any ordinary customer. The drones range and velocity greatly increased, their operating time is ever increasing; furthermore their carry capacity increases as well. The few tens of meters operational range of early commercial drones have increased to 12 km with for example the new Occusync 3 system. [2] Their cameras are capable of taking higher resolution pictures and videos and their navigational precision can reach the cm precision thanks to for example the RTK (real-time kinetic) support. Disguised drones which are only a few grams in weight are available too. Some commercial drones are also capable to carry weapons or equipments for diversion. Their utilisation in case of an attack can be dual therefore; they can both to perform preliminary reconaissance or to take active part in the attack. Hybrid drones that can traverse both in air and water can pose an even more worrying threat. The reason for this concern is that most of the nuclear reactors around the globe are built next to large open waters because of technology reasons (most are either bioling water or pressured water reactors). On the defense side we can see that NPPs are only capable to detect large airborne vehicles.

2 ANTI-DRONE MEASURES OF HUNGARIAN NUCLEAR FACILITIES

The advancements in technological capabilities and the increase in popularity of commercial drones have created a new regulational challenge. The drones don’t only pose a security threat for nuclear facilities like nulcear power plants, research reactors and nuclear waste depots but can be also utilised in many industries for great effect. They could also perform many roles in the nuclear field, such as support of operations, security or monitoring and measurement for environmental protection. [3] When discussing the protection of nuclear facilities one must also mention nuclear security, since the protection of the airspace will be considered a part of it. Nuclear security is the whole of activities, equipment and procedures which are utilized for the goal of prevention, detection and repelling of sabotage, deliberate damage or misappropriation of radioactive material. We must point out though, that airspace violation of a nuclear facility could also happen with no intent on causing damage, with motivations to protest or as a „rite of bravery”, or simply by accident. Taking the potentional risk into consideration and that the intents of the violation can only be evaluated much later any airspace violation has to be considered an active threat for the facility. Security issues related to UAVs are complex and risk assessments require consideration of wider aspects, such as societal, psychological, political and financial factors. [4] UAV risk assessment therefore is a very important tool for thorough identification and evaluation of active and hidden risks. The evaulation of these risks have to propose possible risk mitigations on how to decrease the likelihood of threat events and their effects. With these results security risks become measurable and can be mitigated systematically. The sub-procedures of a risk assessment are: identification of risks, risk estimation, mitigation, documentation. [5] The phyisical protection system has to provide the functions needed for detection, deterrence, delay and repelling while they have to effectively support physical protection goals. The goal of deterrance is to convince the perpetrator to give up his pursuit of a sabotage or misappropriation early in the planning phase of the attack. During the action of the detection capability the actions of the perpetrator have to be detected, the detection has to be verified, identifying the location of misdemeanor and to alert reaction units. The goal of the delay funcion is to increase the time needed for the perpetrator to successfully reach points in his attack, giving time for the reaction units to intercept in time. As part of the repel function the reaction units prepare for action after they received an alert, reach their destination for interception, and impede and neutralize the perpetrator in accordance with the goals of physical protection. In most European countries most nuclear facilities are classified as critical infrastructures in accordance with the European Union directive on protection of EU critical infrastructure We feel it necessary to clarify the meaning of critical infrastructure at this point. Critical infrastructures provide the necessary continuity for the industry, like power supply, personnel and goods transportation, or the financial sector. After long, domestic critical infrastructures have been identified in Hungary as well, with the 2012. CLXVI. act, though nuclear facitility’s nuclear safety, radiological protection, physical protection and safeguards were exempt from the list in the 1st annex. Therefore even though NPP of Paks holds a key role in hungarian industry and the potential consequences of a nuclear catastrophe it is not classified currently as critical infrastructure. [6],[7] It is in the very best interest of the hungarian society and industry that the NPP of Paks can operate safely and continuously. It was realised that it is not enough to evaluate only to the extent of military operations or terror attacks, but the potentional threat to endangerement of power generation have to be taken into consideration as well. It is of importance to protect those objects that, if damaged, though don’t pose a threat to nuclear safety, but can lead to loss of production in one or all power units. Since NPP of Paks provides 49,2% of hungarian power production, such loss of production could have significant effect on the economy. Airborne weapons of destruction or attack groups therefore present an elevated threat, since protection strategies provide greater protection for a ground based threat. The primary objective of a theoretic attack doesn’t need to be destruction solely, it can also be reconaissance, to cause panic, to provoke political and societal effects through news coverage which could greatly deteroirate the safety perception and trust in the government and state authorities of the general population. [8]

The parameters of the required protection against airborne threats are defined in more than one domestic legislative document. The basic requirements for the physical protection systems are defined in the 1996. CXVI. act on Atomic Energy. In the 4/A. § c) it declares that the primary responsibility for the safety of a nuclear facility belongs to the organization which is the licensee of the nuclear facility or activity. The detailed regulations, containing requirements for the DBT and the Physical Protection Plan can be found in the government decree 190/2011 (XI.19.) on physical protection requirements for various applications of atomic energy and the corresponding system of licensing, reporting and inspection. The requirements for the operation of armed security guards that protect the facility requirements are set in the 1997 CLIX. act on armed security guard services, nature and field guard services and in 27/1998. (VI. 10.) Ministry of Interior decree on Operations and Service Code of armed security guards. Neither of the aforementioned legislations deals with the ways how the personnel performing the protection of the facility could act against airborne vehicles and equipment, nor by the possibility to distrupt their flight nor to open armed fire on them.

During evaluation of the possibilities of airborne terrorist attacks it is important to take into consideration both the level of control of the affected airspace and the set regulations for the use of that airspace. Airspace of the Hungarian Republic can be divided between „controlled" and „un-controlled" areas. In the controlled airspaces an authority is responsible for it and for authorizing passage in it if someone wishes to use that airspace. Armed protection of the hungarian airspace is the sovereign right and obligation of the Hungarian Defense Forces in accordance with the 36. § (1) a) of the 2011. CXIII. Act on Hungarian Defense Forces and on applicable actions in case of special legal order. Amongst the nuclear facilities of Hungary, the NPP of Paks has a 3 km radius and up to 5950 meters in elevation to ground level airspace, named LHP1 which is a no-fly zone deisgnated in the 26/2007 (III. 1). GKM-HM-KvVM joint decree on designation of airspace for airtravel. This decree has been modified in 2018, which allowes flight in this zone during peacetime with special authorization by the ministry. This no-fly zone is very important for both nuclear security and for the avoidance of a nuclear accidents caused by accidental airplane crashes. The HAEA have suggested earlier to extend the radius to 15 km around the facility. The authority reasons this would result in the increase of the timeframe available for detection and to repel an attack. The fact that if you consider the current 3 km radius zone, if an object with 180-200 km/h velocity enters the no-fly zone it reaches the facility within 1 minute proves the viability of such suggestion. This velocity can be reached with current drone technology and this has to be a consideration when calculating required reaction times. On the other hand, such measure could prove to be a difficulty for the surrounding settlements and could cause a significant financial burden.

Nuclear catastrophe could occur as a consequence of an accident and a terrorist attack as well. Reactor accident are usually caused by the deprivation or decrease of coolant material in the reactor. In this case the criticality of the fissive material reaches levels that could result in uncontrolled chain reaction. This can lead to radiological exposure of the environment which exceeds the safe levels multiple times. The consequences in case of stolen or lost radiation sources which don't have control by the authority depend on the activity, condition and position of the source and the time of exposure. [9] As we mentioned earlier, most of the commercially available drones are 800-1500 grams in weight, therefore they don't pose a kinetic threat to the facility. Greenpeace have ordered a paper on the risks drones represent to NPPs from a consultant company, which have found that even these low-kinetic, lightweight drones could damage small, vital parts of a facility that could result in nuclear accidents of the magnitude Fukushima represented. For this, during an attack the first wave has to target the coolant supporting systems which are usually outside of the main structure, while a second wave should target the diesel generators which provide auxuliary power supply for the continous cooling of the reactor. An attack like this could lead to cooling distruption or could make cooling impossible. According to the paper lower grade explosives used as a payload attached to the drones could be enough to reach this effect. [10],[11] Malicious intent attacks can be also supported by drones. There are disguised commercial drones available, which are harder to identify. These usually represent some kind of a bird, not only in their looks, but also in the method they fly, mimicing and utilizing wing stroke. The lack of rotors lead to a much lower noise and also provides longer flight time with more efficient power usage. [12]

The potential dangers are the reconaissance performed by drones; the live intelligence support of ongoing terrorist attacks; the transportation of forbidden objects into the protected zones; and the utilization durcommercial of drones as weapons platforms and as explosives delivery method. Weather and environmental resilience of drones also greatly improved, with water resistant drones availabe which aren't held back by rain or high levels of humidity. Some hybrid drones are capable of traversing both in water, under-water and in the air. One example of such hybrid is the Spry drone which became available in 2019. [13] This could prove to be of greater importance because of the usual proximity of open waters and NPPs. The NPP of Paks has direct connection to the river Danube for example. The Danube provides the coolant required for the NPP and it is situated about 2000 meters from the middle of the river. Because of this, violation of the territory of the NPP by an aquatic or submerging drone is a highly realistic possibility. Drones equiped with heat sensors can navigate and reach their targets in bad visual conditions, but simple GPS based navigation can also reach accuracy measured in centimeters. Furthermore some drones are capable of autonmous operations. The operator has to set the flight plan and it performs the flight individually without the need for any interaction by the operator. The industry leading DJI manufactures drones that have the so-called „no-fly zone" protocol which prevents them from entering or taking off in no-fly zones (currently this usually means areas around airports). However, this measure can be circumvented by illegal modification, hacking and some manufacturers don't use these measures. The news about the results of the joint research of Eötvös Lóránd University department of biological physics and MTA-ELTE Biological and Statistical Physical research group on drone swarms have been published in 2014. The research group lead by Tamás Vicsek have created worlds first self-organizing quadrocopter drone swarm consisting of ten drones. The researchers have managed to achieve successful, collision-free cooperation between thousands of high-speed drones in more then 30 cases which have simulated highly difficult environment. These so-called intelligent drone swarms give rise to the need for completely new methods of defense, which challenge is yet to be answered by an accepted protocol. [14] Drones or smaller drone swarms can be equipped by explosives and can be directed to critical structures. They can be also equipped with weapons, small explosives, or with graphite bombs, which can distrupt electric networks. The live monitoring of the defensive forces during attack is also possible and could greatly support an ongoing attack.

3 SUGGESTIONS

Protection against drones has to become high priority in domestic nuclear facilities, because the properties presented prove that they are capable to distrupt operations, can obtain information (pictures, videos) which can support preparation and execution of a terrorist and sabotage actions against the facilities. Below we have summarized the suggestions for measures against drones.

Suggestions for protection against unmanned aerial vehicles:

1. Extension of the no-fly zone around NPP of Paks.
2. Tracking of air vehicles when approaching the facility's 30 km radius airspace for better early warning capability.
3. Unified protection for Paks I, Paks II and Interim Storage of Spent Fuel.
4. Fielding of a complex anti-drone system for the NPP of Paks.
5. Evaluation of aquatic entry point, utilization of preventive measures if necessary.
6. Introduction of obligatory unique identification for drones and their owners, similarly to license plates of cars.
7. Obligatory drone piloting training for every non-leisure category drone owner. (To minimize number of accidents and to assure legislative knowledgeability).
8. Regulations for drone classifications should not only consider the weight of the UAV but also it's effective range, equipment (for example heat vision, suspension for other equipments, etc.), operation time, carrying capacity, and maximal velocity.
9. Obligatory registration and authorization for home-made drones.
10. The use of serious punishments for the violation of no-fly zones which provide deterring power.
11. Active communication of the nuclear facilities defensive capabilities and of the consequences of airspace violation for deterrence.
12. Re-classification of NPP of Paks as EU critical infrastructure while keeping nuclear safety and security requirements.
13. Obligatory reporting to NPP of Paks for owners planning flights in the vicinity of NPP (but outside no-fly zone).
14. Evaluation of possible liability insurance for drone owners.
15. Mandatory periodic technical inspection for drones.

Regarding nuclear facilities, Hungary has one research reactor, the Interim Storage for Spent Fuel, National Radioactive Waste Repository, the Radioactive Waste Treatment and Disposal Facility, and the 4 reactor units of the NPP of Paks. Of the aforementioned facilities the protection of NPP of Paks I, the planned NPP of Paks II and the Interim Storage of Spent Fuel should be unified – with their close proximity and interlapping airspace taken into consideration – for the most effective results. According to the results of a 2018 paper on nuclear safety and security culture effective installment and operation of physical protection and nuclear safety is a joint responsibility of the state and the lincesees. State participation is not only a technological, but also a strategic neccessity, which can be justified by the following. If drone detection measures are not procured and fielded in a unified measure, it can lead to them being uncompatible with each other, making cooperation difficult, which leads to less effective detection capabilities all around. Time becomes a more important factor in case of spearate protection, because communication, coordination between the independent organizations and personnel leads to loss of time that could have been spent on reaction, while can also lead to information distortion. Practical examples show that the optimal actor for procurement of these sometimes military grade equipments is the state, because obligations for the protection of the general population allow much higher budget riskwise compared to a company. The technical/technological personnel responsible for the detection, support and operation of these equipment has to have uniform competencies, which leads to the neccessity of uniform, centrally controlled training and organization. In case an agressor state would perform a drone attack, only the state has the required authority and tools to counter such international atrocity or threat.

4 CONCLUSION

It is key to create nuclear facilities anti-drone systems for a modern protection. In today's world every strategically important facility has to take this new kind of threat into consideration and provide counter-measures for it. In the future we can expect that the numbers of residential, commercial and military drones will increase, while becoming more and more available. Because of the constant technological advancements, these drones will be even faster and more quiet, and could spend more and more time operating. The number and variety of equippable tools and carrying capacity of them will increase, while operation will become easier. Another challenge is most parts can be manufactured by privately owned, hobby-grade 3D printers (a Singapoure based company already produces drones with 3D printers, which have the weight of less then 2 kilos, operation time is 2 hours, and maximal speed is 60 km/h. Every part of it can be 3D printed except for the electronics. With 3D printing utilized design time deceased by 40%, weight decreased by 20 %.) Rapid development of drones justifies the neccessity for greater emphasis on the threat they could pose. It is neccessary to declare the professional basis for drone piloting, the paraphrasing of neccessary regulations, the creation of a framework for drone usage. [15], [16] Drone technolgies is one the most rapidly evolving industries, which provides a waste aray for possible use in many fields from hobby, to agricultural and professional). These positive changes are hand in hand with the development of security threats they give rise to, which has to be handled adequatly by security professionals and industry in a timely manner.

References

[1] Available at: https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=HU

[2] *Anti-terrorist response teams to be created around UK.* (Online). Available at: https://www.theguardian.com/uk-news/2016/apr/01/anti-terrorist-response-teams-uk-david-cameron

[3] SOLODOV, A., WILLIAMS, A., Al HANAEI, S. et al. Analyzing the threat of unmanned aerial vehicles (UAV) to nuclear facilities. (Online). In *Security Journal*, 2018, vol. 31, pp. 305–324. Available at: https://doi.org/10.1057/s41284-017-0102-5

[4] CLOTHIER, R. A. and WALKER, R. A. The safety risk management of unmanned aircraft systems. In *Handbook of unmanned aerial vehicles,* 2015, pp. 2229-2275. ISBN 978-90-481-9706-4. Available at: https://doi.org/10.1007/978-90-481-9707-1_39

[5] WACKWITZ, K. and BOEDECKER, H. *Safety risk assessment for uav operation. Drone Industry Insights, Safe Airspace Integration Project, Part One.* Hamburg, Germany, 2015, 31-53.

[6] HAIG, Z. and KOVÁCS, L. *Kritikus infrastruktúrák és kritikus információs infrastruktúrák.* (Online). Available at: https://www.uni-nke.hu/document/uni-nke-hu/kritikus_infrastrukturak.pdf

[7] JURÁS, Zs. *The Nuclear Power Plant, the main tasks of guarding and protecting the vulnerability of a component in the critical infrastructure.* (Online). Available at: http://bk.bgk.uni-obuda.hu/index.php/BK/article/view/74

[8] HAIG, Z., HAJNAL, B., KOVÁCS, L., MUHA, L. and SIK, Z. N. *A kritikus információs infrastruktúrák meghatározásának módszertana.* (Online). Available at: https://nki.gov.hu/wp-content/uploads/2010/01/a_kritikus_informacios_infrastrukturak_meghatarozasanak_modszertana.pdf

[9] SOLYMOSI, M. *Új eljárások a nukleáris biztonsági és védettségi kultúra felmérésére és fejlesztésére*, PhD dissertation. (Online). Available at: https://www.uni-nke.hu/document/uni-nke-hu/solymosi_mate_doktori_ertekezes_2018.pdf

[10] *Drónveszély: mi lesz az atomerőművekkel?* (Online). Available at: https://iho.hu/hirek/dronveszely-mi-lesz-az-atomeromuvekkel-150302

[11] CATHERINE, P. and CONOR, G. *Most French Nuclear Plants 'Should Be Shut Down' Over Drone Threat.* (Online). Available at: https://www.newsweek.com/2015/03/06/most-

french-nuclear-plants-should-be-shut-down-over-drone-threat-309019.html

[12] STEN, L. *An Icelandic inventor has achieved the holy grail of airborne technology with a drone that flies like a bird.* (Online). Available at: https://www.businessinsider.com/bird-drone-could-revolutionize-surveillance-2018-5

[13] Spry+: All-in-One waterproof drone Available at: https://www.swellpro.com/spry-.html

[14] Beszélgető drónrajok, összehangolt repülés (Online). Available at: https://www.elte.hu/content/beszelgeto-dronrajok-osszehangolt-repules.t.17006

[15] CARLOTA, V. *What benefits do 3D printed drones bring to our society?* (Online). Available at: https://www.3dnatives.com/en/3d-printed-drone-150620204/

[16] VIGH, A. *A drónok rendészeti alkalmazási lehetőségei*. (Online). Available at: https://doi.org/10.38146/BSZ.2018.10.6

Dr. Zoltán **BEBESI,** Ph.D.
Security Strategy Manager
FOXCONN Cloud Network Technology Ltd.
Bánki Donát út. 1.
H-2900 Komárom
Hungary
E-mail: dr.bebesizoltan@gmail.com

Zsolt **JURÁS** (PhD student)
Óbuda University
Doctoral School of Safety
and Security Sciencs
Bécsi út 96/b
H-1034 Budapest
Hungary
E-mail: zsoltjuras@gmail.com

Zoltán BEBESI currently works as the external security expert of MVM Paks I. Nuclear Power Plant. Earlier in his career, he had the opportunity to visit South American countries (Bolivia, Columbia, Venezuela) and take part in educational programs, which he could later benefit from both as a lecturer and security expert. His PhD dissertation was written on narcoterrorism. Thanks to the actuality of his researches, later - between 2009 and 2014 – he has been employed as an adjunct, then docent at Zrínyi Miklós National Defense University (now National University of Public Service). Between 2015 and 2018 he was the founder and the head of the Department of Counterterrorism at the National University of Public Service. The central topics of his scientific publications are mostly the South American terrorist organizations, the main problems of terrorism and the possible methods of acting and preparing against them. He has received numerous honors and acknowledgements, such as the Pro Scientia Medal or the Memorial Plaque of the Police of the Republic of Hungary. He is also a founding member of the History of Hungarian Intelligence Department of the Hungarian Military Science Association.

Zsolt JURÁS was born in 1980. He completed his studies at the Faculty of Electrical Engineering of the University of Óbuda, specializing in electronic asset protection and supervisory IT. In 2012, he obtained a certificate in electrical engineering at Széchenyi István University, also in electrical engineering (MsC), with a „excellent“ qualification. He gained almost 20 years of professional experience in the nuclear industry in the fields of nuclear safety and security. He is currently a PhD student at the Doctoral School of Security Sciences of the University Óbuda.

COOPERATION
INNOVATION
TECHNOLOGY
TRANSFER
2023

THE BIGGEST EVENT DEVOTED TO TECHNOLOGY TRANSFER IN SLOVAKIA WITH INTERNATIONAL PARTICIPATION

COINTT 2023 WILL ALSO GIVE SPACE TO:

NATIONAL R&D AND INNOVATION STRATEGY

OCTOBER 24 – 25, 2023
BRATISLAVA

YOU CAN FIND ALL INFORMATION ON: WWW.COINTT.SK

ORGANIZERS:

EURÓPSKA ÚNIA
Európsky fond regionálneho rozvoja
OP Integrovaná infraštruktúra 2014 – 2020

MINISTRY OF EDUCATION, SCIENCE, RESEARCH AND SPORT OF THE SLOVAK REPUBLIC

SLOVAK CENTRE OF SCIENTIFIC AND TECHNICAL INFORMATION

CENTRUM TRANSFERU TECHNOLÓGIÍ CVTI SR

CO-ORGANIZERS:

NCTTSR – NÁRODNÉ CENTRUM TRANSFERU TECHNOLÓGIÍ SR

EAS – ENTREPRENEURS ASSOCIATION OF SLOVAKIA

sapie

Event is held as a part of National infrastructure for technology transfer support in Slovakia II – NITT SK II implementation.
Investment in your future / This project is sponsored by European Regional Development Fund/ www.opii.gov.sk

SCIENCE & MILITARY - WRITER´S GUIDELINES

1. Scientific articles submitted for publishing have to be original, topical and never been published before.

2. Articles have to be written in English language and in accordance with ethical standards. For more details, please visit the website of the Science & Military Journal (http://sm.aos.sk/index.php/en/for--authors-en/ethical-standards).

3. Length of the article should not exceed 6 pages in defined format. Microsoft Word text editor must be used for writing. Articles must be written using Times New Roman, single line spacing and follow the following form: Title -12 point bold capital letters aligned to the center. Full author´s (co-author´s) name – 10 point normal letters aligned to the center. Abstract – 9 point normal letters, extent 3-5 lines. Keywords – 9 point normal letters. The article text – 10 point normal letters. Contact - full author´s (co-author´s) name, affiliation, e-mail – 9 point normal letters at the end of the article. The article text will be written in 2 columns format with a 75 mm column width and 10 mm empty space separating the columns. The first line of each paragraph must be shifted 5 mm to the right.

4. Upper and lower margins must be set to 25 mm, left and right margins to 20 mm. Select mirror margins and set binding margins to 10 mm. The distance between the header/footer and the page margin must be 12,5 mm, while different odd and even pages must be selected.

5. Photographs for publication must be in black-white (not in color) of excelent quality with good contrast.

6. Equations in the text are also to be written using the equation editor. (Equation must be typed in Microsoft Equation, which is an integral part of Microsoft text editor.) They must be numbered. Numbers are to be enclosed in parentheses and aligned to the right margin of a column.

7. Figures, graphs and tables must be included in the text and numbered and must contain description. Figures must be identified as Fig. 1 followed gradually by the figure description. Graphs must be identified as Graph 1 followed by the graph description. Tables must be identified as Tab. 1, followed by the table description.

8. References must be fully and accurately documented (according to ISO 690). References should be quoted in the text in square brackets and listed in the order they have appear in the text.

9. The specimen article that can be found on the web-site: http://sm.aos.sk/index.php/en/for-authors-en can be used as an example of the correct format.

10. The editorial board will consider submitted articles in the next scheduled meeting. If it decides to include the article in the next issue it submits the manuscript to the editors for the peer review. The final version (before printing) will be sent to the author for the final revision. The authors are fully responsible for the level of language.

11. Contributions in A4 format edited according to the specimen article should be submitted in one hard copy and also in electronic form to the Editorial board.

12. The deadlines for the delivery of the articles in calendar year are: March 1 and September 1.

SCIENCE & MILITARY

No 1 | Volume 18 | 2023

Content

ISSN 1336 – 8885 (print)
ISSN 2453 – 7632 (online)