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Tribological Investigation of the Effects of Engine Oil Additives for Vintage Gasoline Engines

Restoration of vintage vehicles is becoming more and more popular nowadays. Conditions of usage and operation changed throughout recent years, factory recommended lubricants and fuels are no longer available. The usage of improper lubricants can lead to severe engine damages. The aim of our research is to conduct the analytical and tribological investigation of the lubricant used in a Triumph SC 1300 type four-stroke gasoline engine assembled with two carburetors. Our further task is to conduct analytical and tribological investigation of engine oil that we infused with MoS2 to compare it with the oil in accordance with factory parameters after defined test operation. After the analysis and evaluation of results we serve with recommendations in connection with the given engine to operate it with the most appropriate engine oil regarding operation conditions.

Keywords: *lubricant, oil additives, tribology, vintage gasoline engine oil*

1. INTRODUCTION

Vintage vehicles are becoming popular, however most of them are not in everyday use, but they operate rarely to serve nostalgia and hobby purposes along with modern cars. More precious cars are found in museums or collections, the use of them is limited. Fuels and engine oils prescribed by manufacturers are not available, that means problems regarding operation. Engines can be converted to the usage of unleaded fuel, but in the case of lubricants this solution is not that easy. To the safe operation of internal combustion engines, an important condition is to lubricate machine elements properly and this process is only possible with the proper use of lubricant. Improper lubrication can lead to engine damages. In order to increase the lifetime of different moving elements, to repair operation safety and to consume fuel in an optimal way, application of a liquid-state machine element, in this case, engine oil, is inevitable. The oil, which owns the proper parameters, gives lubrication thus minimizes wear and it keeps the friction coefficient in optimal value [1]. However, we have to mention other functions of lubricating oil, such as sealing, for example between piston ring and cylinder wall, it seals high-pressure gases. Oil is a great cooling agent, it has anticorrosion and cleaning functions as well, wear and combustion residuals are transported by it from lubricated spots. Also, it damps different noises inside the engine [2]. If during the operation of engines, not the proper engine oil is used, or the seasonal oil change is postponed, then oil cannot fulfill its functions and machine elements may suffer severe damages. One of the main reasons of engine damages is the wear process created on the surfaces of contacting parts, which can cause problems in the operation of engines or in more serious cases can lead to the failure of the engine. These wear processes are significantly in connection with the lubricant and lubricated areas [3]. Wear occurring during the engine operation cannot be monitored by modern computerized diagnostic methods. Without the disassembly of the engine, wear processes can be determined more quickly with the tribological investigation of the engine oil. Tribological investigation is also useful, because it can present the lubricating parameters of oil [4]. In case, it managed to determine the deterioration of engine oil, probably oil change (using the factory recommended oil) can prevent further engine damages [5]. It is an important task, because repairing the main parts of specially operated engines or general restoration are hard, timeconsuming and expensive processes. It can also be a further problem, if the factory recommended engine oil is no longer available for the given engines. In this case, it is suggested to conduct the tribological investigation of factory and available engine oils to compare the results and to select the most appropriate one. The engine that we investigated is a Triumph SC 1300 type, naturally aspirated gasoline engine assembled with two carburetor which is operated in several vintaged Triumph vehicles. In our research work we took sample from a 1971 Triumph Spitfire 1300 type vehicle which was tribologically tested. The next step was to conduct the analysis after oil change and after the determined oil additives were mixed. The aim was to define different recommendations after the achieved results to apply the proper engine oil in the examined engine, further, to contribute to normal operation. With our research experiences we would like to contribute to the further operation of vintage vehicles. We hope that the results

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we achieved may provide a proper basis for the investigation of further engine types.

2. INVESTIGATIONS

Triumph Spitfire vehicles represent a classic vehicle-construction, inline engine is mounted in the front. It drives the rear wheels with the help of the rear differential through a manual gearbox installed directly on it with the inserted cardan shaft. The vehicle that we investigated it a Triumph Spitfire 1300, its cubic capa–city is 1300 cm3, it's a 1971 year make, it was totally restored in 2000's. It also acquired oldtimer classi–fication. 4790 km was driven with it since then. The en–gine of the vehicle is presented in the next figures. The exploded view shows the engine arrangement and the main structural elements.

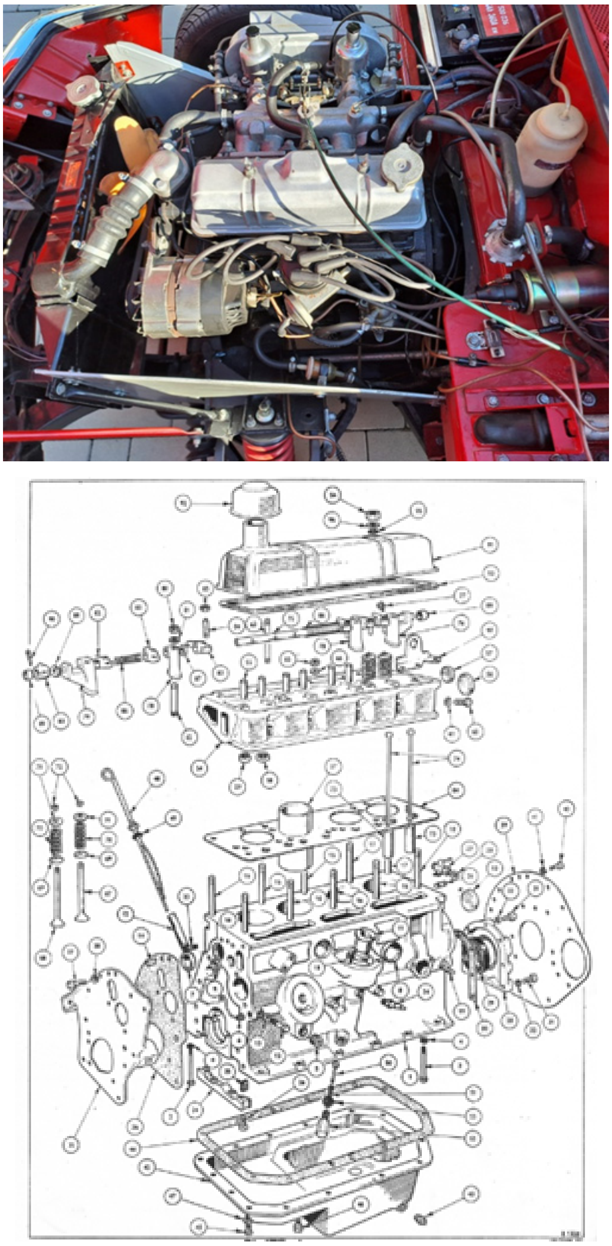
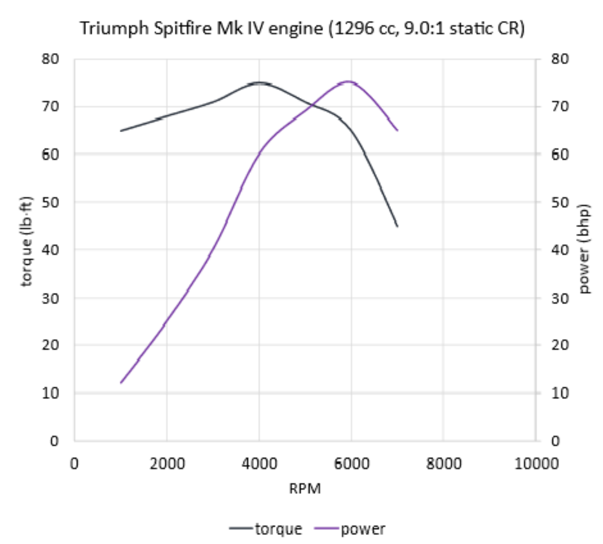


Figure 1. Triumph SC 1300 type gasoline engine (above) and the exploded view (below) (Source: Authors compilation and [6])

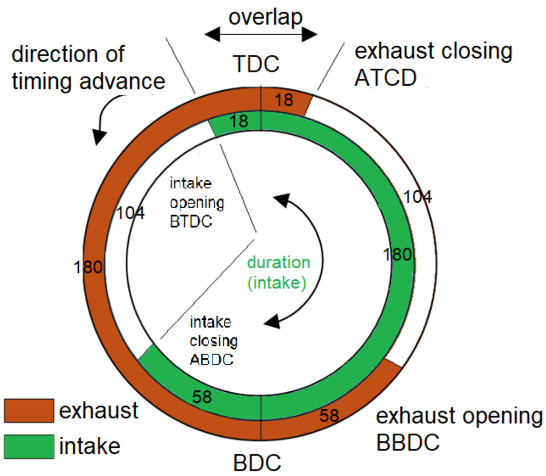
The investigated engine's cubic capacity is exactly 1296 cm^3. It is a 4 cylinder, 4 stroke, inline, OHV, natu–rally aspirated gasoline engine [6]. According to manufacturer instructions oil change is necessary every 10000 km in the engine, also the oil filter is changeable, for European climate 20W50 type engine oil is recom–mended. There is no available instruction for lower run–ning distances from the manufacturer. The present owner purchased the car in 2021 with 4069 run kilo–meters, which was taken during 23 years. Engine oil was evidently thin and had petrol odour, thus 10000 km run could not be reached, it was given a general main–tenance, engine oil and filter change. The vehicle is not usually used, it runs rarely, only for short distances, most of the year it rests in the garage, sometimes the engine is started up for a while. The previous owner also did not use the car every day, it turned out from the mileage. Inspite of few running, the quality of oil decre–ased, detailed laboratory examination of the lubricant is inevitable. After data evaluation, we can determine some recommendations regarding mileage and opera–ting parameters. Before any tribological investigations, we examined the operation parameters of the engines according to available data. The base was an SC 1300 type 4-cylinder inline engine designed and made in 1960s. The engine block is iron cast, also the cylinder head, then power output was enhanced at the end of the decade. That meant increasing compression ratio from 8.5:1 to 9.0:1 and it was given dual carburettor. Stock engine data are the following [6]:

- Cylinder arrangement: inline 4-cylinder, 2 valves each cylinder
- Bore: 73,7 mm
- Stroke: 76 mm
- Displacement: 1296 cm^3
- Compression ratio: 9,0:1
- Power: 75 Hp/6000 rpm
- Torque: 102 Nm/4000rpm
- Pre-ignition: 6^o BTDC
- Clearance: 0,4 mm
- Firing order: 1-3-4-2
- Valve train: OHV

We created the power-torque and valve timing diag–rams of the engine seen below according to the data above.



a) Power-torque curves of SC 1300 type engine



b) Triumph SC 1300 type engine timing diagram

Figure 2: a) Power-torque curves of SC 1300 type engine, b) Triumph SC 1300 type engine timing diagram (Source: Authors compilation)

Examining the figures above, it can be concluded that although the engine was designed in 1960s, its power output is given at respectively high revolution. 75 HP (European unit of measure) moves easily the vehilce with 748 kg mass, to reach optimal engine output the engine has to be revved up dynamiccally. To achieve the expected driving dynamics and to keep it, further for long-time operation, the recommended engine oil pre–sence is necessary. Lower viscosity engine oils are used for modern gasoline engines, thus SAE 20W50 type quality engine oil supply is not an easy task. We took samples from the new and used engine oil to conduct oil content and tribological examinations, then we did a retake from the oils after a 200 km run. Along with 200 km run, the engine was started by the owner at regular intervals, so some operation hours are added to the examined period. According to the results, oil change and additives were necessary. The de-tailed description of the examinations and results are represented in the following chapters. The chemical oil analysis was fol–lowed by a thorough tribological investigation, an Opti–mol SRV®5 machine (Optimol Instruments GmbH., Munich, Germany) was used for this purpose, and its ball-on-disc setup is an excellent, standardized option for characterizing the lubrication properties of the investigated lubricant samples ([7,8]). The tribometer is located in the Tribological laboratory of the Széchenyi István University, Department of Propulsion Technology. Standardized ball and disc specimens were used for the measurements (ISO 19291:2016, [9]), the specimens are manufactured from 100Cr6 material with fine surface finishing technology (ball specimen is polished to Ra 0.02 µm, while the disc specimen is lapped to Ra 0.035-0.05 µm). It is a common and standardised process in the tribological investigation of the lubricants to use standardised materials (in our case 100Cr6 material, based on ISO19291:2016), and not exact materials from the contacting components of the engine. An engine has a high amount of contact pairs with different materials made of, which makes difficult and more finance-demanding to execute measurements from all of the contact pairs. Furthermore, the ball-on-disc contact with 100 N normalforce loads the cotacting surface significantly higher that it is present inside the real engines, and so the very peak performance of the engine oil is tested, which is usually never occurs in real life, especially in the case of vintage vehicles, which are just used for shorter mileage.

The specimens were cleaned in ultrasonic cleaning bath (50°C temperature and 15 minute long, in a clea–ning medium of brake disc cleaner) to remove micro–scopic particles and contaminations from their contac–ting surfaces. A selfdeveloped tribological testing met–hodology was used to define the friction coefficient of the lubricant sample and produce a certain wear pattern on the surfaces [10], which contains a preconditioning step to ensure the starting parameters of the test, a preloading 30-second 50 N step to provide the minimal necessary lubricating film between the contacting surfaces, and a 2-hour long 200 N step to define the frictional losses and produce the wear pattern in a controlled way. Each lubricant sample was measured 3-times independently and the average and standard deviation parameters were calculated, which were used for the comparison of the lubricant sample variations. The tribometer measures the friction coefficient values with 1 second data saving frequency and its average value from the last 30 minutes were considered as eva–luation data, where there is no significant modification in its value. The tribological experiments were followed by a digital microscopic surface analysis using a Keyence VHX-1000 digital microscope (Keyence International, Mechlin, Belgium) to define the mean wear scar diameter on the ball specimens (wear scar diameters were measured parallel and perpendicular to the sliding direction on the surface of the ball specimens and their average was considered as MWSD, correlating with ISO 19291:2016 [9]). The surface analytic investi-gation was executed in the Surface analytic laboratory of the Széchenyi István University, Department of Propulsion Technology.

Four lubricant samples were used for the investigation. The actual owner of this Triumph Spitfire vehicle changed the lubricant right after its purchase to an Eurol Sport Touring 20W50 (kinematic viscosity is 120 mm^2/s, measured at 40°C), according to the written requirements in the official handbook of the vehicle. This engine oil was used for 200 km distance (this distance was covered in approximately 3 years), and an oil sample was taken right before the oil change. The lubricant was than changed to Comma Classic 20W50 motor oil (kinematic viscosity of 146 mm^2/s, measured at 40°C), this type of lubricant is specially recom–mended by the manufacturer of the vehicle but only purchasable from the United Kingdom. A special oil additive was added, which contains MoS_2 particles ([11, 12]) for the purpose of protecting the metal surfaces of the engine and decrease the fuel consumption (purchased from Liqui Moly). The whole bottle of additive (125 ml) was mixed into a full load of lubricant (approximately 4 liters). This lubricant was used for approximately 300 km distance, when an oil sample was also taken and investigated thoroughly.

At the 200 km travelling distance of this vehicle including Eurol Sport Touring 20W50 engine oil, a significant oil pressure decrease (the pressure was app–roximately 0.5 bar lower than expected) was noticeable, which indicated the need of an oil change. During the oil change process, it was to be observed that the dra–ined oil had a strong petrol scent, and its viscosity seemed to be lower in the drain container. It was obvious that the engine oil was mixed with the used petrol fuel, which decreased the lubricating property of the oil, which could be the reason for this remarkable oil pressure decrease. The whole engine oil was changed to the previously mentioned Comma Classic 20W50 inc–luding MoS_2 secondary additive, which was followed by a complete engine revision. This revision included a carburetor adjustment, reinstall the required spark ti–ming using completely new spark plugs and the valve clearance was also adjusted to its original value to en–sure an engine as close to the original status as possible.

3. EXPERIMENTAL RESULTS

The friction coefficient results of the tribological mea–surements are presented in Figure 3. It is clearly visible that there is a minor difference in the tribological beha–vior of the two variations of unused lubricants (Eurol and Comma new lubricants), this difference is appro–ximately 7%. The used lubricant variations present a different tendency: a friction coefficient increase is observable in the case of used lubricant sample of Eurol 20W50 (7% compared to the unused sample), while a significant friction decrease is visible in the case of the Comma used sample (15% friction improvement com–pared to its unused sample). This tendency is possibly explainable with the presence of MoS_2 containing se–condary additive.

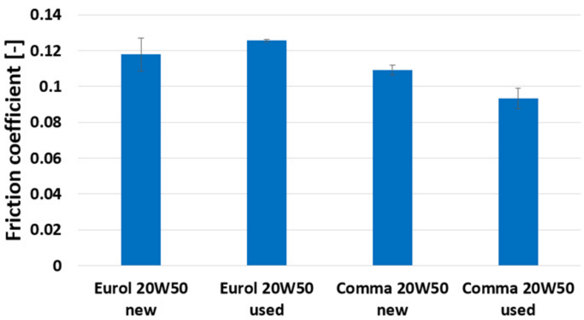


Figure 3. The measured friction coefficient values of the investigated samples (Source: Authors compilation)

The used ball and disc specimens were thoroughly cleaned in ultrasonic cleaning bath (50°C temperature and 15 minute time duration using brake disc cleaner) before the microscopic analysis was carried out.

Figure 4 illustrates the measured mean wear scar diameter values (MWSD) of the wear patterns located on the surface of the ball specimens after the tribological experiments. Similar tendency can be observed in the MWSD values than in the friction coefficient: Comma 20W50 provides significantly better wear protection than the Eurol 20W50 (difference is 15%), MWSD of Eurol new and used is identical, while Comma used (including MoS_2 secondary additive) is significantly better than Comma unused (difference is 12%). According to the friction coefficient and mean wear scar diameter results, the positive effect of the lubricant recommended by the manufacturer seems to be proved and its tribological properties could be improved by using a MoS_2-containing secondary engine oil additive.

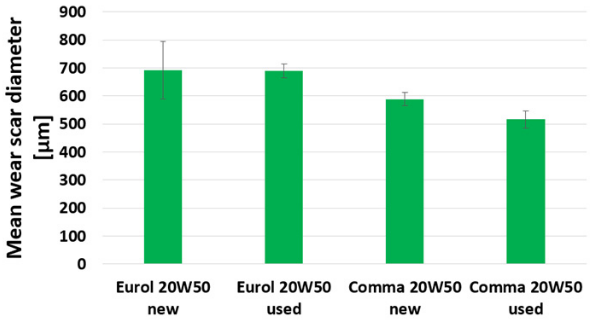


Figure 4. The measured mean wear scar diameter values of the investigated samples (Source: Authors compilation)

Figure 5 represents the acquired digital microscope images (100× magnitude) about the wear patterns on the disc specimens tested with different lubricant samples. The Eurol 20W50 unused lubricant sample provided a smooth wear surface (the original honing scars are still visible), however the used variation shows a darker, more deeper wear scar, and more abrasive wear grooves are also present. The Comma Classic 20W50 engine oil presents a completely different wear behavior. The width of the wear scar is smaller but the whole wear scar seems to be deeper including a higher number of abrasive wear grooves, compared with the results of Eurol lubricant variation. But this behavior changes itself in the case of the used variation of Comma Classic 20W50, which contains MoS_2 additive molecules: the width and depth of the wear scar was decreased while the visible abrasive wear was also less dominant. The positive tribological effect of the MoS_2 additive was proved according to these images and results, that a MoS_2-containing lubricant functioning in an engine of a vintage vehicle with 300 km travelling distance can still provide better antiwear properties to the contacting metal surfaces, than a fresh oil without this secondary additive.

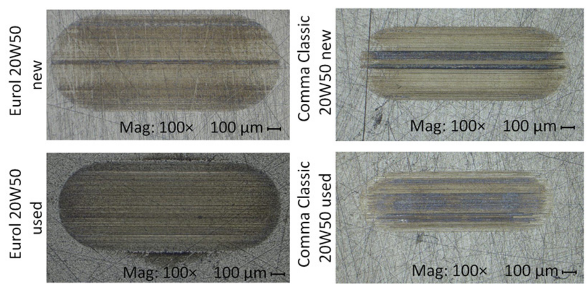


Figure 5. The acquired digital microscopic images about the wear patterns on the disc specimens investigated with different lubricant samples (left column Eurol Sport Touring 20W50, right column Comma Classic 20W50, top row new, bottom row used lubricant variations) (Source: Authors compilation)

Oil samples were examined and compared on the basis of their non-used state, and their used version was compared with their non-used version. Not two used versions were compared with each other. Moreover, secondary additives and their positive effects were proved, since there is information shortage for scientists and for vehicle users. Taking our investigation results into account, we can conclude that oil recommended specially for vintage vehicles (Comma Classic 20W50) plus secondary additive MoS_2 application mean better protection to the engine regarding running and operation. After the planned 300 km travelling distance, a drained lubricant sample from Comma Classic 20W50 were investigated in the LubCheck laboratory of the MOL-LUB Ltd. (Almásfüzitő, Hungary). A small amount of unused Comma Classic 20W50 was also tested with the same process and its results were used as reference values to analyze the differences of the used sample and find correlation between the tribological results and the oil parameters. Table 1 presents the measured parameters, their results for the two lubricant samples, and the corres–ponding standards according to the tests were executed.

Table 1. Measured oil parameters and their results in the case of Comma Classic 20W50 new and used lubricant variations.. (Source: Authors compilation)

Parameter	Measurement unit	Comma Classic 20W50 new	Comma Classic 20W50 used + MoS2	Corresponding standard
Kinematic viscosity 40°C	mm^2/s	146	122	ASTM D 7279-20
Kinematic viscosity 100°C	mm^2/s	17,1	15,1	ASTM D 7279-20
Viscosity Index	--	127	128	ASTM D 2270-24
Ca content	mg/kg	2194	2058	ASTM D 5185-18
P content	mg/kg	629	616	ASTM D 5185-18
Zn content	mg/kg	709	693	ASTM D 5185-18
S content	mg/kg	1974	2348	ASTM D 5185-18
Mo content	mg/kg	25	65	ASTM D 5185-18
Fuel con–tent (GC, petrol)	% (m/m)	0	1,2	ASTM D 3525-20
Cooling water content	grade	Negative	Positive	MOL-LUB M-66:2023
Na content	mg/kg	<1	24	ASTM D 5185-18
K content	mg/kg	<1	48	ASTM D 5185-18
Si content	mg/kg	3	36	ASTM D 5185-18
Soot content	%	0,1	0,1	ASTM D 7899-24
Fe wear particles	mg/kg	<1	19	ASTM D 5185-18
Pb wear particles	mg/kg	<1	16	ASTM D 5185-18

The results from Table 1 clearly shows that the viscosity of the lubricant sample with 300 km distance was decreased with a significant amount (approximately 16% compared to the unused lubricant): Furthermore, the presence of cooling water was also defined in the investigated used oil sample: the grading of cooling water content became positive and natrium, kalium and silica content was also detected which are a usual element in cooling water additives of commercial vehicles (Na and K containing cooling water has excellent thermal conductivity [13]). These results suggest the regular investigation of the status of the cooling system, but it is also possible that this water is coming from evaporation of water during the combustion process. The element increase of Mo and S in the 300 km engine oil is also remarkable, they are present in the used oil sample with higher concentration, which is the clear sign that the secondary MoS_2 containing additive were not completely depleted after this 300 km travelling distance and they could function as antiwear additives even in the case of the tribological tests executed in this research. The other parameters measured by the LubCheck laboratory of MOL-LUB Ltd. were defined as ac-ceptable: no significant sign of additive depletion (Ca, P and Zn), and no wear particle enrichment (mainly Fe and Pb), which indicates the excellent tribological condition of the lubricant which is still inside the investigated Triumph SC 1300 type engine. A thorough endoscope investigation was also executed to analyze the actual status of the cylinder liner and pistons without engine disassembly. This examination was necessary, because laboratory examination represented the presence of different metals in the oil, that results in the wear of several engine parts. For this measurement, only the spark plugs had to remove and a tiny tube including light source, and a CCD camera was inserted into the combustion chamber through the holes of the spark plugs. An Olympus IPLEX LX Industrial Videoscope (Olympus Europa SE & Co. KG, Hamburg, Germany) was used for acquiring the necessary endoscope pictures about the cylinder liner and pistons (optical adapter IV86, diameter of optics 8.5 mm, resolution 768 × 576 pixel, articulation angle 150°, 1× zoom). The acquired images are presented in Figure 6.

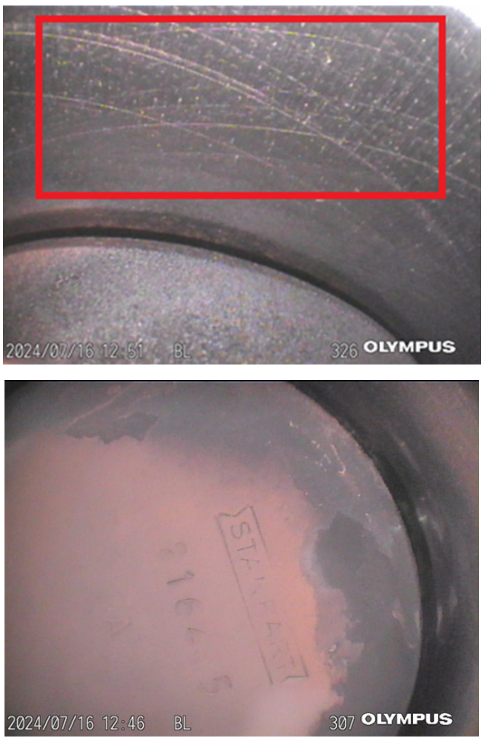


Figure 6. Endoscope image about the cylinder liner (above) and piston (below) of the investigated Triumph SC 1300 engine.

The images shown in Figure 6 clearly presents the excellent physical status of the cylinder liner and pistons. The original honing grooves are still easily visible on the cylinder liner surface (above image of Figure 6 marked with red), and the original serial number markings are also visible without any cleaning on the top surface of the piston (below image of Figure 6). Honing has a great role in keeping the lubricant on the cylinder wall, so it supports continous lubrication inbetween the piston and the cylinder. It is essential, especially in the case of vintage vehicles and their engines) to ensure the continuation of its oldtimer classification. In the case of an overworn cylinder liner surface, the only restoration option is the rebore and hone the surface, which ensures the continuation of the vehicle usage, but the surface roughness parameters cannot be reproduced due to the lack of the original machining parameters. Sztankovics presented in his article [14], that the honing parameters significantly influence the surface roughness parameters and thus the texture of the cylinder liner which will modify the tribology of the cylinder liner and piston ring contact and can result an earlier complete motor restauration.

4. DISCUSSION

Vintage vehicles are operated differently from commonly used vehicles, thus lubricant deteriorates quicker in the engine, which can lead to engine damages. In our previous research [2], we detected petrol in engine oil, however it was not as much as in the case of this investigated Triumph SC 1300 engine. This was such a problem that needed an effective solution. The owner of the examined Triumph uses the vehicle rarely and he takes short distances. He occasionally starts the engine and lets it run for a few minutes, which differs from normal operation. Gasoline engines assembled with carburetor start with choke in case of cold start, during its operation a very dense mixture gets in the engine. The investigated Triumph Spitfire car was equipped with two carburetors. Surplus gasoline does not burn, but rather leaks next to the piston rings to the oil reservoir, during which it cleans lubricating film from the cylinder wall. Meanwhile the vehicle runs short distances, gasoline cannot fully evaporate from the engine oil, it dilutes oil and ruins its lubricating function. Short engine starts lets even more gasoline in oil and its consequence is that oil loses its viscosity. Another problem is that short runs create water vapor in the crankcase, which also enters oil, that is the reason behind water content in the oil condition examination. The review of operating parameters of engine assembled with double carburetor and the analytical and tribological examination of used engine oils pointed out that improper operation cause a great amount of patrol to enter the oil. Probably several vintage vehicle owners had encountered with the same problem, thus we formulated some recommendations for safe operation.

•First step in order to safe operation is to adjust the injectors and ignition to factory values

•After oil change only oil recommended by the manufacturer or with the same quality should be used

•Short runs after cold starts may be avoided, this exposes the engine to bad conditions

•Short distance run, mainly in towns, also harms the engine

•If oil pressure drop is detected during operation, instant oil check is a must

•During operation direct gear and travelling speed for at least 20-30 km are suggested

•Properly doped secondary oil additives can increase operation safety

Application of oil additives require great attention considering the proper additive to be selected, its type and the use of vehicle. Several research was conducted to investigate lubricants [15], [16], moreover the application of different additives was also represented [17-18]. Experiences prove that it is worth to investigate lubricants that were treated with additives with tribological methods and after the analysis of results it can be decided whether the lubricant achieved the wished effects. In case, there is a need for the change of the additive, it is practical to conduct a further tribological and content investigation of the oil after a given run-distance or operating hours.

5. CONCLUSION

The main goal of the article is to draw the attention of the continuous operation of vintage vehicles and its challenges. One of its key factors is the engine oil and it has the greatest challenge to select the most appropriate from the available ones. Examination results repre–sented the fact that short-time operation cause the saturation of oil with patrol.

In this article, according to the results, it can be stated that continuous monitor of lubricants and engine parts is needed to keep vintage vehicles in good condition and to support proper operating condition. The investigation we carried out, revealed that strongly used engine oil lost its ability to protect the engine, so contacting surfaces suffered increased wear in further use. These types of examinations also reveal the fact that a very detailed engine failure detection and forecast can be conducted with the disassembly of the engine itself, which can spare money and time for the owners.

Oil samples show that depletion of oil additives and the growth of oil contaminants lead to the deterioration of protecting film on contacting surfaces, that results in greater wear at both investigational temperatures. The determined wear may be acceptable considering short runs, but it is strongly recommended to change engine oil. As it turns out from research results, the proper engine oil application may contribute to longer engine lifetime. With the help of these types of tribological measurements and chemical oil analyses, the selection of proper engine oil is supported, mainly if the manufacturer recommended oil is no longer available. In our research we focused only on a Triumph SC 1300 type engine, because we wished to verify the efficiency of lubricant additive we used to increase the lifetime of engine oil with further investigations. It was proved that oil additives increase the lifetime of lubricant and engine as well and contribute to optimal operation. MoS_2 type oil additive that we used, is applicable for older built engines. In those cases, when vintage vehicles are run fewer such as the investigated one, oil additive usage is strongly recommended. We assumed that the results we represented in this article and experiences we gained during practice can provide a good basis for further investigation regarding other types of engines, thus we are planning to conduct research about the operation parameters and tribological examination of other engines.

According to our opinion, the results represented can be applied in engineering practices. With our recommendations we would like to help the owners of vintage vehicles contributing to safe operation.

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ТРИБОЛОШКО ИСПИТИВАЊЕ ЕФЕКАТА АДИТИВА ЗА МОТОРНО УЉЕ ЗА СТАРЕ БЕНЗИНСКЕ МОТОРЕ

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Рестаурација старих возила данас постаје све популарнија. Услови коришћења и рада су се мењали последњих година, фабрички препоручена мазива и горива више нису доступни. Употреба неодговарајућих мазива може довести до тешких оштећења мотора. Циљ нашег истраживања је да извршимо аналитичко и триболошко испитивање мазива које се користи у четворотактном бензинском мотору Триумпх СЦ 1300 са два карбуратора. Наш даљи задатак је да извршимо аналитичко и триболошко испитивање моторног уља које смо инфузирали са МоС2 да бисмо га упоредили са уљем у складу са фабричким параметрима након дефинисаног пробног рада. Након анализе и процене резултата дајемо препоруке у вези са датим мотором да се ради са најприкладнијим моторним уљем у односу на услове рада.