TEKA. COMMISSION OF MOTORIZATION AND ENERGETICS IN AGRICULTURE – 2012, Vol. 12, No. 1, 263–267

The influence of the operating conditions of farm tractors on the wear of crankshaft slide bearings

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Summary. The paper presents selected results of in-use investigations of a farm tractor U 912 and a harvester BIZON SUPER Z056. Based on the recorded engine operating states of both the tested machines the number of start-ups and the time of operation were recorded. The results of tribological investigations have also been presented performed in the friction pair: crankshaft journal - slide bearing. Based on the analysis of the collected material the authors attempted to determine whether the dynamic (non-steady) states of the operation of slide bearings, characteristic of engine start-ups can result in a significant reduction of their life until the moment its normative durability is depleted.

Key words: farm tractor, operation, slide bearings, friction, wear.

INTRODUCTION

The process of machine use is characterized by a high dynamics of changes in the operating states, which influenced the elements of the kinematic pairs. The durability and reliability of the machinery to a large extent depend on the above and it is this particular dynamics causing that the kinematic pair usable potential is consequently reduced. In such machines as farm tractors there exists uncertainty in modeling of the operating conditions, which is the result of changes in the engine thermal states, variations in the motion resistance and the ambient conditions [1, 14]. To other determinants of the process of operation that decide about the specificity of the farm application of machines we can include differences in the operation routines of drivers and irregular frequency of use throughout the year. Scientific works frequently point to a relatively small efficiency of farm tractors (average operating times 300 h/year, which translates into extended periods of depreciation – up to 40 years) and ineffective use of their engines, whose average loads range from 60-70 % of the rated power [4, 3].

The analysis of the operation on the durability of the kinematic pairs is particularly needed in relation to friction pairs that due to their proneness to failure, repair costs and operating safety are treated as weak links (critical pair). In the case standalone farm machinery that would be the engine crankshaft slide bearings. These friction pairs are designed for liquid lubrication. It is, however, impossible in the overall range of external shocks.

During start-up, stoppage and operating overloads, non-steady states of the slide bearing operation occur that make the hydrodynamic liquid lubrication of the bearing impossible [13]. In such a situation direct metal-to-metal contact may occur at the points of actual friction and adhesive grafts may occur as a result of molecular forces that will lead to a quicker material wear in the friction pairs [7, 2]. Since, under non-steady states of operation, the motion resistance may grow abruptly (at dry friction the friction coefficient may exceed the value characteristic of liquid friction over 100 times [7]) this may significantly reduce the durability of the friction pair, even if the collective operating time under such conditions is relatively short in relation to the total operating time of a given friction pair. The above considerations constituted a basis for further studies of the problem of determining of the influence of the operating conditions on the durability of slide bearings of the crankshaft in farm machinery.

RESEARCH METHODS

The investigated problem was realized in two stages. The first stage was the analysis of information on the operating parameters of standalone farm machinery. The object of the research were: farm tractor U 912 and a harvester BIZON SUPER Z056 used in one of the farms in the province of Zachodniopomorskie (West

Pomerania). In the case of the farm tractor the operating tests were carried out in the period 07.2006-10.2008 and the data related to the harvester were obtained during harvest works in 2009 and 2011. For the recording of the engine operating states TRS (Tractor Recording System) was used developed in the Chair of Basics of Technology at the University of Agriculture in Szczecin [6]. This system allows recording of the following data related to the engine operating states and conditions of operation:
- Engine start-up and stoppage time,
- Engine time of operation,
- Engine speed,
- Hourly fuel consumption,
- Geographical location of the Machinery.

Due to the character of the research the object of particular interest were data on the engine start-ups and engine times of operation. Since, during the engine start-up and stoppage there are engine speeds for which hydrodynamic liquid lubrication is impossible it was assumed that their number may reduce the durability of the crankshaft journal-slide bearing pair.

In the second stage of the investigations tribological tests were carried out in the friction pair that reflected the crankshaft journal - slide bearing pair. The authors aimed at determining the influence of the sliding velocity on the wear of the bimetal tape before its shaping into a half-bearing. The flat samples of the bearing material operated with steel rollers (counter sample material: steel 40 HM, 51-53 HRC) on the length of the friction contact corresponding to the width of the sample *l* = 7 mm. The wear tests were carried out for the following operating parameters of the test pair:
- Velocity of slide v : 0,6; 0,9; 1,2; 1,45 [m · s^{-1}],
- Load P = 300 N,
- Friction distance 2500 m,
- Lubrication medium: engine oil *Superol M CC 30, 15W/40.*

The selection of the velocity of slide was made based on the preliminary tests for which the parameters of the test working pair were analyzed at the engine speeds characteristic of the start-up phase for diesel engines (it is assumed that the engine speed when starting up should be in he range of 100-200 rpm). For each of the applied speeds 6 test runs were performed.

RESEARCH RESULTS

The research cycle of the U 912 farm tractor extended over a period of over two years of operation i.e. from 03.07.2006 to 14.10.2008. Through the TRS system installed in the machinery, information was obtained on the parameters of the tractor operation through data recording with a 30-second resolution. The operation of the measurement system was initiated when the engine was started and lasted until the engine stopped. Based on the analysis of the obtained data the authors ascertained that *the collective tractor operating time in the whole research cycle was almost 301 hours, which corresponds to 1009 engine start-ups*.

The obtained results indicate low effectiveness of the tractor use in the given farm, which is characteristic of Polish farms [Kocira 2005, Pawlak 2005]. In the analyzed period the tractor was used with different intensity and the hours of operation and number of start-ups showed a similar trend of changes in analogical agricultural seasons (Fig. 1), adequately to the nature of the realized farm work. An exception is December 2008 when the recorded operating time and number of start-ups are not the resultants of the farm work. At that time the tractor was used for collecting timber for heating purposes.

The results of the in-use investigations of the harvester in the form of number of start-ups and engine

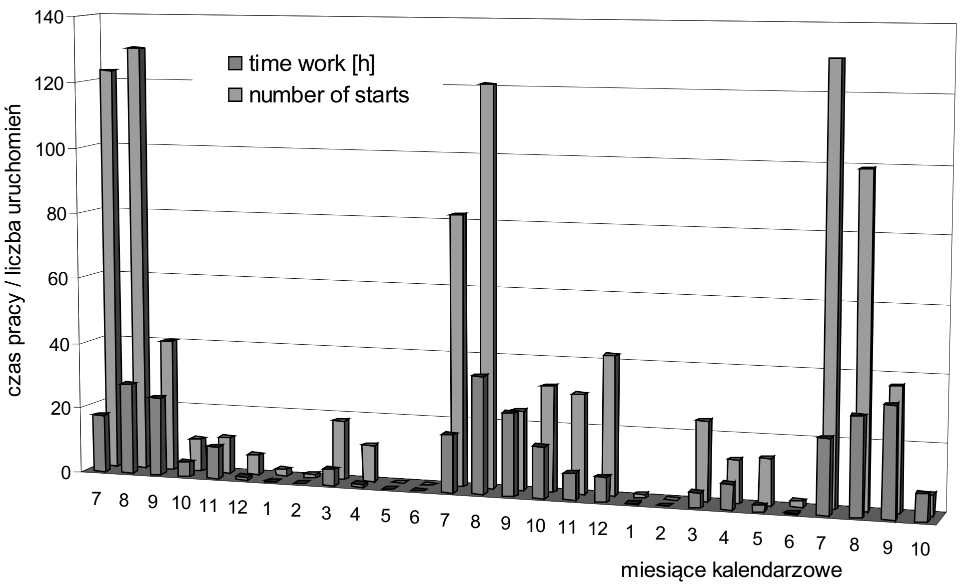

Fig. 1. Number of star-ups and engine operating time in the whole research cycle (3 July 2006 to 14 October 2008)

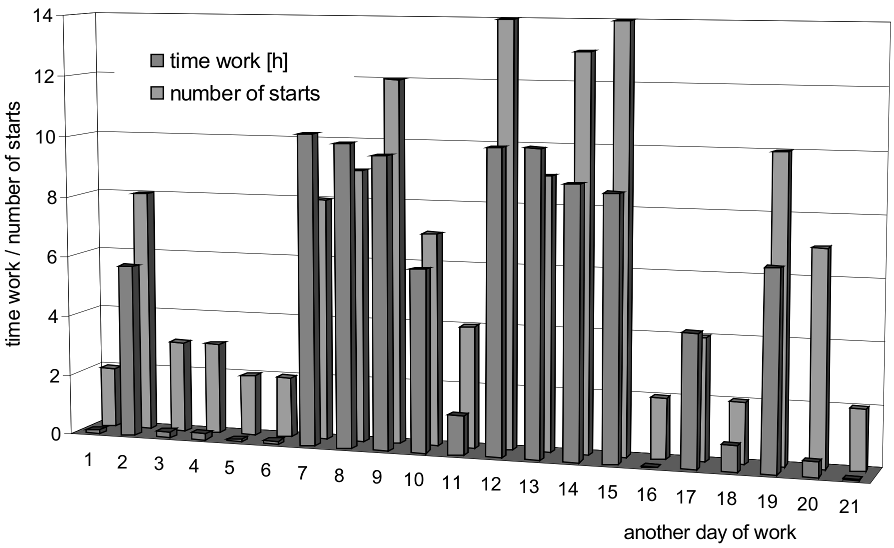

Fig. 2. Number of start-ups and engine operating time of the harvester during summer field works in 2009

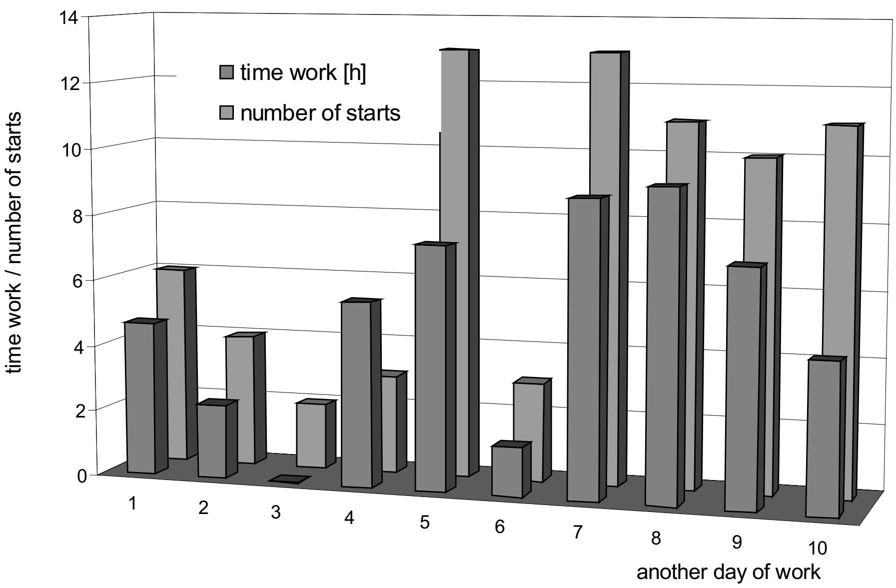

Fig. 3. Number of start-ups and engine operating time of the harvester during summer field works in 2011

operating time in relation to the days of its use have been presented in Fig. 2 and 3.

As results from the obtained data, *in the fieldwork in 2009 the harvester operated for 93 hours and was started 137 times and in 2011 its operating time was 51 hours and the engine was started 76 times*. The recorded engine operating time in 2011 was over 80 % shorter than in the agricultural season 2009, which was the result of limited services rendered by the owner of the machine, and harvesting only in his own farm. The presented data clearly confirm the lack of effectiveness of use of the harvester, as it is generally assumed that the rational time of operation of a harvester should be 20-25 years, which at the normative durability of 3000 hours, denotes an annual use on the level of 150-120 hours [8, 11].

The presented results of the tests on the U 912 farm tractor and the BIZON harvester correspond to the specificity of use of agricultural machinery. The specific conditions of operation lead to a quicker moral (functional) wear of the machinery rather than their physical wear. This results from the small effectiveness of use of the machine potential and the dynamics of introducing new generations of technologically advanced machinery. This generates a problem of particular importance i.e. ensuring an appropriate level of long-term reliability of the farm machinery in the long run (40 years and more). The efforts of the service technicians should obviously minimize the potential failure through, for example adhering to the repair intervals that should be realized depending on the actual needs. Helpful may also be the data on the engine operating states as well as the tribological data related to the intensity of the destruction processes of the kinematic pair, characteristic of these operating states.

As mentioned earlier in the paper, engine start-ups generate the occurrence of dynamic states of the operation of the slide bearings of the crankshaft. The knowledge as to the number of these states together with the intensity of the material wear of the friction pairs during start-up can be used to forecast the intervals between the crankshaft rebuilds (honing to further repair undersize). This constituted an assumption for the experimental exploration of the triboligical characteristics of the sliding material pair crankshaft journal - bearing and its relation to the operating conditions in the life cycle.

Through the results of the tribological tests the authors attempted to determine the measure of the linear wear of the samples made from the slide bearing material depending on the velocity of slide of the counter sample simulating the crankshaft journal. Under the conditions of actual operation of the crankshaft journal - slide bearing pair, when the elements come into contact the friction contact is distributed, while the here discussed wear tests began from concentrated friction contact of the roller (counter sample) with the sample coat. The tests were performed for the steady loads on the pair and four selected velocities, which is naturally far from the operating shocks. The assumed rigor of the laboratory tests reduced and simplified the tests and shortened their duration and at the same time provided interesting information in relation to the energy interactions in the friction pair under the conditions of combined friction, characteristic of the non-steady states of the operation of sliding pairs.

Table 1 presents the results of the wear tests obtained for all the performed test runs. The results were averaged, and, based on these results, the characteristics of the changes of the linear wear of the samples as a function of velocity and slide were developed (Fig. 4) [12].

Table 1. Wear tests results

Velocity of slide [m · s $^{-1}$]	Linear wear in the tests [mm]						Average wear [mm]	Standard deviation s [mm]
	1	2	3	4	5	6		
0,6	0,393	0,588	0,547	0,292	0,569	0,297	0,448	0,137
0,9	0,289	0,231	0,277	0,151	0,170	0,162	0,213	0,061
1,2	0,109	0,228	0,131	0,282	0,108	0,164	0,170	0,071
1,45	0,219	0,203	0,241	0,227	0,182	0,271	0,224	0,031

The greatest wear of the samples was determined for the lowest velocity of the counter sample. Also in this case the authors observed a great spread of the results in the measurement trial. An explanation of such a status quo can be provided in the data contained in the bibliography. In the results of tribological studies it is stressed that low relative velocities < 0,8 m · s $^{-1}$, at unit stresses above 10 Mpa facilitate adhesive grafts [7]. As the tests were carried out on concentrated friction contact and at relatively low velocities of slide, in the case of the lowest applied velocities both of the above conditions were fulfilled.

Great development and separation of the adhesive grafts with the effect of generating of the wear products leads to a seizure of kinematic pairs and in extreme cases when the friction process begins to dominate inside the surface layer it can lead to emergency stoppage of the friction pairs [10, 5]. During the tests, the recorded changes of the moment of friction for tests performed at the velocity of 0,6 m · s $^{-1}$ are characterized by the least stable course. The observed changes in the motion resistance correspond to the highest intensity of the damaging occurrences in the tested pair, which could be attributed to the courses of the wear processes consisting in destruction of the adhesive grafts [10].

In the range of the assumed slide velocities, the lowest wear occurred for the velocity of 1,2 m · s $^{-1}$. Taking the observed relations we can conclude that it is purposeful to seek start-up engine speeds that are optimum in terms of durability. It is noteworthy to relate this to the daily practices. The circumferential velocities of the

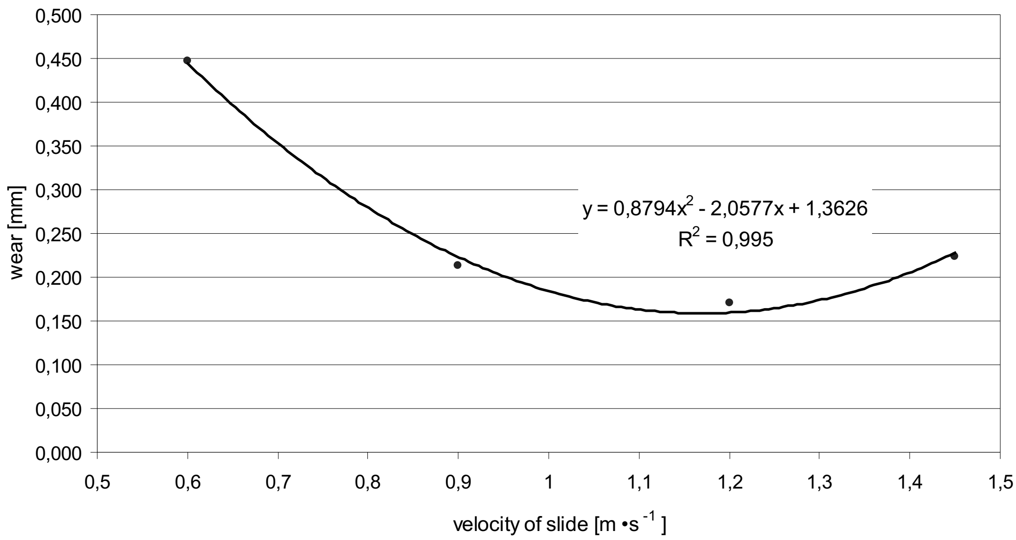

Fig. 4. Linear bearing material's wear depending on the velocity of slide of the roller simulating the crankshaft journal

points located on the surface of the crankshaft journals of nominal diameters of 80 and 90 mm, for, as assumed, the proper start-up engine speeds of 100-200 rpm are 0,42-0,84 $m \cdot s^{-1}$ (80 mm journal) and 0,47-0,94 $m \cdot s^{-1}$ (90 mm journal). These are, thus, in the context of the obtained results of wear tests disadvantageous slide velocities. The presented estimate calculations, due to the assumed order of the diameters of the crankshaft journals, can correspond to the farm tractors of higher power output. In the case of widely applied farm tractors of low and medium power class (as mostly used in Poland - URSUS 912, C 385, C 360, or MF 235) at the start-up engine speeds as mentioned above, the obtained velocities of slide of the crankshaft journals will be much lower, hence the risk of intensification of the wear process of the kinematic pairs will be higher. The obtained adjustment of the trend line for the empirical data ($R^2 >$ 0,8) indicates the possibility of forecasting of the slide bearing material wear for the slide velocities other than those used in the tests.

CONCLUSIONS

1. The results of the in-use tests point to a need of analysis of the operation of engines of farm machinery in terms of their usable specificity conditioned by the nature of the agricultural works.
2. The recorded times of the operation of the engines and the number of start-ups (in the case of the farm tractor it was over three times higher than the number of hours of operation and in the case of the BIZON harvester 1,5 times higher than the number of hours of operation) juxtaposed with the general duration of the research indicate a possible significant influence of the start-ups on the durability of the crankshaft journal-slide bearing kinematic pair.
3. The wear tests indicate that optimum start-up engine speeds be sought in order to reduce the wear of the friction pairs under the non-steady conditions of operation of the slide pair.

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WPŁYW WARUNKÓW EKSPLOATACYJNYCH CIĄGNIKÓW ROLNICZYCH NA ZUŻYCIE ŁOŻYSK WAŁU KORBOWEGO SLAJDÓW

Streszczenie. W artykule przedstawiono wybrane wyniki w użyciu badań gospodarstwa ciągnika U 912 oraz kombajn zbożowy Bizon Super Z056. Na podstawie zapisanych stanów pracy silnika obu maszyn badanych liczba nowopowstających oraz czas pracy zostały zarejestrowane. Wyniki badań tribologicznych zostały również przedstawione wykonywane w parze tarcia: Dz wał korbowy - łożysko ślizgowe. Na podstawie analizy zebranego materiału autorzy próbowali ustalić, czy dynamicznych (nie wzrasta) stany eksploatacji łożysk ślizgowych, charakterystyczne dla silnika typu start-up może doprowadzić do znacznego obniżenia ich życia do chwili jego trwałość normatywny jest wyczerpany.

Słowa kluczowe: ciągnik rolniczy, praca, łożyska ślizgowe, tarcie, zużycie.