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COMPARISON OF TRIBOLOGICAL PROPERTIES OF SAE 0W-40 AND 5W-40 DIESEL ENGINE OILS

R. Kreivaitis, A. Andriušis
Aleksandras Stulginskis University, Lithuania

Abstract

Nowadays friction reduction is of great importance due to fuel economy and energy saving issues. The internal combustion (IC) engine is widely used in rotation power production for moving machinery. The performance of internal combustion engine is closely related to its lubrication. Engine oil must ensure sufficient lubrication at all the lubrication regimes. Recently marketed lubrication oils possess different performance. However these differences are not always cost efficient. In those cases when cost is an issue some simple evaluation and comparison can be useful. The aim of current study is to compare tribological properties of two different diesel engine oils 0W-40 and 5W-40. Tribological test were performed using pin-on-disc and four-ball test schemes. The observed results show marginal difference between investigated lubrication oils. Their performances mostly differ at boundary lubrication regime where 0W-40 oil was superior to 5W-40. Moreover 0W-40 oil faster reaches transition boundary-to-mixed lubrication regime. However 5W-40 was considered to have better wear reduction ability.
Key words: engine oil, friction, boundary lubrication, wear

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Introduction

Due to increasing pollution restrictions and energy saving issues machinery moved a big step forward in the last decade. Recently developed internal combustion engines have higher power to volume ratio. Their mechanisms operate under higher temperature and loading conditions. The sliding speeds are also higher. Hence lubricants used in recent IC engines operate under more severe conditions.

Current IC engine oils must be compatible with exhaust gas after treatment systems. Therefore low SAPS (sulphate ash, phosphorous and sulphur content) lubricants were introduced. Reducing amount of generally used additives made more pressure on lubricant formulation. Moreover there were efforts to introduce some environmentally friendly species into engine oil. In particular these were trimethylolpropane (TMP) ester and even waste cooking oil (Zulkifli, et al., 2013; Hisham, et al., 2017).

The friction and wear reduction are still of great importance for engine lubricants. Friction is related to fuel economy and wear – downtime due to replacement of worn parts.

Tribological properties of engine oil continually changes during its usage. The changes are initiated by ageing and contamination (Yadav, et al., 2018; Niculescu, et al., 2016). These changes can reduce or even increase the lubricity. For instance, there were studies on soot particles contaminated 15W-40 engine oil. It was found that some concentration of soot particles can improve friction reduction properties. The phenomenon was attributed to absorption and agglomerate effects (Hu, et al., 2013).

There were studies on comparison of tribological properties of 10W-30 engine oil obtained from different manufacturers. It was reviled that there is a difference in both friction and wear reduction (Farhanah, Bahak, 2015).

In some cases there is an opportunity to choose between two oils having similar performance. In those cases when cost is an issue some simple evaluation and comparison can be useful. Therefore the aim of current study is to compare tribological properties of two low SAPS diesel engine oils.

Object and methodology

Two motor oils 0W-40 ACEA C2 and 5W-40 ACEA C3 were obtained from local dealer and used as received. Their physicochemical properties are given in Table 1. According to Lubrizol relative performance comparison tool these oils differ in fuel economy, having values of 7 and 3 for C2 and C3 respectively (Fig. 1) (Lubrizol, 2016). These values come from different viscosity and friction reduction ability.

Table 1. Physicochemical properties of investigated engine oils

Lubricant	Sulphated Ash, %	Phosphorus, %	Sulphur, %	Viscosity at high temperature and shear (cP)	Kinematic viscosity, cSt		Viscosity index
					40 °C	100 °C	
0W-40 ACEA C2	≤0.8	≥0.07 to ≤0.09	≤0.3	≥2.9	79.0	13.5	169
5W-40 ACEA C3	≤0.8	≥0.07 to ≤0.09	≤0.3	≥3.5	82.0	13.9	174

Figure 1. Performance of investigated engine oils according to Lubrizol relative performance comparison tool (Lubrizol, 2016)

The friction reduction was evaluated using Stribeck curves on pin-on-disc test scheme. The disc was made of carbon steel having hardness of 35 HRC and surface roughness Ra – 0.8 µm. Diameter of the disc - 80 mm, while the diameter of sliding track - 60 mm. The pin has diameter of 6 mm and its sliding surface was flat (parallel to the disc surface). It was also made of carbon steel having hardness of 40 HRC and surface roughness Ra – 0.7 µm.

The test temperature of 40 °C, was chosen to evaluate friction loses while the engine is not warmed up and oil viscosity has the highest influence. This stage can be abundant in short distance city driving where engine does not warm up. To investigate influence of loading, four different contact pressures were selected - 4, 6, 8 and 12 MPa. The sliding speed from 0.001 was increased to 5 m/s using 21 speed steps. The duration of 3 minutes friction, at every step, was recorded and average was used for Stribeck curve. The sample Stribeck curve, together with lubrication regime transition point's determination, is presented in Fig. 2. Two lubrication transition points boundary-to-mixed and mixed-to-elastohydrodynamic were determined. To determine these points' tangential lines were drawn parallel to respective lubrication regime. The intersection of these lines was considered as transition point.

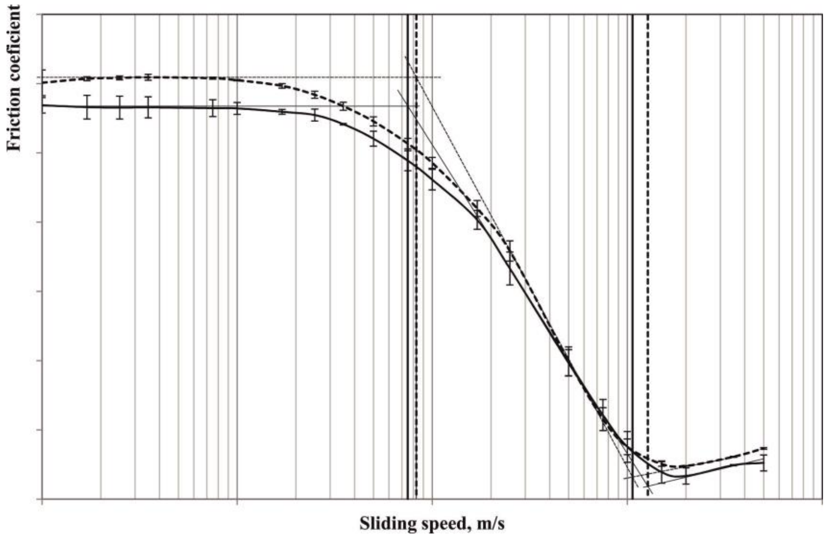

Figure 2. Sample Stribeck curve, together with lubrication regime transition point's determination

Wear reduction was evaluated using four-ball tribometer. The 12.7 mm diameter bearing steel balls were used. The load of 150 N and rotation speed of 1500 rpm was chosen to simulate boundary lubrication conditions. The maximum contact pressure of 1053 MPa was generated under certain conditions. 22 ml of sample oil per test was used. Test duration was 1 hour. The diameters of the wear scars on three stationary balls were measured using an optical microscope Nikon Eclipse MA 100 and the average diameter of three balls was reported as WSD (Wear Scar Diameter). The worn surfaces were analysed using the same optical microscope.

Results and Discussions

The obtained Stribeck's curves represent all the lubrication regimes starting with high friction in boundary lubrication followed by mixed lubrication regime (Fig. 3-5). The lowest friction is observed in elastohydrodynamic lubrication followed by hydrodynamic lubrication characterised by friction increase due to share between lubricant layers.

It is evident from the obtained Stribeck graphs that friction pair loading has a major influence on lubrication regime at certain speed. The onset of consequent regime is shifted toward higher speed with increasing load. Having contact pressure of 4 MPa the boundary lubrication regime is changed by mixed lubrication at a speed of 0.033 and 0.036 m/s for 0W-40 and 5W-40 respectively (Fig. 3). Increased load leads to increased sliding speed where transition starts 0.075 and 0.083 m/s at load of 8 MPa (Fig. 5). The transition point speed increase is proportional to increased load. In the cases of mixed-to-elastohydrodynamic transition, to have the same lubrication regime when loading is increased 2 times, the speed must be more than 3 times higher. Both the investigated oils follow the same rule.

There is no big difference between investigated 0W-40 and 5W-40 oils when considering observed friction values. The highest difference is in boundary lubrication regime. The difference in boundary lubrication is observed in all loading conditions. It was found that during boundary lubrication the friction tends to increase with increasing loading. It could be related to additives ability to withstand loading.

In the mixed and elastohydrodynamic lubrication regimes the investigated oils show similar performance. However, despite lower viscosity, synthetic oil comes into mixed lubrication regime at lower speeds.

In hydrodynamic lubrication the friction of synthetic oil 0W-40 is less dependent on sliding speed. It is in the line with the values of viscosity at high temperature and shear presented in the Table 1. The synthetic oil 0W-40 has lower viscosity (≥2.9 cSt) in comparison to 5W-40 (≥3.5 cSt) oil.

Increasing sliding speed in the highest investigated load (12 MPa) the test system undergoes some type of vibration and friction changes. Appearance of seizure was suspected. The tests were terminated and friction surfaces were carefully inspected. However there were no noticeable changes in geometry or surface roughness. Most likely phenomena of stick-slip are responsible for the vibration. This phenomenon was investigated by many other authors elsewhere. It was found that stick-slip between interacting surfaces can cause vibration and friction force increase (Iman, et al. 2013; Liping, et al. 2015; Liu, et al. 2015). Due to misleading friction force recording, at this point, the tests was terminated and there is no full date in the graph of Fig. 6.

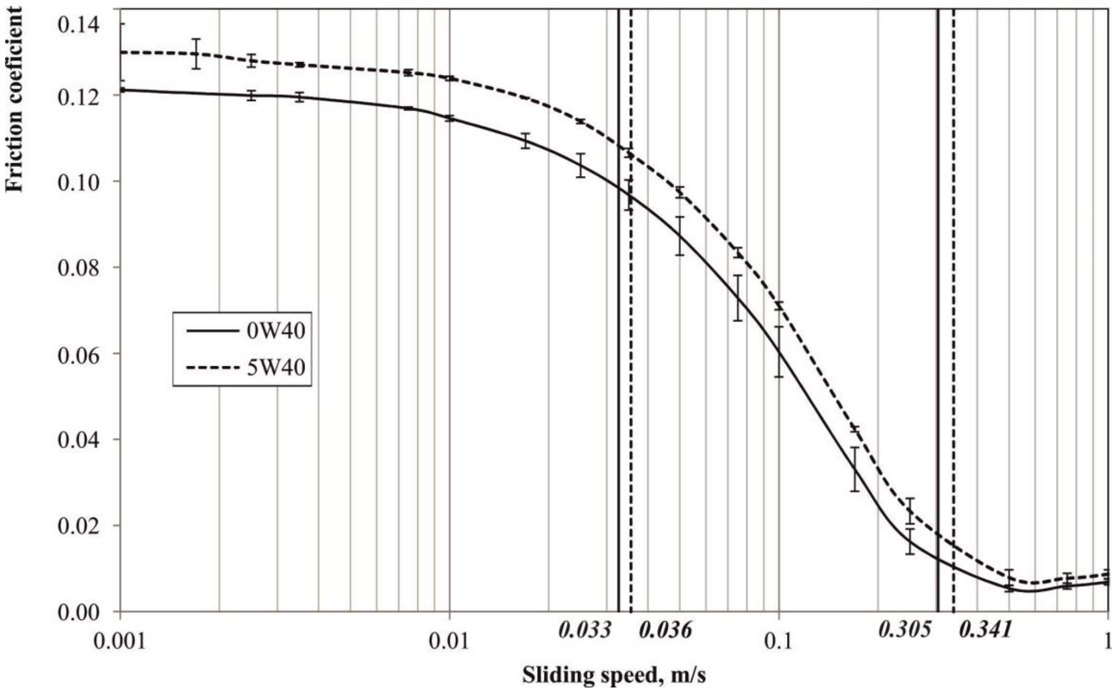

Figure 3. Sliding friction Stribeck curve at the load of 4 MPa

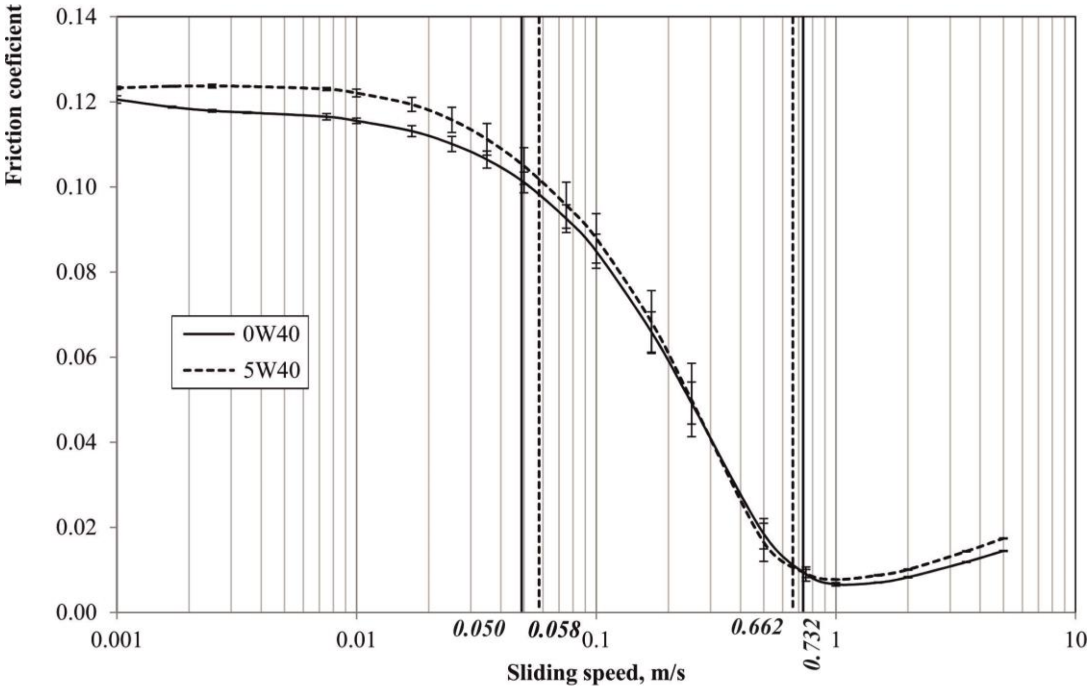

Figure 4. Sliding friction Stribeck curve at the load of 6 MPa

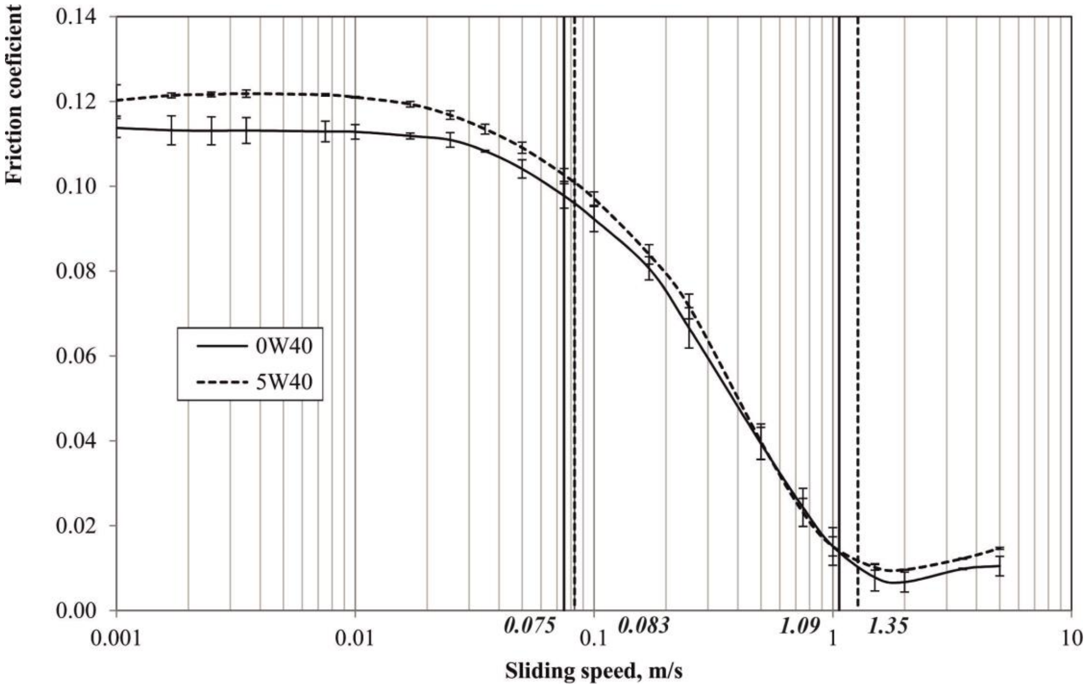

Figure 5. Sliding friction Stribeck curve at the load of 8 MPa

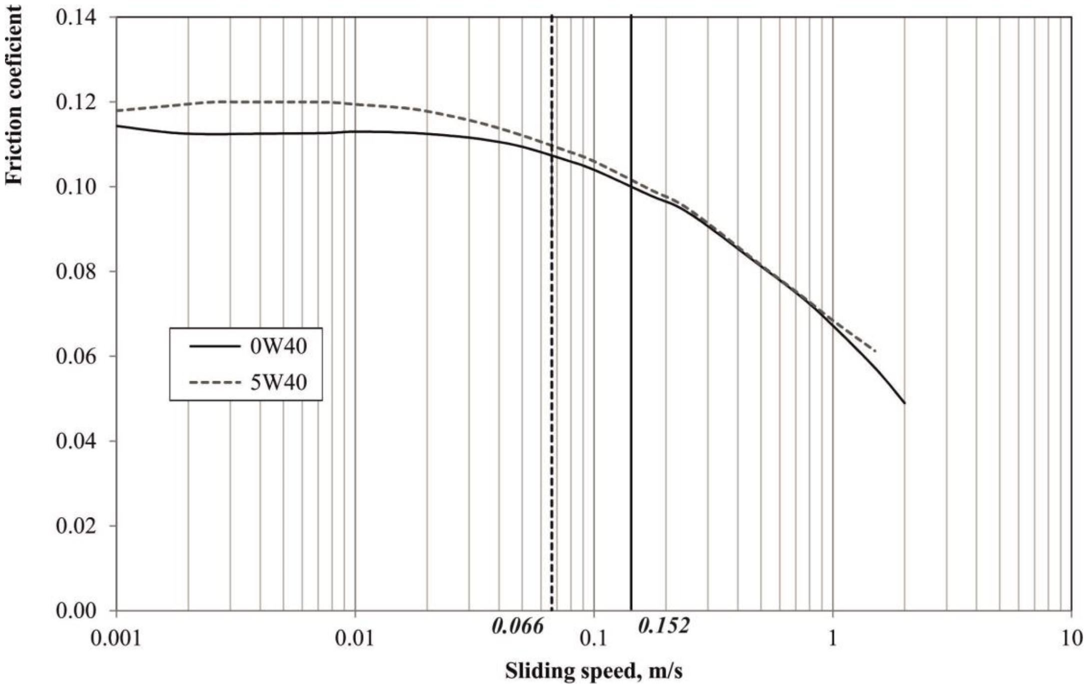

Figure 6. Sliding friction Stribeck curve at the load of 12 MPa

The wear reduction behaviour of investigated oils is presented in Fig. 7. In present case the IC oil 5W-40 showed better performance than 0W-40. This phenomenon can be attributed to different efficiency of anti-wear additive packages and slightly higher viscosity of 5W-40 IC oil.

The wear scars formed on the balls during the wear test are presented in Fig. 8. It is evident that surface abrasion was the main wear mechanism. Inspection of wear scars revealed that despite slightly higher wear the wear scars on the balls lubricated with 0W-40 oil have less abrasion. Both the stationary and rotating balls have shallower groves on friction damaged surfaces. These results are in the line with the above discussed friction results.

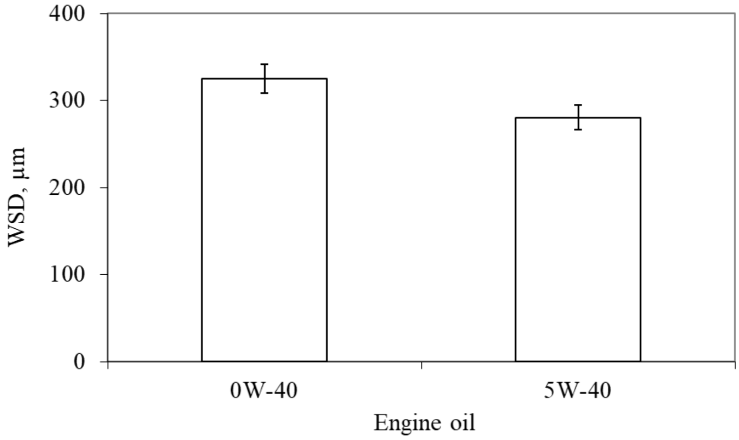

Figure 7. Wear reduction behaviour of investigated engine oils

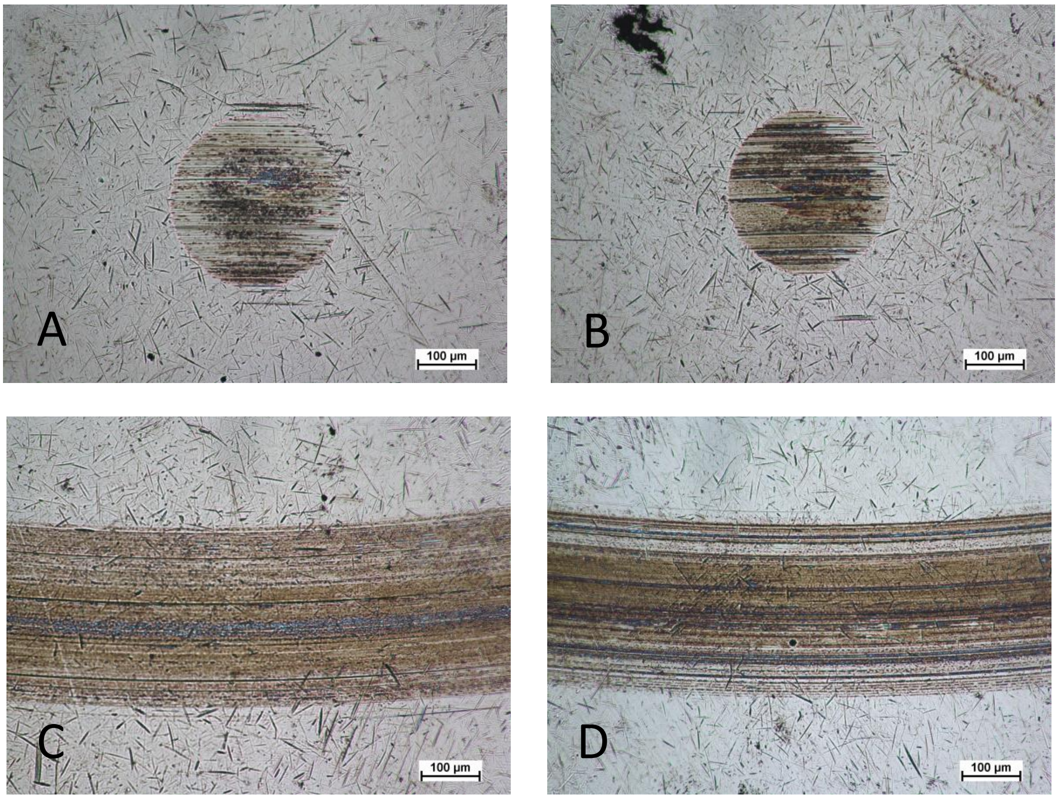

Figure 7. Wear scars on stationary A and B and rotating C and D balls for 0W-40 and 5W-40 respectively

Conclusions

The investigated internal combustion diesel engine oils have similar tribological properties at investigated conditions. Some minor differences can be noticed:

- The 0W-40 C2 oil showed slightly lower friction in boundary lubrication conditions and lower boundary-to-mixed lubrication transition speed;
- The 5W-40 C3 oil have better wear reduction ability, however inspection of worn surfaces revealed lower abrasion in the case of 0W-40 oil lubrication;
- At the higher load and speed the phenomenon of stick-slip can occur which can be caused by pure lubrication or incompatibility of interacting surfaces.

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Authors for contacts:
Dr. Raimondas Kreivaitis
Institute of Power and Transport Machinery Engineering,
Aleksandras Stulginskis University.
Phone: e-mail: raimondas.kreivaitis@asu.com

Master, Eng. Albinas Andriušis
Institute of Power and Transport Machinery Engineering,
Aleksandras Stulginskis University.
Phone: e-mail: albinas.andriusis@asu.com