Maintenance limits to marine diesel engines fuel injectors on board ships

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Abstract

As recorded by Classification Societies, statistics indicate that up to 70% percent of major marine diesel engines combustion space components suffer breakdown due to poorly operating fuel injectors. The paper draws the attention of marine engineers to the complexity of fuel injectors production and their re-conditioning. Methods of proper and skilled worn fuel valve nozzles renewal are discussed. The possibilities and limitations regarding the reconditioning of fuel valve nozzles on board ship are highlighted with the principal aim of making the marine engineer on board aware of existing constraints on fuel injectors maintenance.

1. Introduction

According to quoted by Classification Societies statistics 70% or so marine diesel engines but mainly the larger bore destined for propulsion are suffering of various breakdowns due to fuel injectors malfunctioning. It is not always so obvious that a specific breakdown, for example a cylinder liner crack was caused by wrongly performing injector, but in quite a number of cases the beginning of serious engine major components breakdown finally is traced back to a not properly atomizing fuel valve. If a poorly performing fuel injector doesn’t immediately leads to calamitous effects, then at least it will contribute immensely to abnormal wear of corrosive or abrasive nature. So sound and perfect atomization of fuel into the cylinder is of paramount importance for the engine reliable and economic operation. The fuel nozzles are exposed to harsh working conditions and have to be regarded as consumable parts but before they are totally scrapped they may be restored back to perfect performance either by proper handling on board or send for reconditioning to a
specialist firm. And here at this point when a fuel injection nozzle has been found no longer atomizing perfectly the dilemma starts what can we do on board by means of available tools and crew skills and what can’t and shouldn’t be done by the crew, but must be sent ashore to a reputable firm re-conditioning injector nozzles. Re-conditioning relates obviously only to the nozzle body seat and the needle, it is relatively easy to assess the condition of the nozzle head (atomizer or nozzle tip) itself, which in today’s modern slow speed engines – see Fig. 1a, constitutes a separate item contributing to price reduction of spares enabling the owner a much cheaper and simpler exchange of worn nozzle tips only instead of complete nozzles.

Fig. 1. Sulzer’s RTA engine a) and B&W-MAN LMC engine b) fuel valve nozzle assembly

2. Ways of fuel nozzles optimization

Engine makers and producers of injection equipment are continuously searching for better optimized and more durable fuel nozzles. Sophisticated tools and methods are introduced in engine laboratories and research centres. Spray pattern analysis by video and image processing, Laser Doppler Anemometry (LDA) velocity measurements are today the efficient used methods.
The most conducive for optimization of the flow measurements is the FE – calculation method based on a simplified potential flow computing model. If we assume an incompressible flow a differential equation for the velocity potential can be obtained. The condition of irrationality simplifies the process of finding the velocity distribution. Knowing that the velocity components in a three-dimensional, three directional flow can be expressed in a form

\[ u = \frac{\partial \Phi}{\partial x} \]  

\[ v = \frac{\partial \Phi}{\partial y} \]  

\[ w = \frac{\partial \Phi}{\partial z} \]  

and substituting Eqs. (1) – (3) into the continuity equation

\[ \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \]  

(4)

gives

\[ \frac{\partial^2 \Phi}{\partial x^2} + \frac{\partial^2 \Phi}{\partial y^2} + \frac{\partial^2 \Phi}{\partial z^2} = \nabla^2 \Phi = 0 \]  

(5)

Equation (5) called Laplace’s equation can be converted into an exact equivalent integral form

\[ \int \nabla^2 \Phi \, d\mathbf{V} = 0 \]  

(6)

Fig. 2. Flux flow vector field between the valve seat and spray hole outlet [1]
Fig. 2 illustrates a flux flow vector field and the velocity patterns of the fluid below the valve seat and the spray hole outlet which is produced by the shape of the needle (cone angle) the position of the spray hole in the sac, the pressure - closing - (axiality) and the surface conditions. The most advantageous flow and pre-atomization conditions in the section needle - seat to spray - hole are found by an iterative procedure, by varying form, surface and pressure parameters.

Fig. 3 shows a velocity configuration of an optimized nozzle, to compare Fig. 4 illustrates a not optimized fuel nozzle with pressure and velocity losses through the seat section, losses in the sac and sprayholes of a nozzle. On Fig. 5
shown is a catastrophic failure when interactions of tolerances in seat concentricity and roundness of the needle are at the worse. During the valve closing phase the result of asymmetric friction, seat and needle deformation cause damaged and inhomogeneous sprays. Another example of lack of highest accuracy in precision machining is pictured on Fig. 6 where spring force or pushrod is out of valve needle axis, the asymmetric spray pattern due to this shortcoming is also shown, however compared with Fig. 5 the atomization is of a certain regularity, but the complete system must be checked and reassembled, otherwise such a nozzle will show signs of gradual performance deterioration.

Fig. 6. Spring force not acting along the axis of the needle [2]

3. Wear and malfunctioning of fuel injectors

Independently from mechanical loads stemming from fuel pressure, spring thrust and inertia forces of the needle, the fuel nozzle is subjected to high temperatures of the exhaust gases and their corrosive action. The flowing out with high speeds fuel (100 - 300 m/s) causes erosive wear.

In the friction pair needle - nozzle body the prevailing wear is of adhesive type, except that fatigue and corrosive processes also occur. An important factor contributing to nozzles wear can also be the coking of fuel. Despite that
the temperature of the injectors (200 °C to 250 °C) does not exceed the coking temperature of the fuel, quite frequently due to malfunctioning of the engine or the injection system itself, it may rise considerably, leading to local fuel decomposition occurrence with emission of its products which adhere to the mating parts and cause the loss of freedom movement and connection sealing effect. The durability of fuel injector nozzle and the necessity of carrying out a repair is most frequently decided by the degree of conical needle face and its seat in the nozzle body wear. The degree of wear influences the sealing effect as a result of which dripping of non-atomized fuel and penetration of hot gases inside the fuel injector takes place. This in turn causes building up of carbon deposits which either clog the nozzle spray holes or make difficult its tight and fast closing, what amplifies unfavourable phenomena of losing the sealing effect and worsens the fuel atomization.

To especially dangerous fuel injectors failures belongs the sticking of the valve needle, and it doesn’t matter whether it was caused by coking of fuel or it was brought about by particles of impurities which reached the injector. The not being closed by the needle injector needle seat allows the flow out of not atomized fuel i.e. in a form of a stream (the fuel valve pours) which can’t undergo fast evaporation and after burns longer causing an increase of exhaust gas temperature. The not burnt fuel is coking, building up deposits on the combustion chamber and fuel valve nozzle tip. The engine as a consequence is smoking, throwing out particles of soot through the ship’s funnel, the fuel consumption increases severely and the injector operating then at an elevated temperature is so badly damaged that usually it isn’t anymore fit for normal operation. A separate issue is the wear of the nozzle tip itself. The spray holes may be either enlarged due to erosion or clogged by fuel coking. But as the nozzle tips are consumable parts they are obviously not objects for any repairs or re-conditioning, and should only be checked and replaced for new one’s if approaching wear limits.

4. Fuel valve maintenance and re-conditioning on board ships

As hinted already in section 2—the production of fuel injectors and in particular fuel nozzles assemblies requires the highest top precision machining accuracy, sophisticated equipment and a highly skilled professional to do the proper maintenance. Any handling of fuel nozzles must be therefore carried out with utmost care as one deals with clearances and working tolerances placed in the range of few microns and few minutes of an angle. Usually the renovation of fuel injectors valves concerns the proper regeneration of the precision pair i.e. the nozzle needle - nozzle body.

Should careful cleaning of the nozzle not suffice to restore its serviceability, although needle lift and diameter of the injector nozzle spray holes are still in order the nozzle has to be overhauled by a specialist firm (requiring usually re-grinding or replacement of the needle for a new one). Should it, however, be necessary to have a nozzle overhauled on the spot, the following
advice may prove helpful to experienced personnel with the necessary know-how.

The grinding of the needle seat in the nozzle body is a very delicate operation requiring relevant skills and tools. If the job is not carried out properly the needle seat may be wrongly grinded so that the nozzle becomes a scrap. This can happen due to excessive grinding off of the hardened surface layer as a result of what the nozzle seat surface alters to a soft one. Saying excessive grinding off means just taking away 2-3 tenth of a millimetre. Fig 7 illustrates the usual pattern the nozzle seat is hardened by nitriding, thus it becomes obvious that improper even short too tough grinding will do the irretrievable damage. Actually about 0.05 to 0.08 mm should be only grinded off to stay in the hardened layer. In some (older) types of fuel valve nozzles with shrink-fit nozzle tips, the tips are hardened totally through and then obviously it doesn’t matter how much material will be grinded off. There may be also another alternative of nozzle seat design, namely the seat itself constitutes a hardened through piece inserted in the nozzle body in this case the thickness of grinded off material is also not critical. The needle as a rule is always fully hardened and shouldn’t be used for grinding the seat which normally is only surface hardened.

![Vickers Hardness Graph](image)

Fig. 7. Fuel nozzle seat hardened thickness layer

When fuel valve nozzles are re-conditioned by a specialist firm which often happen to be the marine diesel engine manufacturer itself, usually in 60% cases or so the needle is replaced for a new one at the same time the nozzle seat is legalized enlarged by 5 - 6 μm, the new needle must have then obviously a larger diameter and be longer so to have the required needle lift what usually also involves the grinding of the contact surfaces of injector nozzle and injector nozzle holder.
This is yet not the end of the fuel nozzle maintenance complexity. The sealing between the needle and needle seat must take place along a narrow annular contact stripe at the top of the needle cone the width of that stripe may be even as small as $0.5 \div 1.0 \mu m$ in some injectors but won’t exceed in others nozzles $1.0 \text{ mm}$ see Fig. 8a. It is very essential during injector nozzle overhaul to save the geometry of both the needle and the needle seat, the apex angle of the needle is by $30'$ to $70'$ larger then the seat angle see Fig. 8a. Thus by not careful enough maintenance, for example by trying to grind the seat with the needle the difference between the angles will vanish with fatal consequences not only for the fuel valve nozzle itself. This bad habit unfortunately still lingers on among some marine engineers on board, who are trying to do actually the impossible with aggravating results, as the fuel nozzle starts dripping and not atomizing the fuel properly, this situation pictures Fig. 8b it can be seen that the $30'$ or so minutes angle difference ceased to exist and the nozzle needle fits now tightly into the whole cone of the nozzle seat. The misleading fact in such a case is that sometimes the engineer may consider the nozzle as being successfully reconditioned because during subsequent testing it on a valve test stand the fuel valve is somehow atomizing properly, but it is not realized by the engineer that it takes few hours if at all, when the fuel valve operating in the engine under normal load plays havoc with the engine combustion space parts as the deprived of hard layer nozzle body seat cann’t withstand the hard knocking against it needle.

Fig. 8 a) Fuel nozzle seat and needle correct mating
8 b) Fuel nozzle seat and needle mating after unskilled grinding
What can be done on board ship in extreme cases and only by experienced personnel if re-grinding is endeavoured is to use for grinding the needle seat face a made up set of cast-iron pins with a shape similar to that of the nozzle needle (the angle of the pin’s point must be exactly 60°), which should slide exactly into the needle barrel but have a somewhat thicker front part then the nozzle needle see Fig. 8 c) at the same time the nozzle needle point should be made even with an angular grinding machine securing back the exact point angle 61°. From the above stated requirements it can be concluded that rarely on board a ship we may have the demanded tools and even less likely is that the engine crew has the perfect skills to do the job.

5. Conclusions

It is expected that the paper has revealed and rediscovered for the marine engineering family the maybe not always fully realized truth concerning the limits imposed on fuel valves re-conditioning on board ships. If there was a belief among some marine engineers that they could do quite a lot maintenance on board ship to a fuel valve then they should be fully aware that actually there isn’t much they can do on board.
Unconcerned and unskilled endeavour to recondition a worn fuel valve nozzle on board ship should be prohibited as a rule. That fact should be even more obvious for the technical staff at the shipowners office responsible for spare parts delivery and repairs, there are known cases when the shipowner’s superintendents encourage or ask the engine staff to carry out repairs of fuel valve nozzles on board. Such an attitude is really to be regretted being a penny wise and pound foolish policy, after all a new nozzle may only cost a few hundred dollars whereas a cylinder liner crack caused by a worn or mishandled fuel valve nozzle will cost tens of thousands of dollars.

References