Journal of POLISH CIMAC
Faculty of Ocean Engineering & Ship Technology
GDAŃSK UNIVERSITY OF TECHNOLOGY

TRIBOLOGICAL WEAR OF DIESEL ENGINE ATOMISERS

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Abstract

The authors indicate design changes in injection systems that result in increased tribological loads of atomizers. It is observed that mechanisms of tribological wear of atomizers should be examined in detail. The following four tribological nodes were identified in an atomizer: guide-cylindrical part of the needle, atomizer seat-closing cone of the needle, needle front surface-front surface of injector spring, atomizer front surface-body front surface. A limited set of one type of atomizers was visually examined. Typical images of damage for each node are presented and wear mechanisms are described as well as the feedback between the technical conditions of atomizer tribological nodes and the node load. The authors indicate that: the technical condition of the needle-guide node affects the force imposing a load on the other nodes; the wear of needle front surface-spring node and the seat-needle cone node results in an increased travel of the needle; the time to failure should be considered as the time to the loss of tightness and depends on the distribution of wear on the ring circumference of the conical seat-needle contact.

Keywords: *technical diagnostic, combustion engine, injection system, atomizer, tribological nodes, tribological wear*

1. Introduction

Until recently injection systems of marine engines were not essentially changed for decades, and statistics of engine failures showed that components ranked high. At present growing requirements relating to exhaust emissions and fuel consumption force manufacturers to introduce dramatic modifications in injection systems. In case of atomizers it is predicted that their design will not change significantly, however their mechanical and thermal loads will be increasing. In order to maintain the efficiency and acceptable loads of atomizers it becomes necessary to examine closely the mechanisms of their wear, particularly tribological wear.

2. Atomizer defects

Atomizers are affected by various loads. As a result of these loads, atomizer elements get worn out. Due to the specific construction and load acting on atomizer elements, possible wear can be of various type: erosive, tribological, mechanical fatigue, thermal fatigue, corrosion and creep. Specialist publications lack comprehensive descriptions of atomizer wear mechanisms, considering mostly causes and effects of damage and providing relevant images.

In order to meet requirements on emissions of exhaust gases imposed by the EPA and IMO, fuels used in ships contain less sulphur (below 4.5% depending on the trading range of the ship), and injection system makers increase injection pressures and implement a possibility of multiple injection. Here are example data: injection pressures ranging from 250 to 2200 bar (even 2500 bar is projected), flow intensity in the injector – 400 to 1300 cm^3/30 s at trial oil pressure of 100 bar, injected fuel dose 1.5 to 450 mm^3/stroke, a sequence of up to seven injections will be possible [2]. With such operating conditions, we can expect that corrosive load will decrease, mechanical and thermal loads will increase and so will friction path length.

Mechanical load that acts along the friction path results in tribological wear of atomizer elements that make up tribological nodes. Four tribological nodes can be identified in an atomizer:

1. Guide–cylindrical part of the needle.
2. Atomizer seat–closing cone of the needle.
3. Needle front surface–front surface of injector spring.
4. Atomizer front surface–body front surface.

The latter of the mentioned nodes usually makes up a stationary connection and becomes a tribological node only in certain conditions, while tribological wear in such node is an effect of wrong workmanship and assembly of the injector.

It should be assumed that there exists a feedback between the nodes, so that the wear of one node affects the wear process of the others. Conclusions from the relevant literature are that the process of tribological wear depends on thermal load and condition of the separating liquid, and that apart from tribological wear in the nodes there may occur chemical and erosive wear.

The tribological nodes were visually examined in a limited set of one type atomizers.

3. The node: guide–needle cylindrical part

The function of this node is to provide the movement of the needle so that the centre line of the needle–closing cone is aligned with the centre line of seat cone preventing any seizure of the needle in the guide. The guide–needle node is a congruent node lubricated by overflow fuel. In ideal conditions the load and friction are next to zero. Unavoidable deviations of shape and position, such as misalignment of the cones, orifices and cylinders, and solid particles cause pressures perpendicular to the needle centre line resulting in significant increase of friction. Abrasive wear is the main type of damage. Solid particles that get into the node may cause damage in the form of grooves and cracks, mostly parallel to the needle and guide centre lines, Fig. 1.

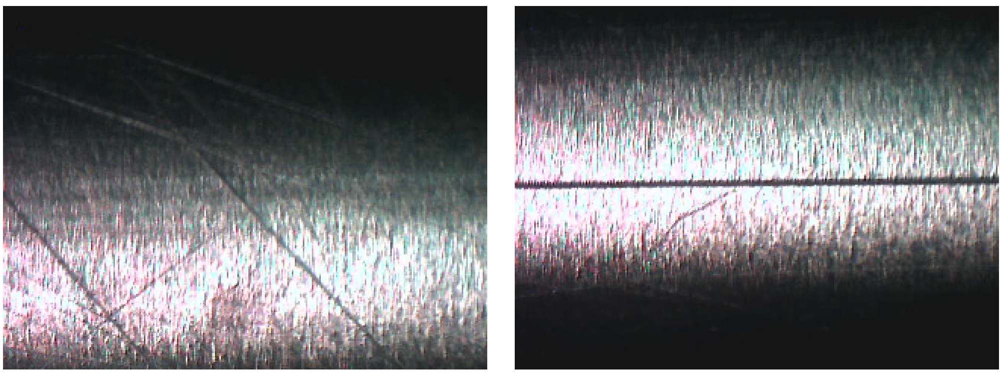

Fig. 1. Cracks and grooves on the surface of needle guiding part

Cracks are caused by hard particles pushed into the needle guiding surface, while grooves are an effect of particles rolling between the guide and the needle. Hard particles pushed into the guide may cause on the needle guiding cylinder the formation of strips of cracks parallel to the generatrix. The strip length is measurable and can be a measure of the actual needle travel.

4. The node: seat–needle cone

The function of this node is to provide tight closing of the injector in both directions: fuel to the combustion chamber and exhaust gases to the injector and to deliver an optimal amount of fuel to the combustion chamber as a function of crankshaft rotation.

In the cone-in-cone shape of the node, the internal cone has a larger top angle which makes the contact similar to that in non-congruent nodes. Under a load deformations occur and the linear contact changes into a ring contact (Fig. 6). The node will be tight if all defects on the surface disappear as a result of elastic or plastic strains.

The load on the needle is due to the difference between the force of fuel pressure acting on the needle cone and the force applied by spring tension.

The seat load consists of the force from spring tension (when the atomizer is closed) and the dynamic force resulting from needle movement speed relative to the seat, fuel viscosity and the materials elasticity – friction force in the guide.

The needle movement speed = f(resultant force, needle travel). The needle travel is a constructional parameter. As it can increase due to wear, it can be a measure of atomizer technical condition.

The construction and movement direction make the atomizer liable to abrasive and adhesive wear, pitting and spalling.

Other types of wear are also possible: erosion from fuel and exhausts, thermal wear, corrosive wear and action of particulate matter.

Images of worn elements of the tribological node seat–needle are presented in figures 2 to 5.

Visual inspection of the seat–needle node results in these remarks:

- both seat cone and needle cone surfaces are subject to wear. The wear of the two surfaces around their circumference is quasi uniform;
- uniform circumferential wear causes the mating needle–seat area to shift as the wear increases along the generatrix of the seat cone, Fig. 6;
- the node loses its tightness the moment it becomes a non-congruent node: non-uniform surface wear of one of the cones results in a break of the seat–needle contact ring;
- as the wear increases, the needle travel also increases; consequently, fuel charge is increased, exhaust gas temperature rises, etc.

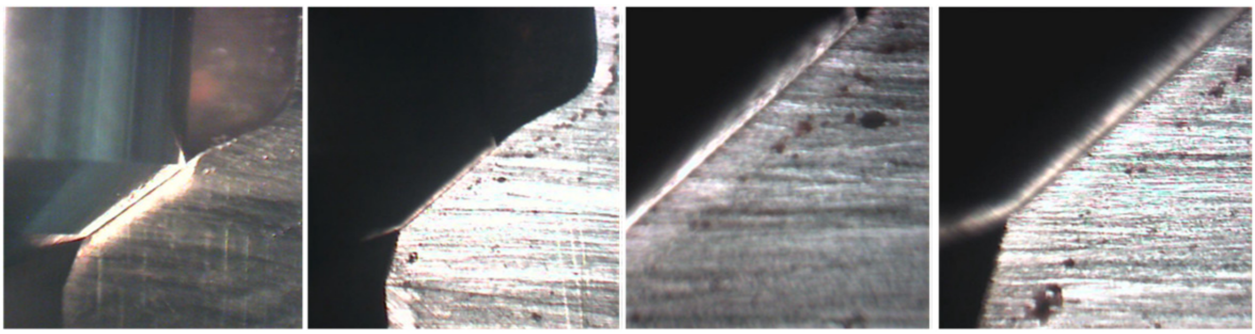

Fig. 2. A new atomizer: the edge of seat cone with a needle

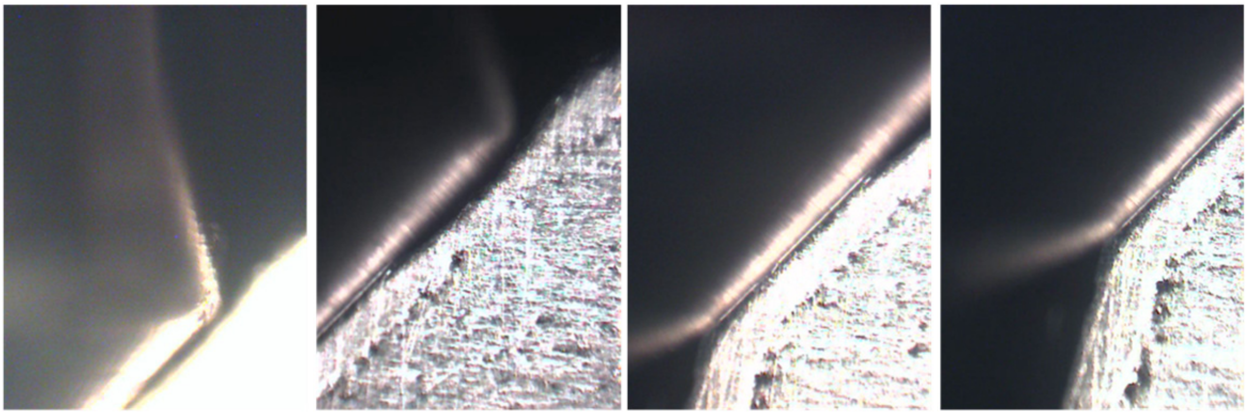

Fig. 3. A worn atomizer: edge (generatrix) of the seat cone with the needle

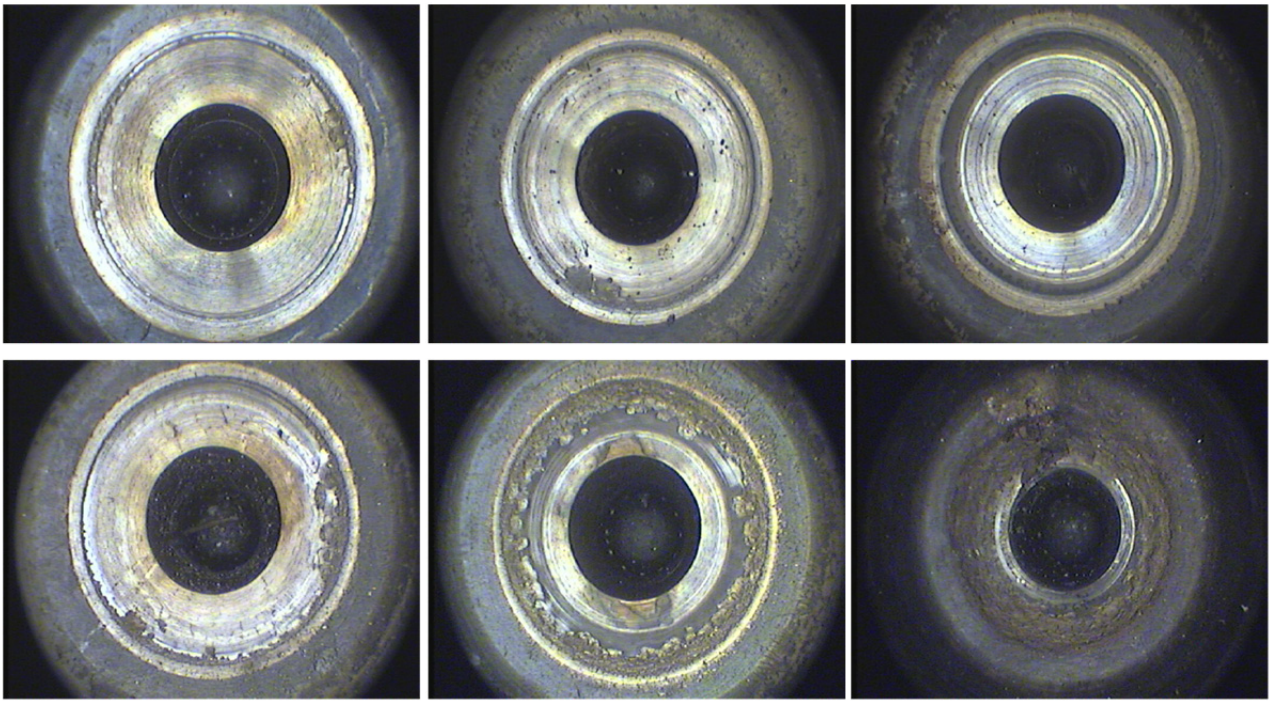

Fig. 4. Images of atomizer seat wear: from the smallest to largest degree of wear

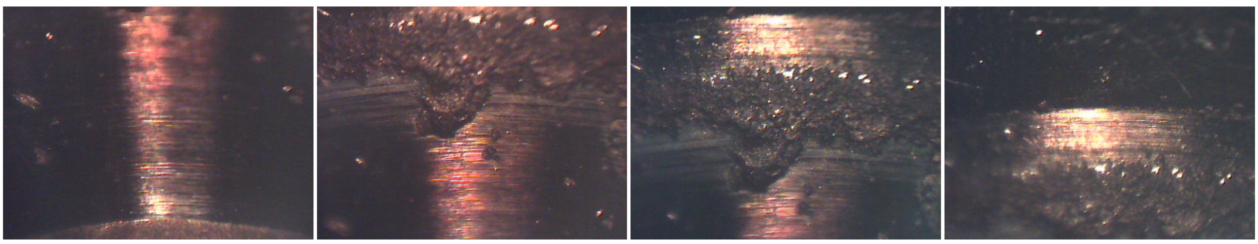

Fig. 5. Fragments of a worn seat: sequence of images from the orifices towards the needle

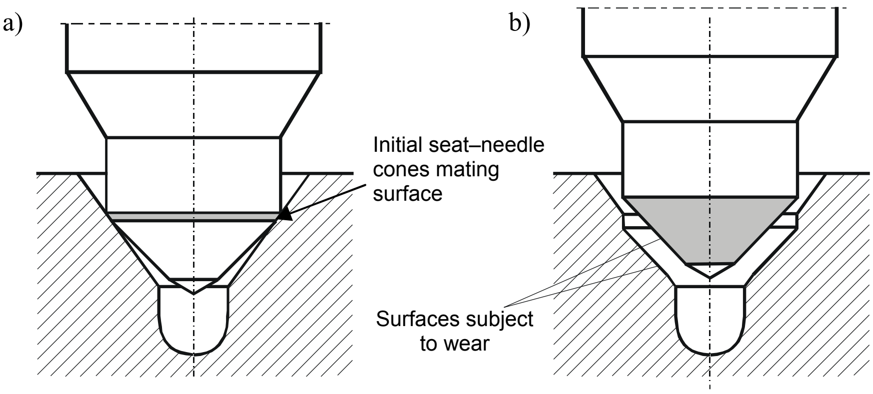

Fig. 6. The tribological node seat–needle cone: a) the shapes of cones before operation, b) shape of worn out seat cone [3]

5. The node: needle front surface–front surface of injector spring

This node conveys the spring pressure force onto the needle. In ideal conditions there should not be a relative motion between the spring and the needle front surface. Deformations and shape / position deviations of the two node elements lead to micro-motions perpendicular to the needle centre line while the spring is squeezed and expanded. Possibly, also relative motions occur of both elements along the needle centre line.

The node load depends on the spring tension and condition and is a function of spring lift.

An image of the wear of needle front surface is shown in Fig. 7.

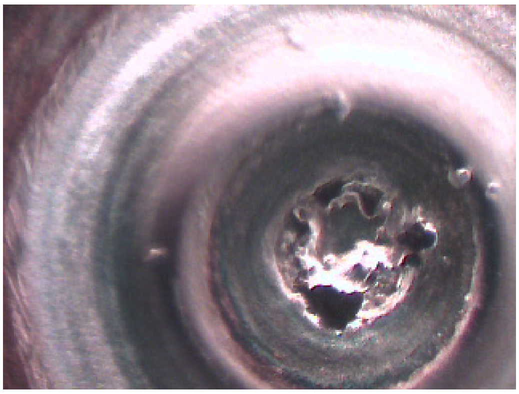

Fig. 7. Wear by spalling of the needle front surface

The prevailing wear on the surfaces of the node under consideration is abrasive wear and spalling. It follows from [1] that it can lengthen the needle travel, consequently increasing the speed of needle striking the seat. This leads to higher load, which in turn may be a cause of fatigue wear: atomizer nipple fractures.

6. The node: atomizer front surface–body front surface

The atomizer and injector body make up a metal-metal contact, therefore both front contacting surfaces have to be manufactured to meet requirements specifying the allowable deviations of dimensions, shape and position, assumed by the designer. For the joint to be tight, there cannot be any assembly errors (e.g. too small a moment of tightening the nut connecting the atomizer and injector body may lead to fuel leaks into injector coolant). At certain combinations of shape, position and assembly deviations, the front surfaces of the atomizer and injector may become main elements of the tribological node and, apart from erosive and corrosive wear and surface cracks, abrasive wear will be likely.

Figure 8 presents an example front surface of the injector body: after removing a worn atomizer (Fig. 8a), and after reconditioning (Fig. 8b).

a) b)

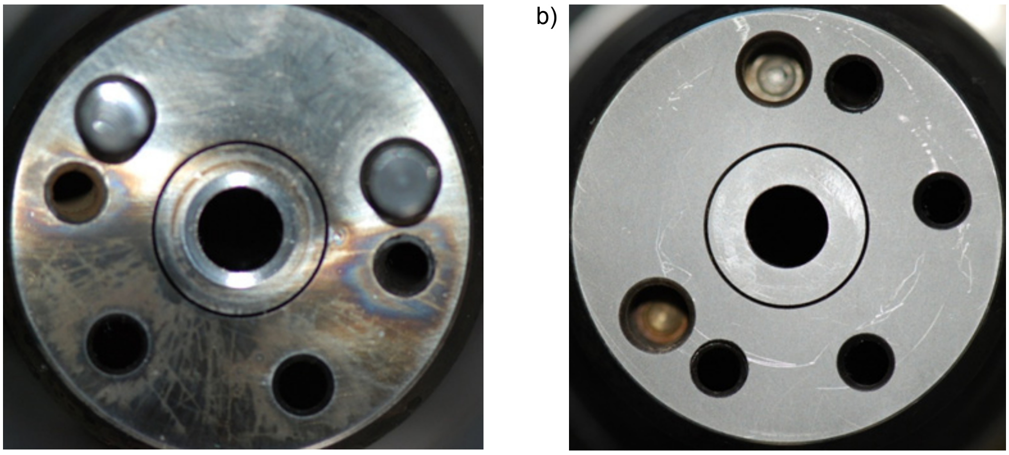

Fig. 8. Front surface of an injector body: a) worn, b) after reconditioning

7. Conclusion

Tribological wear is one of the main types of atomizer wear. At least three tribological nodes can be distinguished in atomizers. There is a feedback between the technical condition of these nodes and their loads. The technical condition of the needle–guide node affects the force imposing a load on the other nodes. The wear of needle front surface–spring node and the seat–needle cone node results in an increased travel of the needle, which not only accelerates the wear of surfaces of the mentioned nodes abut also may lead to a sudden fracture of atomizer bottom (the atomizing part). The time to failure, considered as the time to the loss of tightness, depends on the distribution of wear on the ring circumference of the conical seat–needle contact.

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