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EXPERIMENTAL INVESTIGATIONS ON OPERATIONAL RELIABILITY OF DIESEL LOCOMOTIVES ENGINES

BADANIA EKSPERYMENTALNE OPERACYJNEJ NIEZAWODNOŚCI EKSPLOATACYJNEJ SILNIKÓW DIESEL DLA SPALINOWOZÓW

In work experimental researches of longevity and technical and operating parameters of diesel engine diesels are presented 10D100 with modified tribosystems. The last are instrumental in the rapid starting and decline of wear depending on time of starting, thus, such diesel practically on any speed and loading modes can be exploited without the promoted wear. At the modified shells of cylinders the wear of compression rings does not affect the size of breach of gases in carter. Thus, the modified tribosystems provide maximal longevity and providing of high technical and operating parameters of diesel engine.

***Keywords:** longevity, technical and operating parameters, diesel engine, tribosystem, wear.*

W artykule przedstawiono rezultaty badań eksperymentalnych trwałości i parametrów techniczno-eksploatacyjnych silnika diesla spalinowozu 10D100 ze zmodyfikowanymi systemami ciernymi. Zmodyfikowane systemy cierne gwarantują szybsze uruchomienie silnika, tym samym zmniejszając zużycie związane z uruchamianiem. Ponadto taki diesel może być praktycznie eksploatowany we wszystkich trybach prędkości i obciążenia bez podwyższonego zużycia. W wyniku modyfikacji tulei cylindrów ścieranie pierścieni kompresyjnych nie powoduje zwiększonego przedostawania się gazu do skrzyni korbowej. W ten sposób zmodyfikowane systemy cierne gwarantują maksymalną niezawodność parametrów eksploatacyjnych spalinowozów z silnikiem diesla.

***Słowa kluczowe:** trwałość, parametry techniczno-eksploatacyjne, silniki spalinowozów, system cierny, zużycie.*

1. Introduction

Operating railway's locomotives leads to natural obsolescence of the engines as well as other components and details that consequently increases the number of failures. In order to increase operating reliability and durability of locomotive's diesel engines it is purposeful to monitor their technical condition constantly as elimination of failures requires plenty of time and material resources during exploitation [10, 11, 13].

In this work, the subject of research has been chosen an engine 10D100 that is installed in locomotives and there is plenty of statistical data collected about it [1].

The main impact on the diesels durability is made by the resistance to wear [4, 9, 12, 14] of cylinder – piston group and crank – rocker tribosystem mechanisms (TS). Diesel locomotives durability can be increased by hardening (supporting) or modifying (TS) elements, accelerating friction as well as performing technical maintenance and repair qualitatively.

Plenty of wear resistance increasing methods are not applied for the improvement of cylinder – piston and crank – rocker tribosystems due to high cost and scale factor [3, 11]. While selecting surface hardening method for the above-mentioned details of the mechanisms it is necessary to estimate their production scale and technical – economic benefits of the hardening [7]. Accordingly, existing methods for the increasing wear resistance of the surfaces cannot be applied for the diesels throughout [5, 8].

It is possible to use several methods at once as applying complex of several technical methods with constructional solutions and proper attitude to diesels operating process can be achieved an ultimate effect. Using known parts surface hardening methods for the diesels it is possible to reduce wear from 1 to 10 times [9, 12], however objectionable phenomenon (faults) can occur [1, 2, 6].

Introduced diesels durability increase method [9] distinguishes for TS working surfaces being processed by laser suing carbonic acid gas or natural graphite with niobis all-together [4]. We will review and compare modified and unmodified tribosystems of the diesel locomotives by these methods hereinafter.

2. Results of the investigations

Under winter conditions starting-up diesel locomotives within the low temperatures of cooling fluid and oil leads to high increase of tribosystems wear particularly those as „casing-rim" and „crankshaft-insert". It can be shown graphically by wear rate dependency on start-up duration of tribosystem by the example of 10D100 diesel (Fig. 1)

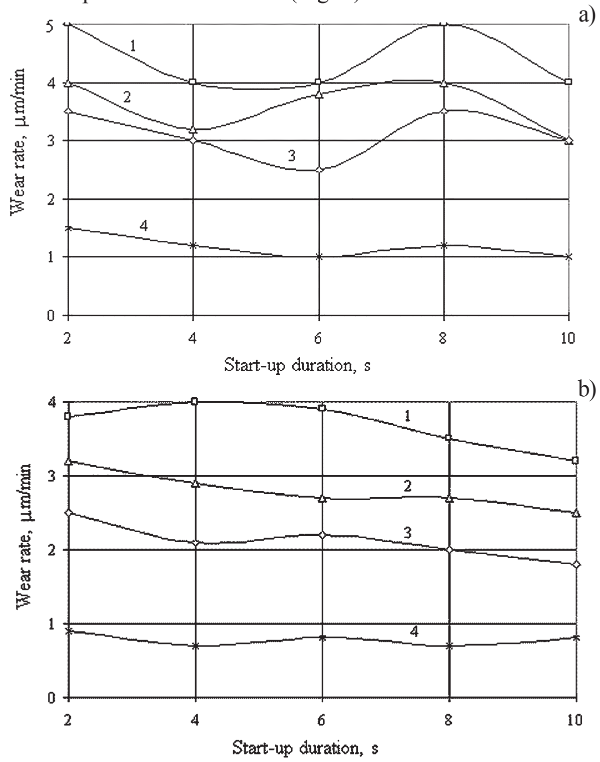

Fig. 1. Wear rate dependency on start-up duration of diesel 10D100 tribosystems „casing - rim" (a) and „crankshaft – insert" (b) within oil temperatures of the engine: 1 – 0ºC; 2 – 5ºC; 3 – 10ºC; 4 – 20ºC

We can see from the graphs that wear rate is 4 times greater comparing at temperatures 1ºC and 20ºC in both cases with cylinder casings and crankshaft inserts. This graph testifies that the more we want to reduce wear resistance of the diesel tribosystem the more we need to heat engine oil and reduce duration of the start-up. Here comes additional question – when it is expedient to stop diesel and when it is not? However, it is necessary to evaluate all economic fuel rates and engine wear indexes for that.

Under slight relative displacements of the surfaces of tribosystems during the start-up, wear rate of the diesel locomotives increases due to absence of oil film between the contact surfaces. Superficial layers of the TS are disrupted as they contact with each other without any gap, dominated by dry friction or boundary friction and resulting all negative outcomes.

There are given experimental wear results of bearing inserts of crankshaft and cylindrical casing when diesel locomotives are operating loaded in Fig. 2.

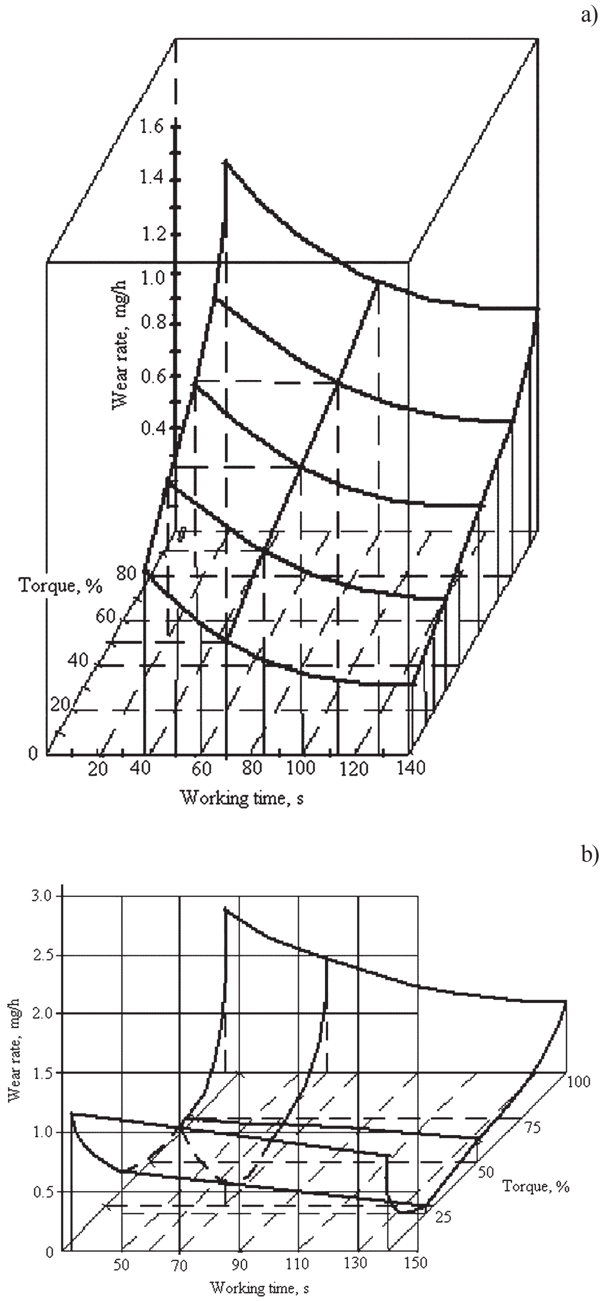

Fig. 2. Wear rate dependency on the workload duration of the cylindrical casings (a) and main inserts of the crankshaft (b) of the diesel locomotives 10D100

We can see here that load, i.e. torque of the crankshaft impacts wear of the diesel tribosystem at the beginning of engines' work. It is also explainable by the non-graded lubrication of the crankshaft bearing inserts and cylindrical casings.

Diesel locomotives are started-up 10–30 times per day. Moreover, technical – exploitation values (heating temperature, thickness of the oil film between contacting surfaces etc.) of the indexes varies at any case. Accordingly, in order to secure the highest durability possible, it is necessary to motivate diesels usage logarithm throughout all steps: start-up, heating, operating and braking.

Start-up of the engines is conditioned by the heated air at the end of compression stroke. Air temperature at the end of compression stroke depends on the reached pressure, temperature of the environment, revolution frequency of the crankshaft as well as wears degree of cylindrical piston parts. Pressure at the cylinder falls and frequency of revolutions of the crankshaft required for the start-up of the engine, i.e. minimal frequency of the crankshaft revolutions at which start-up of the engine is possible, increases regarding to the last reason.

Some of the air gets into the crankcase through the gaps when air is under pressure in the cylinder and parts of the cylinder-piston are too much affected by wear. Therefore falls the pressure in the cylinder herewith temperature at the end of compression stroke. Carburation proceeds worse, i.e. solution of small fuel drops, evaporation and mixing with air, that ignitable compound could flame up. In this case, frequency of the crankshaft revolutions must be high enough. Other significant amount of heat that diverges after pressing air is transferred to the cooling fluid through the walls of the cylinders resulting in the lowering pressure and temperature at the cylinder. Further increasing wear of cylinder – piston tribosystem leads to the moment when it is impossible diesel to set into action.

Huge impact in the start-up of the diesel has an oil film between the walls of the casings. Oil not only reduces wear of the cylinder walls but performs a cylinder presurizement function. Oil flow from the wall of cylinder has been decreased after performed laser modification on diesel tribosystem using natural graphite and carbonic acid gas that leads to the faster start-up of the diesel engine and reduce wear during the start-up by 7–10 times. Certainly, those diesels that are stopped and started-up more often experience more rapid wear. It is proven by the experimental results given in Fig. 3.

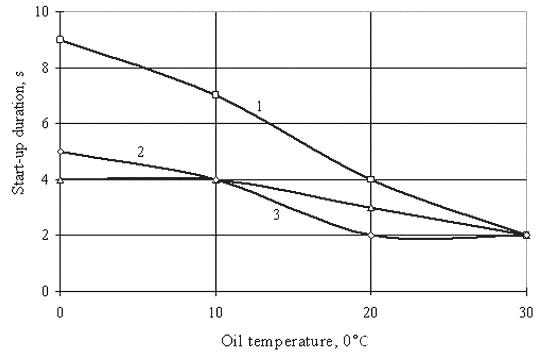

Fig. 3. Start-up duration dependency on the engine oil temperature of the diesel locomotives 10D100: 1 – basic version; 2 – modified by the TS carbonic acid gas; 3 – modified tribological system by natural graphite with niobis

Data of Fig. 3 testifies that start-up time shortens from 1.8 to 2.2 times when oil temperature is 0°C when diesel tribosystem is modified. At the beginning of the start-up wear of the tribosystems has been increased and exceeds constant operating regime's value of the resistance several times. That can be explained by poor lubricating conditions of the contact surfaces at the initial state of diesels operation.

Hereinafter TS wear data of diesel locomotives are specified according to their working hours after the start-up (Fig. 4).

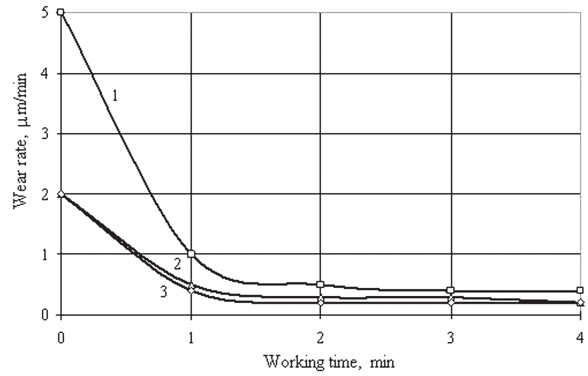

Fig. 4. Wear manner of the diesel locomotive 10D100 tribosystems after the start-up: 1 – basic version; 2 – modified by TS carbonic acid gas; 3 – modified by TS natural graphite with niobis

It is clearly observable that wear of the modified diesel tribosystems during first working minutes (during the start-up) is 2.0–2.5 times lower. Hereby, in order to assure minimal duration of the diesels start-up, minimal wear of tribosystem and hugest exploitation durability it is purposeful to apply la-

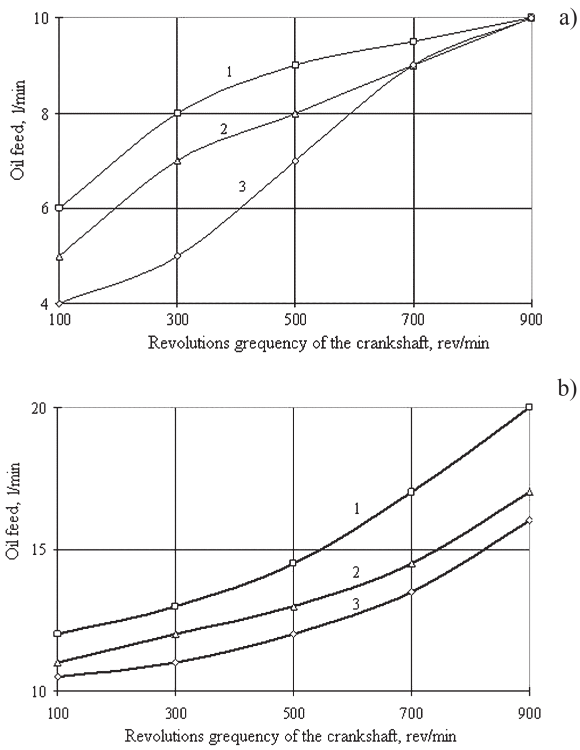

Fig. 5. Diesel 10D100 feed of the oil depending on the frequency of crankshaft revolutions at given oil temperature 20°C (a) and 40°C (b): 1 – basic version; 2 – modified by TS carbonic acid gas; 3 – modified by TS natural graphite with niobis

ser modification of TS by carbonic acid gas or natural graphite with niobis.

Usually, diesel locomotives are heated without load gradually whilst rising temperature of the engine's oil until exploitation values.

As it was above-mentioned, huge impact on the locomotive tribosystems wear is performed by the amount of oil that accesses contacting friction surfaces. Its amount depends on the efficiency of the oil pump (Fig. 5).

The graphs in Fig. 5 show that amount of oil in modified TS is noticeably smaller than comparing with basic variant at both temperatures 20°C and 40°C, implying that film of oil keeps a tight hold in modified tribosystems and thus guarantees the most beneficial liquid friction and hermetic condition in the casing pair. It was observed during investigations that oil feed remains almost steady after the locomotive has been driven more than 300 thousand km implying in uniform, slow-motioned manner of wear.

Amount of oil that is supplied between contact surfaces is insufficient at low temperatures and can lead to damage of the tribosystems friction surfaces (melting of bearings, chips of cylindrical casings). Modification of TS contacting surfaces by carbonic acid gas or natural graphite with niobis helps in preventing from the above-mentioned failures starting-up engines at low temperatures as modification maintains sufficient lubrication of contacting surfaces.

Characteristic value of wear degree for the main tribosystem of diesel locomotives is an amount of burnt-out oil depending on the grind-in (Fig. 6). Furthermore, increasing amount of burnt-out oil leads to conclusion that wear level of the main tribosystems is close or at critical state. Wear of the cylinder-piston group can be also described by the amount of the gas lead to the crankcase (Fig. 7).

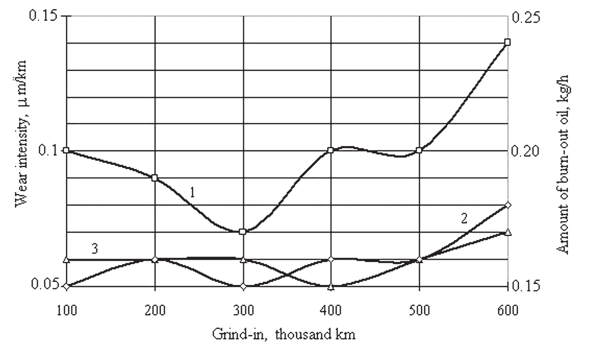

Fig. 6. Wear and amount of burnt-out oil dependency in cylinder-piston tribosystem of the diesel locomotive 10D100 depending on the grind-in: 1 – basic version; 2 – modified by TS carbonic acid gas; 3 – modified by TS natural graphite with niobis

As it is shown in the graphs, the amount of burnt-out oil during the exploitation period from 100 to 600 thousand km of locomotives is proportionate to the wear level of the cylinder-piston group at the tribosystem. When 600 thousand km are reached, i.e. when wear level is highest, burnt-out amount of oil is 1.4 times lower comparing to the basic engine in the diesels if using modified tribosystems.

As we can see from the graphs, gas leak to the crankcase is noticeably lower (2) when comparing to the basic variant (1) when modified cylinder casings of the diesel 10D100 are used,

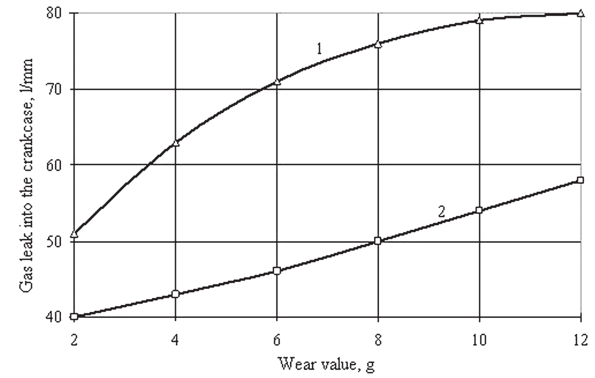

Fig. 7. Compression rims wear influence on the gas leak to the crankcase of the diesel locomotives 10D100: 1 – basic variant; 2 – cylinder casings modified by the natural graphite with niobis

the implication is that the gap of tribosystem „cylinder casing-compression rims" varies very slightly.

Wear resistance of diesel locomotive TS under the loaded regime can be evaluated according to their wearing rate when constant frequency of the crankshaft revolutions and variable oil supplies with the high pressure pump are applied: results are given in Fig. 8.

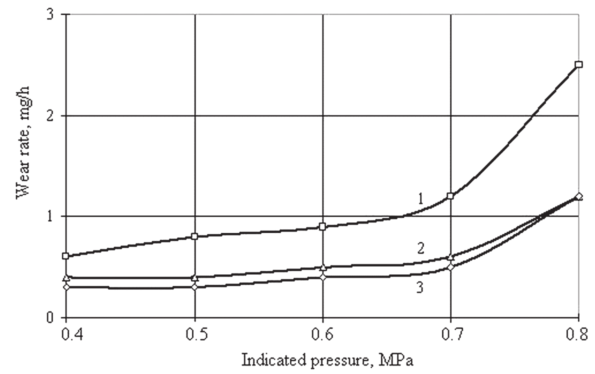

Fig. 8. Wear rate of the first piston rim of the diesel locomotives 10D100 depending on the indicated pressure: 1 – basic variant; 2 – TS modified by the carbonic acid gas; 3 – TS modified by the natural graphite with niobis

As we can see from the graphs, an absolute value of the TS wear that determine resource of the diesel increases due to the increase of load.

Resistance to wear at various velocity regimes of the diesel locomotive tribosystems can be evaluated while changing frequency of revolutions of the crankshaft at the same time feeding fuels to the cylinders by high pressure pump. Change of velocity regime has an impact on the formation of ignitable compound and its combustion as well as on the mechanical and thermal loads of diesel tribosystems. Increasing frequency of revolutions of the crankshaft increase wear rate of tribosystems because of the temperature increase and higher dynamical and friction forces in „cylinder-piston" and „crank - rocker" tribosystems.

Decreasing frequency of revolutions of the crankshaft below the recommended limit leads in increase of wear rate as hydrodynamic lubrication regime becomes worse. Comparative wear rate of the „crankshaft-insert" tribosystem of diesel locomotives depending on the frequency of revolutions of the

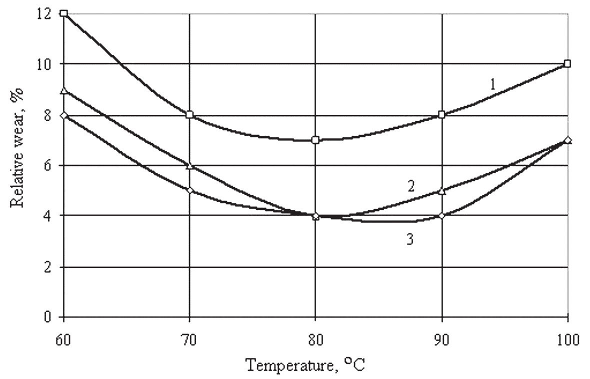

Fig. 9. Relative wear dependency on the temperature of cooling fluid of the diesel locomotives 10D100 tribosystems: 1 – basic variant; 2 – modified tribosystems by carbonic acid gas; 3 – modified tribosystems by natural graphite with niobis

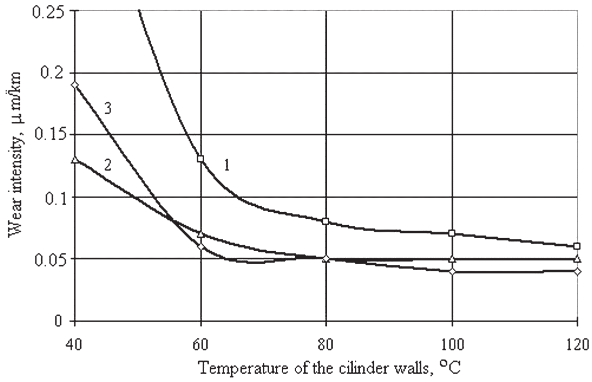

Fig. 10. Cylindrical casing wear dependency on the wall temperature of the diesel locomotive 10D100: 1 – basic variant; 2 – modified tribosystems by carbonic acid gas; 3 – modified tribosystems by natural graphite with niobis

crankshaft is the same as in cylinder-piston tribosystem. Minimal wear occurs in the revolutions to 500 rev/mm.

Increased wear of tribosystems in the range of high frequency revolutions of the crankshaft is explained by increased pressure and resistance, higher temperature of working surfaces and oils, whilst at low frequency revolutions of the crankshaft is explained by decreased effectiveness of the oil film on diesel tribosystems.

Hereby, the results of the investigation show that after modification of diesel locomotive tribosystems with carbonic acid gas or natural graphite there exist an optimal working regime which maintenance leads to guaranteed minimal wear and maximal durability of main diesel elements.

Temperature working regime of the locomotives can be graded according to temperatures of cooling fluid and engine oil during the exploitation. Superheat of the engine decreases viscosity of oil, cracks film of oil, deforms parts that results in increased wear rate of the latter.

It is known from the passport data that optimal thermal regime of cooling fluid is 70–90°C at which wear of tribosystems is minimal. There were performed investigations for the wear rate of tribosystems at the temperature range 60–100°C. The total results of wearing of the diesel depend on the temperature of cooling fluid and are shown in Fig. 9.

Results of the investigations indicates that certificate's data are confirmed for the basic variant of the diesels and the one modified by carbonic acid gas, i.e. the lowest wear is achieved when temperature of the cooling fluid is held approximately by 80°C. However, for the diesels modified by natural graphite with niobis an optimal temperature is nearly 90°C.

Besides that, considerable importance for the wear intensity of cylindrical casings of locomotives has corrosion processes. At low cooling fluid and oil temperatures some surfaces of the casings are irrigated by condensate which consists of diesel products containing combinations of sulphur and other gases active for corrosion. Resulting to that a chemical corrosion occur forming oxides that increase corrosion - mechanical wear in tribosystem „cylindrical casing- rim". Wear of cylindrical casing of diesels 10D100 depending on the wall temperature of the casing is shown in Fig. 10.

Results indicate that sufficiently intense wear of the cylinder casings occurs while diesel is heated after the launch. Wear intensity becomes practically steady after it reaches optimal temperature of 80–90°C. We can also see here that the most favorable kind of TS modification is the one with natural graphite with niobis.

While investigation of wear manner of diesels TS at non-stationary (non-steady) regimes it was observed that wear of the cylindrical casings, pistons, main and rocker crankshaft inserts increases by more than 20 %. That is associated with fact what at non-steady regimes, when comparing to steady ones, increases influence of the inertia forces on loads, operating conditions of oil become worse, normal steady combustion process at the cylinders breaks down. As it was above-mentioned, it is impossible to reject transitions from liquid friction to the critical as well as increased corrosive wear.

In such a way, it is necessary to maintain constant (stationary) regimes during exploitation of locomotives with unmodified diesel tribosystems. If it is impossible then transitions from one regime to another must be performed uniformly that can be hardly implemented on the railroad.

Diesels are not that sensitive to the change of regimes and fulfill operating conditions on the railroads much better at the same time as well as increase durability and their usage effectiveness when tribosystems of the diesel locomotives are modified.

3. Conclusions

The following conclusions can be made after performed investigations on engines of diesel locomotives 10D100:

1. Wear of the parts is 10 times higher comparing to established diesel working regimes during the diesels start-up.
2. Modified diesel tribosystems shorten start-up duration and depending on that decreases wear 7–10 times.
3. Diesels can be operated at all velocity and load regimes without increased wear with modified tribosystems.
4. Wear of compression rims does not have influence on the gas leak to the crankcase of the engine using modified casings of the cylinders i.e. gap of the tribosystem „cylinder casing – compression rims" does not vary practically as its slight increase is compensated by the hard film of oil.

Maximum durability of diesel locomotives can be achieved by modified tribosystems.

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