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[1.]Miroslav MILUTINOVIĆ, [2.] Spasoje TRIFKOVIĆ, [3.] Aleksije ĐURIĆ, [4.] Nikola VUČETIĆ

GEAR FAILURES EMBEDDED IN MANUAL GEARBOXES

[1-4.] University of East Sarajevo, Faculty of Mechanical Engineering, East Sarajevo, BOSNIA & HERZEGOVINA

Abstract: During exploitation motor vehicle gearboxes are exposed to varying conditions. The changes are stochastic and dependent on many factors. These changes directly affect also to the gearboxes damage, and therefore the gears damage. Different types of damage can occur on gears, so that this paper will give focus on the damage on gears. According to DIN 3979 over 20 types of damage appearing on gear are given, while in this paper only damages on gears that are in gearboxes embedded will be presented. The paper contains the results of the damage percentage of manual gearboxes and the results of cumulative damage of manual six-speed gearboxes.
Keywords: gear, gearbox, micro pitting, pitting, scoring, scuffing

INTRODUCTION

During operation of the gearbox, gears occupy a very important place. Defects and damages during the work of gearbox occur on the gears, so diagnosing of failures shows that the received signal is efficient and suitable for early detection of local failures of gearboxes [1]. In [1] monitoring and diagnostics of industrial gearbox was carried out. According to the lowest spectrum that is based on the current frequency spectrum, new parameter was developed. The parameter for estimation of the gearbox damage, on the basis of real measured signals, has been proved as insensitive to variations due to changes caused by various speeds and loads.

During operation of gearboxes, gear tooth flanks are exposed to the contact pressures, and therefore the combination of rolling and sliding [2]. This kind of load can cause a specific type of fatigue that is called rolling-sliding contact fatigue [2]. In order to successfully construction and dimensioning of gear pairs, in [2, 3], the possible damaged of gear pairs due to fatigue are given, as well as the mechanisms that lead to their occurrence.

During the work of gearbox comes to damage of gears, bearings, couplings, seals, etc... The damage speed of these components are influenced by the working conditions of gear. Based on years of research the authors of [4] presents the results which indicate that all gear failures occur due to the frequency of the system startup. Summarizing the results, it was concluded that the bearings are subject of damage more than 49%, while the gear failure occurs 41%. The remaining 10% damages are related to the other components [4].

Based on the Neale Consulting Engineers Ltd (NCEL) report, mistake making gear, outdoor dirt, the input torque of the gearbox, oil and metal particles in it, bearings damages and unexpected loads of bearings have been established as primary effects which may cause the damage on the gear teeth and bearings [4]. In that report the defects when making gears were represented by 6%, which are the result of different influences which depend on machines, measuring equipment, process control and various other influences. If we specify stricter criteria in control of gear making, and thereby strictly control of subsequent processing, these errors could be minimized. However, without stringent control the percentage of errors could increase. Since the destruction of gears depend on several factors and how there are stochastic, in [5] author gives a destruction probability diagram of gears for annealed gears, where we can see that with the increasing number of changes the stress that gears can withstand is decreased. With stress decreases, which gears can with stand during operation, possibility of damage is increased. Author of [6] gives the results of gear damage due to pitting, poor lubrication and explains destruction of surface-annealed gears, while the authors of the paper [7] carry out an analysis of the impact of gear pairs with different damages and their effect on the generation of noise and vibration. In the paper [7] tests were performed on eight different gear pairs, of which on one pair was no damage, three pairs of gear were damaged by pitting, three pairs were damaged by spalling, while one pair was with a broken tooth.

During the tests it was concluded that there is no a direct proportion between the vibration generated by gears and their wear, as well as other damages caused during their operation (rotation). Contrary, wear may affect the reduction of vibration level since the gears mutually adjusted.

Investigation in [8] and [9] were performed on test benches with closed power flow and with application of standardized respectively FZG methodologies (TU Munich).

POTENTIAL DAMAGES THAT MAY APPEAR IN GEARBOXES

During operation of gearbox, i.e. during power transmission through the gear different types of damage may incur. During the years of testing gear power transmitters, damages at 931 gears were appeared, of which the most prominent is fracture of gears [10]. On the other side, on high-power gear drives most common damage are incurred due to overload (21.7% [11]). These are some of the indicators that the gears are exposed to stochastic changes and that should be paid great attention to the potential damage that can occur on them. Depending on the load, as well as working conditions which they are exposed, it is possible occurrence of over 20 types of defects of gears, which are given in DIN 3979th. Basically, fracture of gears in gearboxes happens very rarely, or if arise they are consequence of accidents, while damage or complete destruction of the working surfaces of gear teeth more frequently appear. Any of these defects can be formed by combining various influences, such as defects in material, residual stresses, poor production quality of the gears, poor lubrication, etc. The process of gear destruction is permanent and initially poorly expressed and it is very slow, while at the end of life circle becomes progressive. Operating conditions of gearboxes are variable, so that this process consists of different entities such as: micro pitting, pitting, spalling, abrasion, scratch and plastic injection of particles, scuffing, etc. An overview of some possible damages in gearboxes will be given below.

Micro pitting is a type of damage to the tooth flanks, which occurs due to high pressure and increased speed of skating. As such kind of damage occurs in the beginning of life circle of gear due to even out irregularities on the gear flanks. Micro pitting is similar to abrasive wear in the initial stages of formation and development, which creates confusion among many young engineers. Besides that, micro pitting can occur after a relatively small number of coupling (if the gears are made of a material of poor quality) or after a larger number of coupling (surface reinforced gears). Usage of inadequate sophisticated additive to enable the operation of gear in extreme conditions may indirectly contribute to the emergence of micro pitting. The process can be identified with the naked eye as a gray color or spots on the flanks, which represents the formation of micro cracks or dimple depth up to several microns. Figure 1 shows a schematic representation of damage due to micro-pitting and Figure 2 presents the resulting micro pitting on the side of the gear. Identical damage is possible on the gear that is built into the gearbox.

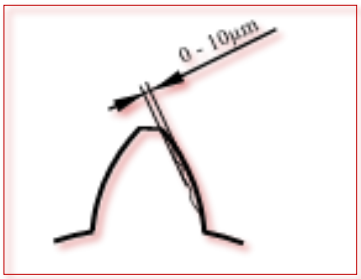

Figure 1. Micropitting

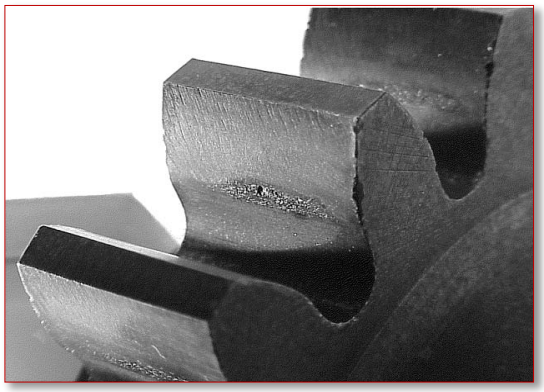

Figure 2. Micropitting[2]

Pitting is the type of gear failure that occurs between the sliding surfaces under high pressure. In the case of pairing gears made of various materials pitting occurs on the gear made of poorer material, whereas in the case when the gears are made of the same material pitting occurs on the gear with a smaller number of teeth. In the case of gears built into the gearbox, pitting occurs on gears with the smaller number of teeth, which are usually driven gears, that is not the case at the higher speeds where the driver gears have a higher number of teeth of the driven gears. The cracks are small at the beginning, while during the lifetime lubricant enters the cracks, causing further damage. Depending on the lubricant, according to Hertz's pressure, the maximum stress can occur below the surface layer (by poorer lubrication) or between the bumps on contact surfaces (by better lubrication) [6]. Unlike micro pitting, pitting occurs after larger number of changes (10^5), and its appearance is not possible at the number of changes of less than 10^4. A better machined surface reduces the possibility of pitting, which causes an increasing of machined surfaces quality. Increasing of the quality of lubrication and oil film thickness decreases the frictional force and the possibility of pitting.

According to ISO 10825 there are two types of pitting: initial and destructive pitting. The cause of the initial pitting can be attributed to the accuracy of making gear pair or poorer quality of the machined surfaces of gear. The destructive pitting can occur due to the development of micro cracks under certain overloads, while it can also appear as a growth of damages of initial pitting. Figure 3 shows a schematic representation of damage due to pitting.

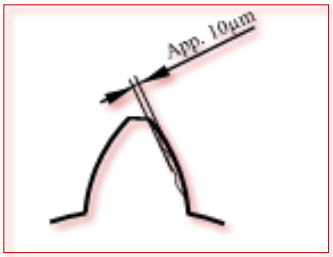

Figure 3. Gear pitting failures

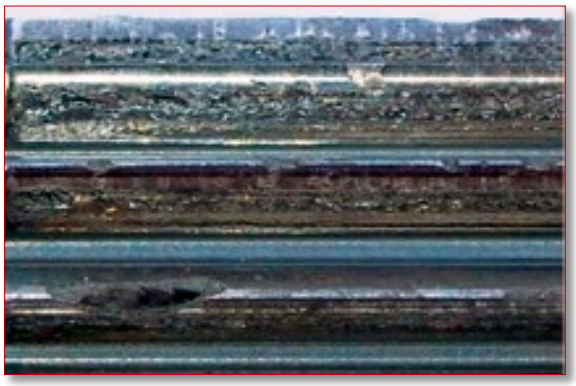

Figure 4. Gear pitting failures [12]

Spalling is another form of failure of hardened gear tooth flanks. It is characterized by appearing as a brittle fracture. Spalling is characterized by the appearance of cavities of several tens of microns to 0.2 mm (Figure 5) i.e. from 0.25-0.35 to the half of length of the contact line on gears flank [13].

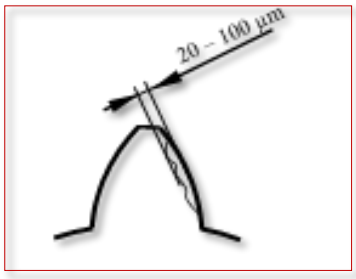

Figure 5. Spalling

Basically, spalling is similar to destructive pitting, with the difference that the damages are higher. In this type of gear failure cracks are initially wider under the surface of the gear (parallel to the surface), so that at one time, due to the increased surface pressure, changes their direction to the surface layer, bursting material particles in the form of flakes leaving the form of brittle fracture. Usually from the gear surface strengthening depend the size of torn particles. In the case of surface hardened gear flanks, separation of larger pieces of the gear surface layer is occurred, whereby the bottom of the fracture is usually between hardened and unhardened layer. On gear damages caused by spalling, the characteristic sharp edges along the surface can be noticed. Initial cracks are small, and when the number of such particles accumulating in one place creates larger cracks. Figure 6 presents the damage due spalling on the gear flank.

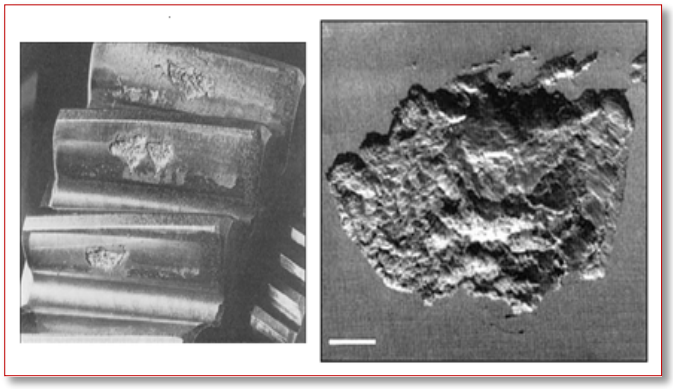

Figure 6. Spalling [14]

Scuffing is a type of gear failure, which is manifesting by large number of longitudinal damages in the form of furrows in the direction of sliding (figure 7). The position of furrows depends on the contact surfaces (Figure 8).

Figure 7. Gear scuffing failures [12]

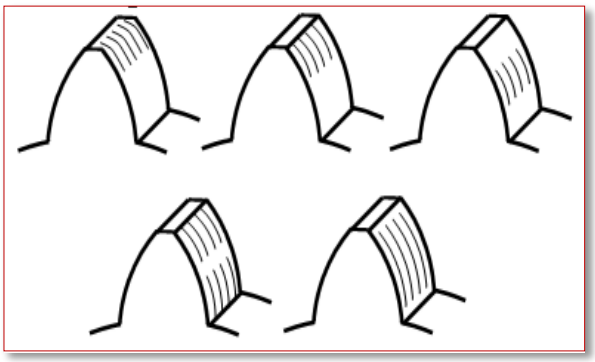

Figure 8. The position of furrows due to scuffing damage

The cause of this type of damage is interruption of oil film between the contact surfaces of the gear flanks caused by overload or high sliding speeds.

Due to the interruption of the oil film, comes to direct contact between gear flanks, whereby the contact surfaces are heated because of the increasing of friction. This heating causes connection (welding) contact surfaces of gear flanks. Further operating of gear causes the violent separation and tearing of the surface layers. Surfaces remain welded to the gear flanks and damage each subsequent surface of gear flanks that it is paired.

There are basically two types of scuffing: cold and hot scuffing. Cold scuffing occurs at low speed of sliding between the materials of lower quality, while hot scuffing occurs at a much higher speeds of sliding and surface pressures by heat-treated surfaces.

Breakage of gear. During operation of the gear, occurrence of fatal damage is possible, such as breakage of gears. This damage occurs very rarely in gearboxes. The cause of such damage is the occurrence of initial cracks that occurs in the weakest areas, where there is a high concentration of stress and bending stress. The damage extends over the entire surface of the tooth root, causing breakage that can be violent or fatigue.

Fatigue fractures are due to impact loads, causing a stress at the base of the gear teeth, which is larger than the static strength and are characterized by the fact that the refractive surfaces are coarse-grained structure. A fatigue fractures occurs as a result of action of dynamic loads in the tooth root and they are higher than permanent dynamic strength. Such damages are characterized by two zones of fractures, zone of fine-grained structure that arises due to the fatigue and the zone of coarse grain structure due to complete destruction. By the shape and structure of the breakage, it can be concluded which case of breakage was come. Gear teeth breakage is rare in gearboxes, but when it occur its cause of fatigue loads. This kind of breakage occurs mostly on gears which are build gearboxes of vehicles that drive over rough terrain, as a result of stochastic changes. According to available literature, there is no evidence that was coming to the violent breakages at the gearboxes.

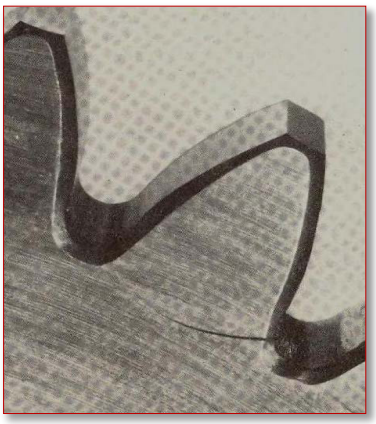

Figure 9. Crack of tooth root [14]

Figure 10. Breakage of more gearteeth [15]

One example of a crack in the root of the tooth is shown in figure 9, while figure 10 shown breakage of more gear teeth caused by a high-cyclic fatigue.

During the work of gearbox comes to rapid changes of loads that directly act on the gears. Load changes influence directly the expansion of initial cracks, and thereby to gear breakage.

ANALYSIS OF GEARBOX DAMAGES

During operation of the gearboxes in the exploitation in different conditions, most of the components are exposed to changeable loads. Changes in working conditions, and thus changes of stress and the parameters of operating conditions can be constant or stochastic. Besides, conditions of use of same type gearboxes can be different. All of that directly affects to the damage of components, which may be different. According to statistics, 80% of cases of mechanical damage occurring due to fatigue.

Based on years of monitoring of the occurrence of damage at the gearboxes, obtained results are: 60% of damage occurs on the gears, while 20% damage occurs in bearings and 20% to other components .

Interview method with long-term users and maintainers of gearboxes was used for the data acquisition. The average age of the maintainers of freight motor vehicles was 32 years and 4 months. Most of the respondents had a full years of service in the maintenance freight vehicles. On the basis of this experience, it can be considered that their answers are very reliable.

According to the results, it did not coming to significant damages at the gearboxes before freight motor vehicle has done 300.000 km, and failures that have occurred was mainly on the synchro coupling. Some of the failures that have emerged are falling out one ball from synchro coupling, which causing the jamming of the system of speed change. Only after 500.000 km significant failures on the gearboxes were emerged and become more and more common, as confirmed by 28% of respondents. The damages has been appeared in the inner bearing and synchro coupling, but also occasionally traces damage by wear have emerged at gear pair.

Significant damages of the gears which are embedded in manual gearboxes emerged after 900.000 km. Respondents maintained manual and automatic gearboxes. In this paper only the analysis of manual gearboxes are included. Figure 11 shows the percentage of failures for different types of manual gearbox. The largest number of defects was emerging at the five-speed gearboxes. In addition to damage to the gears, failures on the sealing seams and synchro coupling were occurring.

Damage to gear pairs is generally created after driving 300.000 km and more. These damages are more balanced by freight motor vehicles which are driven across different terrains, while by freight motor vehicles, which are driven across mountainous terrains, damages appeared to lower gearbox speeds. In the case of vehicle driving only across lowland terrains, damages were created to higher gearbox speeds. Figure 12 shows the diagram of gear pairs damages for each respective speed of six-speed gearbox, for freight motor vehicles which were driven across different terrains.

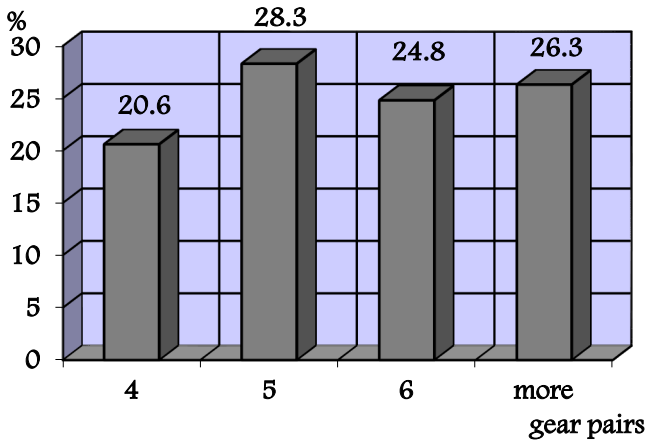

Figure 11. The percentage of failures for different types of manual gearbox

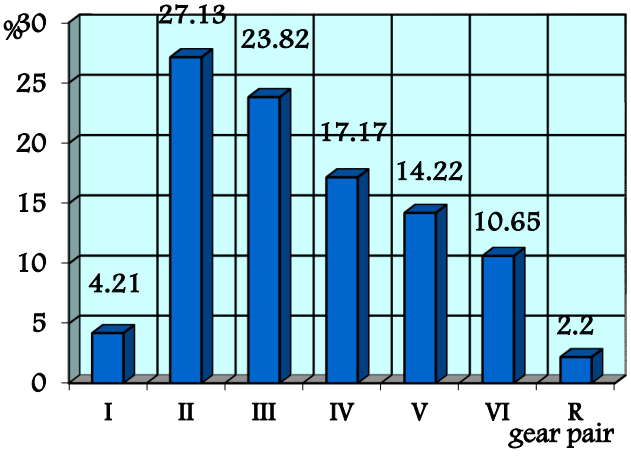

Figure 12. Diagram of gear pairs damages for each respective speed of six-speed gearbox

During the disassembly of each gearbox, verification of all elements was carried out and the possible damages were determined. Types of damages have depended on many factors on which generally affect the operating conditions.

CONCLUSION

During operation of the motor vehicle gearbox transmissions are subjected to stochastic changes that depend on a number of factors, which directly affect the damages of gearbox, and thereby the gears. There are several types of gear failure, and in this paper are described only damages caused at gearboxes. This paper reviews the results of the percentage damages of gears built in six-speed gearbox. The results are based on empirical data, as well as on information obtained by the maintainers of motor vehicle in which these types of gearboxes were incorporated.

Note

This paper is based on the paper presented at The Vth International Conference Industrial Engineering and Environmental Protection 2015 – IIZS 2015, University of Novi Sad, Technical Faculty „Mihajlo Pupin", Zrenjanin, SERBIA, October 15-16th, 2015, referred here as[16].

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