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: **M**otor 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.

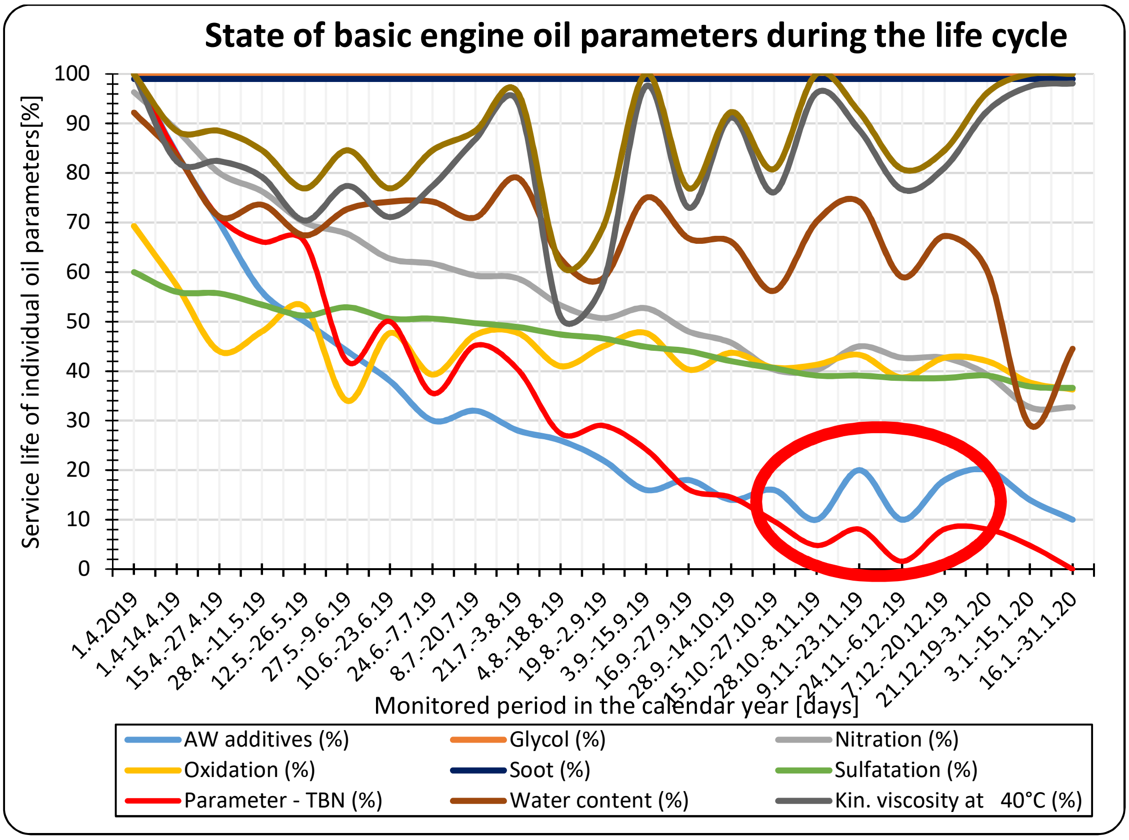

Fig. 5 Illustrative example service life of engine oil in an internal combustion engine and the most fragile parameters (parameter TBN, AW additives) [1]
Source: authors.

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	[km/Mh]	xx	xx	**18.7.2021**		**29.3.2021**		**13.11.2019**		**11.2.2020**		**28.22019**		**12.3.2019**		**23.5.2019**	
					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.

Table 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		MEASURED VALUES							
			REFERENE SAMPLE		Sample No.1		Sample No.2		Sample No.3	
			09.09.2020		6.5.2022		6.5.2022		6.5.2022	
			SAE 20W-50		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	-88,46	-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]

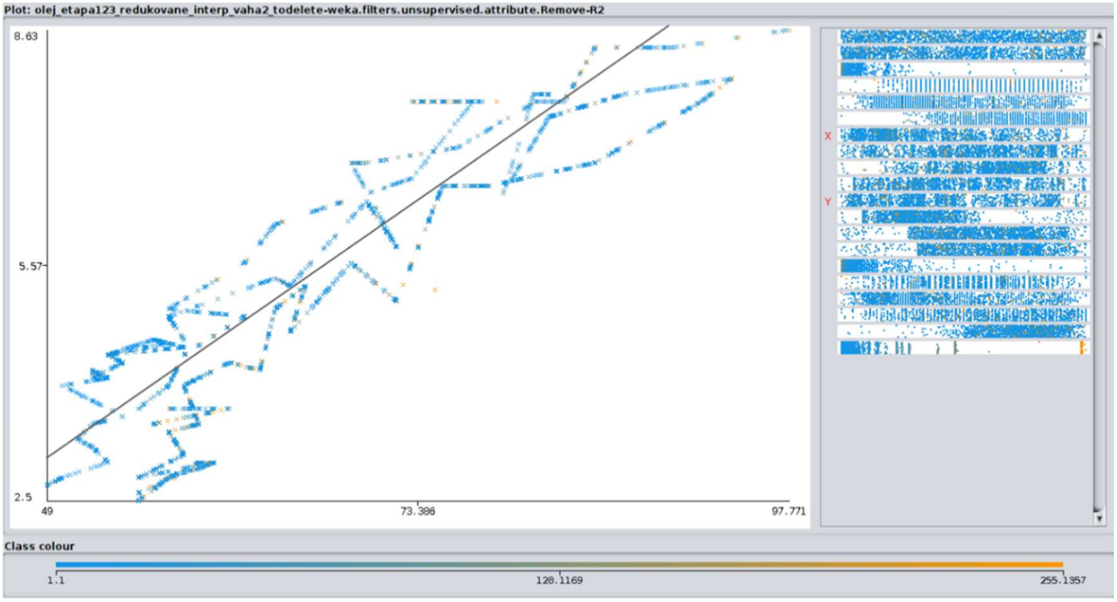

Fig. 8 Correlation of TBN parameter and AW additives displayed in WEKA software [3]
Source: autors.

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.

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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.