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FAILURE OF ROLLER-SHOE CONTACT FROM HIGH PRESSURE INJECTION PUMPS

BY

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Abstract. The appearance of wear is inevitable for the moving parts of machines and equipments. This leads to changes in geometrical shape of the contacting surfaces and possible machine's failure. The shoe-roller contact from high-pressure injection pump is subjected to different types of wear, but one of the most dangerous is the adhesion. The severe adhesion in the contact developed into scuffing, which becomes catastrophic for the equipment. The aim of this paper is to provide an overview of studies on roller-shoe contact, highlighting unfavourable conditions with failure potential within the contact. The literature offers exhaustive analyses regarding failure occurrence on roller-shoe contact and important factors are analysed such as: contact design, material, lubrication, temperature, contamination, overloading, unadjusted clearance. Our paper analyses the existing studies regarding roller-shoe contact in order to offer new perspectives and improvements in the operation of this type of contact, important in the proper functioning of a high-pressure injection pump.

Keywords: roller; shoe; high-pressure pump; failure; adhesion.

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1. Introduction

The high-pressure pump is the most important component of common rail system and its role is to send the high-pressure fuel into rail, regardless of the engine-operating mode. The constructive solutions are diverse, and are classify primarily according to the transmission mechanism. The pumps used nowadays achieve the motion transmission by means of two types of mechanisms: roller-shoe or tappet-cam. Regardless of the constructive solution, inside the pump there is fuel with high or low pressure and there are components in direct contact. Considering these, the wear appearance is inevitable and can be by several types. The wear can be defined as an irreversible change of friction coupling surfaces during functioning process. The wear phenomenon is manifested either by loss of material on the active surfaces of the elements in contact, or by surfaces parameters. The main types of wear in high-pressure pumps are corrosion, erosion, fatigue and adhesion. The presence of the corrosive substances and additives in fuel, can leads to corrosion and the areas where the fluid acts with high pressure are prone to erosion. The fatigue can lead to fracture of surfaces and can have as effect the scuffing initiation (Devaranju, 2015). Contact fatigue is considered the main reliability criterion of machine elements that work with rolling contact and their constructive-functional optimisation mainly had the same criterion. The presence of particles in the fuel or after the adhesion process can lead to abrasive wear. In addition, the most severe wear type is adhesion and this refers to scuffing components that are in direct contact. This failure occurs when two surfaces have a similar chemical composition, and one surface adheres to another one with material transfer. From all of damages types of contact surfaces, the adhesion wear can occur practically in all friction-lubrication regimes, when the surfaces in contact are not completely separated by the lubricant film. This type of destruction is manifested by the initiation of welding joints between micro-zones contact (Bujoreanu *et al*., 2003). The scuffing is an aggravating wear type that usually leads to components malfunctions. This is the main reason for which this phenomenon is analysed by various researchers. The purpose of our paper is to analyse the currents studies about scuffing process in order to get an overview of this deterioration so that we can understand how it can be produced. To achieve this overview, there are taken into account just the researches that can describe the behaviour of the high-pressure pumps components affected by scuffing. Basically, the scuffing occurs between components where there is sliding motion and this failure can be detected through symptoms such as vibrations, noise or high temperatures. This phenomenon is very complex and can be affected by factors such as inadequate running, lubrication, lubricant proprieties, temperatures, wrong materials, wrong design or inadequate clearance (Yoon and Cusano, 1999). In high-pressure pumps, these factors can be correlated and can cause the scuffing. Also, the result can be the pump malfunction. The transmission mechanism most affected of scuffing is roller-shoe. The most common causes that lead to scuffing of these two components are clearance out of manufacturer's specification, wrong design and materials, inadequate coating, lubricant viscosity, old or non-additive lubricant, over-performance of functional parameters or particles removed from an inadequate machining process. The most important indicator of scuffing initiation is the return temperature, because the frictions from the pump are increased. For this reason, this phenomenon finds itself in a tight interdependence of the thermal regime, depending on its rate of friction losses.

2. Mechanism Prone to Scuffing in High Pressure Pumps

Although high-pressure pumps have different construction options, the automotive manufacturers are based on two criteria: performance and the achievement of the imposed pollution rules.

The constructive solution that succeed to meet easiest these requirements is one in which the movement transmission is done with roller-shoe mechanism. It helps to transform the driveshaft rotation movement in a translation one.

The shoe is in contact with the piston that has the role to pumping fuel into hydraulic head (Fig. 1). The shoe is the static element from roller and shoe assembly, and the roller is the sliding element (Fig. 2) (Iordache *et al*., 2019). The roller has a cylindrical shape with a very good calculated profile and is made of hard material. The shoe is made of material that is very well compatible with roller material, is shock resistant, allows oil adhesion and is coated with diamond like carbon (DLC) for higher strength. Besides the many wear types that can occur in the pump, the most destructive failure is the scuffing between roller and shoe.

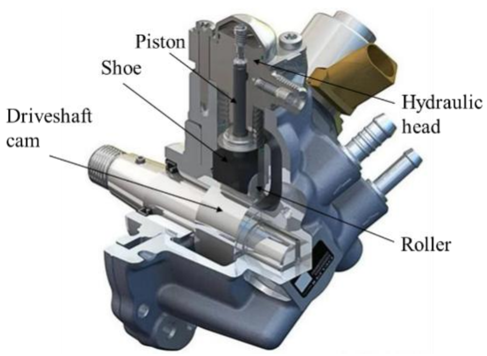

Fig. 1 – High-pressure pump.

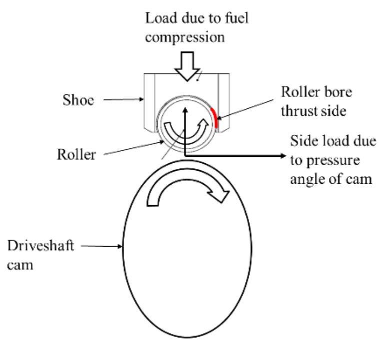

Fig. 2 – Roller-shoe mechanism.

3. Parameters that Influence Lubrication and Lead to Scuffing

The lubrication has a very important role in scuffing reduction. According to a previous study (Ajayi *et al*., 2011), the wear and friction of the sliding surfaces in contact are determined by three factors: the lubricant film, the surface chemical reaction to the lubrication regime and the surface material to which it adheres. Thus, an insufficient quantity of lubricant can cause the breaking lubricant film, and as a result the two surfaces will come into direct contact, metal with metal and leads to scuffing. However, if the materials from which the components are made are similar and have a positive chemical reaction to lubrication, even a reduced quantity of lubricant may be sufficient to avoid the scuffing.

In high-pressure pumps, the components lubrication is done with fuel. The permanently monitored parameters during pump running are fuel temperature, speed and pressure. These can be considered the most important factors that can influence the scuffing occurrence in high-pressure pumps. Depending on them, the lubrication behaves differently. Due to the increasing of the superficial temperature of the elements in contact, local overheating is created and can cause structural changes, breaking of lubricant film between surfaces, with the possibility to triggering the scuffing. For important sliding speeds and fairly low pressures of rolling contact, the deterioration process generates adhesion or abrasive wear (tearing and material transfer at microscopic scale). Combining high speed sliding with low load can limit the temperature rise under the contact surfaces. In case of incorrect functioning of rolling contact through increasing of contact pressure or sliding, it may result the scuffing. The thickness of the lubricant film is dependent of the contact sliding speed, when the sliding speed increases, the thickness of the fluid film decreases (Yoon and Cusano, 1999). To better illustrate this idea, a graph was created (Fig. 3) and this highlights the appropriate and inappropriate lubrication of the sliding components made of steel. In this graph, the division is done on three areas depending of the scuffing evolution. In the first area there is a low wear and a low friction coefficient, in the second part the lubricant film is thinned but still exists and in the third area scuffing occurs (Yoon and Cusano, 1999).

Also, one of the researches is based on pressure and temperature theory, and according with this, the scuffing occurs when the contact temperature reach a limit value resulting from the lubricant pressure generated by the action of the elastohydrodinamic contact (Lee and Chen, 1995).

Another study (Wojciechowskia *et al*., 2017), highlights the idea that running under high load condition and low speed leads to scuffing initiation. Because of this, the EHD lubrication area can be overcome and this can cause to asperities plastering. This is resulting in boundary lubrication, which lead to scuffing occurrence.

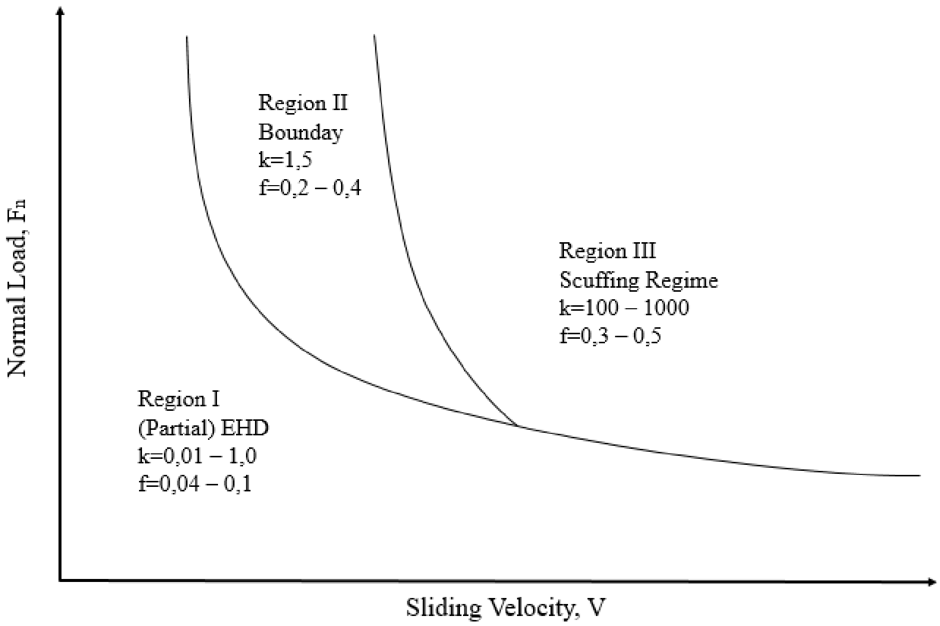

Fig. 3 – Transition diagram for oil at constant temperature;
k: wear rate (10-6 mm^3/Nm), f: coefficient of friction (Yoon and Cusano, 1999).

4. Materials and Coatings

The materials of the contacting components have a very important role in avoiding scuffing process. Basically, the used materials for roller and shoe manufacturing are steels, highly allied, remarkable by their high hardness. In the literature, there are studies done on certain steel types, evaluating their behaviour in limit conditions.

Some studies (Hai-Dou *et al*., 2002) highlight the improvement of anti-scuffing properties of these steels with a new technology. This technology is based on ions blowing at low temperature in order to change the steel surface. The improvement of the steels hardness is done with heat treatments and with coatings. Diamond Like Carbon (DLC) is one of the most used coating due to wear resistance, low friction coefficient and high mechanical hardness (Junjun *et al*., 2017). It is often used in the automotive industry due to superior tribological performance. Under oil lubricating conditions, DLC-coated rollers have shown higher level performance anti-wear and a low friction coefficient (Masahiro *et al*., 2011). Compared with other coatings it has been shown that the friction is much lower when the materials are coated with DLC and also the friction coefficient is the lowest (Fig. 4) (Dae-Hyun and Young-Ze, 2009).

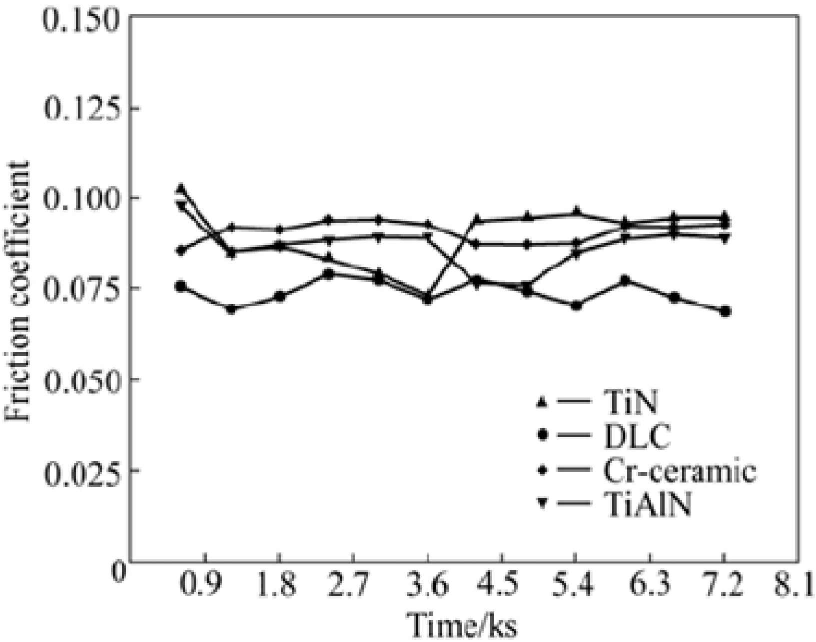

Fig. 4 – Friction coefficients of cylinder blocks with different coatings.

5. Conclusions

Our paper is an analysis of the factors which lead to high-pressure pumps mechanisms. Speed, pressure and temperature are the main parameters which can be controlled and it is shown they have an important role in scuffing initiation. Since the past, this phenomenon was studied by various researchers and the result highlights the relationship between the lubrication, contacting surfaces relative speed, temperature and load. The exploitation of these factors in inadequate conditions leads to boundary lubrication and the scuffing can occur. Also, the materials and coatings have a big importance in wear prevention. There are used materials with good hardness such as high-alloyed steels. Coating help to friction reduction and decreasing of the friction coefficient. After many tests it was demonstrate that the Diamond like Carbon is the coating which fulfils these qualities. A future work will consist in a theoretical study, taking into account of the dimensions of the contact area, in order to obtain the optimum lubrication. This study helps to understand the impact of the aggravating factors in contact area. These factors should be taken into account to improve the functioning of high-pressure pumps mechanisms.

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DEFECTAREA MECANISMULUI ROLĂ-SABOT ÎN POMPELE DE INJECŢIE DE ÎNALTĂ PRESIUNE

(Rezumat)

Apariţia uzurii este inevitabilă pentru componentele maşinilor şi echipamentelor aflate în mişcare. Acest lucru conduce la modificări ale formei geometrice ale suprafeţelor de contact și la posibila defectare a mașinii. Contactul dintre rolă şi sabot din pompa de injecție de înaltă presiune este supus diferitelor tipuri de uzură, dar una dintre cele mai periculoase este adeziunea. Adeziunea severă dintre suprafeţele componentelor în contact conduce la gripare, ceea ce devine catastrofic pentru echipament. Scopul acestei lucrări este de a oferi o imagine de ansamblu a studiilor privind contactul dintre rolă şi sabot, evidențiind condițiile nefavorabile şi potențialul de eșec în cadrul contactului. Literatura de specialitate oferă analize exhaustive privind apariția defecțiunilor la contactul dintre rolă şi sabot. Aceasta analizează factori importanți precum: designul contactului, materialul, lubrifierea, temperatura, contaminarea, supraîncărcarea sau jocul neajustat. Lucrarea analizează studiile existente privind contactul rolă-sabot pentru a oferi noi perspective de îmbunătățire în funcționarea acestui tip de contact, important în funcționarea corectă a unei pompe de injecție de înaltă presiune.