Journal of Polish CIMAC
Gdansk University of Technology
The Faculty of Ocean Engineering and Ship Technology

THE POSSIBILITIES OF DIAGNOSING COMMON-RAIL INJECTION SYSTEMS OF MARINE DIESEL ENGINES

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Abstract

This article presents the application of acoustic stress wave emission for diagnosing Common-Rail injection systems of engines. Failures typical to such systems, as well as problems connected with faulty operation of injectors, have been presented. One of the methods of acoustic emission signal analysis has been discussed. It enables a non-invasive way of diagnosing the injection system of an engine with self-ignition and the Common-Rail system.

Keywords*: acoustic emission, technical diagnostics, Common-Rail injection system, marine diesel engines, injector*

1. Introduction

On the basis of the author's own studies, it can be claimed that failures of marine diesel engines caused by faults connected with the system of fuel supply comprise about 70 % of all failures among the functional systems of the studied engines with self-ignition. Faulty operation of the injection system causes, apart from the engine being out of service, higher pollution of the environment with exhaust gases.

Industrially developed countries have undertaken collective activities whose aim is to diminish the amount of harmful gases coming from combustion of fuel in the studied engines. Introduction of stricter and stricter limits on the content of NO_x , SO_x, solid particles, CO is now, from the practical point of view, the main reason for construction changes of industrial engines.. Present regulations require constant decrease of toxicity of engine exhaust gases. It is still a challenge for many manufacturers of ship engines to meet the *Tier Stage II* and *Tier Stage III* requirements concerning exhaust emissions.

In marine engines with self-ignition the most possible and at the same time an effective method of fulfilling the above regulations is the application of the Common- Rail system (C-R), but also more and more attention is paid to for example dual fuel systems: oil – gas LPG[2] or the systems with the so-called "recirculation of exhaust" EGR (Exhaust Gas Recirculation).

Analysing the solutions of the injection systems suggested by different engine manufacturers offering industrial engines with self-ignition, a tendency confirming the efficiency of the Common- Rail system in reaching the required regulations on exhaust emissions can be observed. Ship engines with the Common- Rail system are introduced (for example the medium-speed engines: Wartsila 46F (Fig. 1),Wartsila 32, Wartsila 38 or the low-speed ones: Wartsila RT-flex50-B, RT-flex58T-B, RT-flex68-D, Rt-flex82C, Rt-flex82T, RT-flex84T-D) with the increased pressure up to 160-180 MPa.

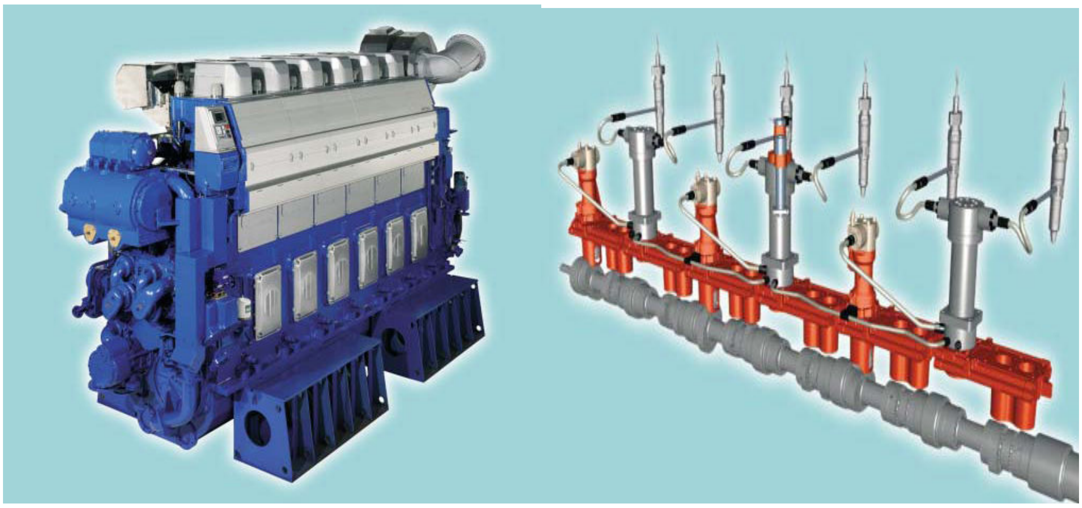

Fig. 1 An overview of the Wartsila 46 F engine with the injection system of the Common- Rail type [1]

2. Typical failures of the Common- Rail injection system

Analysing the formerly presented issues, it is therefore important to study univocally both the wear/damage of the injection system and its direct influence on the quantity and kind of toxic components comprised in the exhaust. Sometimes damage that is fairly inconspicuous to the user and may be of no consequence to the proper functioning of the engine, may be of great importance for environmental protection. Thus, it is an additional reason for the constant search of newer and better diagnostic methods. Typical failures connected with the C-R system and practical methods of dealing with them can be classified in the following way:

- Injector failures. They are divided into two types:
  - electrical damage – relatively easy to detect with the use of a diagnostic programme and performing the injector coil test
  - mechanical damage – possible to detect throughout studying the amount of fuel leaving the injectors. The amount of fuel flowing through the injector is precisely determined by the manufacturer for a certain period of time and a certain rotational speed of the engine(both at operation and as is the case with smaller engines at rotating the starter). The volume of fuel exceeding the ranges stated by the manufacturer indicates a mechanical failure in one or all injectors. Practically the removal of the fault requires a replacement of the whole set of injectors in the engine. Because of high pressures which occur there, in such a case high pressure conduits are replaced, as they cannot be reused after loosening their connector pipes (most manufacturers' recommendation)

- Leakages of the high pressure system – easy to locate throughout visual inpection, as the fuel under high pressure is instantly visible as leaks in the system

- Faults of electrical elements which take part in controlling the fuel pressure such as the fuel pressure detector in the fuel rail, electrical pressure regulator, electrical "stop" valve. Electrical faults are detected using a diagnostic programme of the engine. Mechanical faults are much more difficult to detect and in practice the problem can be solved by replacing the faulty element with a new one.

- Pressure pump failure caused by damage in mechanical elements for pumping, regulating, driving and electrical purposes. Diagnostics of the fault is performed after determining the pressure values in the Common-Rail by using signals obtained from installed detectors and later from the engine diagnostic programme after accepting the assumption that the detectors and engine regulators work properly. Comparing the reference pressure for a given speed or engine load it is possible to determine (for example in the form of a graph) the values of the real pressure (or the lack of it).

3. Diagnosing the Common- Rail injection systems

Obtaining a correct diagnosis is one of the most vital problems that is expected to be dealt with by diagnostic personnel. The user would like to obtain information about the occurring problem quickly and preferably with a 100% guarantee of certainty. Obviously it would be ideal to make a prognosis of a given system state with a very high probability.
When diagnosing very "sensitive" injection systems such as the Common-Rail, the most well-known and generally used by servicing companies are the so-called "on site" methods which focus mainly on "electrical" and "hydraulic" inspection of the injectors. Faults would be relatively easy to detect with the use of an oscilloscope monitoring the correctness of the signals controlling the injector. It is also possible to study the voltage in the piezoelectric injector or the current in the electromagnetic injector. Similarly, using the hydraulic method the "overflow" from particular injectors (or collectively from all of them) can be studied, but unfortunately only after dismounting them. In the case of marine diesel engines the second method is unfortunately without a practical application.

There are, however, the so-called "interim states" of real faults, in which the above mentioned diagnostic methods do not work, i.e. sticking together of the piezoelectric layers or overheating of coils in electromagnetic injectors. As a result a faulty signal is generated (inappropriate regulation) from control channels and in effect the injector operates incorrectly. It may happen that in spite of applying the C-R system which should meet the requirements of the regulations on toxicity of exhaust, due to such faults, the engine emits unacceptable quantities of toxins, not to mention the problems connected with the reliability of the propulsion system itself.

Obviously, other measurements can be performed, like for example capacity measurements in particular piezoelectric injectors (using a typical RCL bridge) or the inductance in electromagnetic injectors, which would enable determination of the values exceeding the given limiting signal and indicating to a faulty operation of the injector. However, application of such methods in not very realistic in practice. It can be claimed that they do not work at all in the case of marine engines. In fact, "laboratory measurement" methods are too expensive and first of all they consume too much time.

4. Elastic waves of Acoustic Emission

In practice, acoustic emission AE is understood [4] as a physical phenomenon and a measurement method. Acoustic emission is defined as “elastic waves caused by energy emission in a material or by a process” [5]. It is based on creation of elastic waves in a material, at the same time this phenomenon is caused by a dynamic local reconstruction of the material. Acoustic emission is also generated as a result of energy emission coming from intermolecular bonding due to deformations, cracking or phase transformations. Energy of acoustic emission wave (AE) also occurs when there is an external cause changing the existing state.

5. Application of Acoustic Emission waves for diagnosing the C-R injection system

Optimization of the fuel system repairs can be reached (taking into account both its time and costs) in the case of injector failures, by applying a diagnostic method detecting typical mechanical faults of injectors of the Common-Rail system. Due to a multi-phase injection and thus the speed of needle opening and the period of injection in one cycle of combustion process, the diagnostic method has to be very accurate and at the same time available and feasible to be used for an engine operating in a machine “on site”. The Common-Rail fuel system requires “ideal” servicing conditions as far as the purity of air filtering in the workshop or maintaining proper humidity and so on are concerned. Therefore, any servicing activities on the engine in its operation site are limited – it especially refers to ship engines. Thus it additionally implies requirements on verification or diagnosing injection elements in such a way that the need for their dismounting would be minimized. The author of this paper used acoustic stress wave emission for studying engines with the Common-Rail injection system. It is usually a high frequency stress wave caused by different external factors [4,5] (thus also by such as fuel flow, opening and closing of injector needle, tribological processes, chemical processes, material structure dislocations and so on).

Figures 2 and 3 show a comparison of spectral density of an acoustic emission signal for a faultlessly operating injector and for a faulty injector, respectively. The faulty injector had de-calibrated injection holes, incorrect period of injection and a scuffing injector needle. In the case of the faultless operation one can distinguish two distinctly enlarged amplitude values connected with the opening and later closing of the injector needle. The frequency of the emitted stress wave important for the process of faultlessly operating injector was about 9 to 12 kHZ (Fig. 2), whereas for the faulty one (Fig.3) – there is a distinctive disturbance of the emitted acoustic stress wave and its shift towards lower frequencies characteristic for the so-called “flowing injector” and a clearly lower value of signal amplitude connected with the pressure of fuel injection.

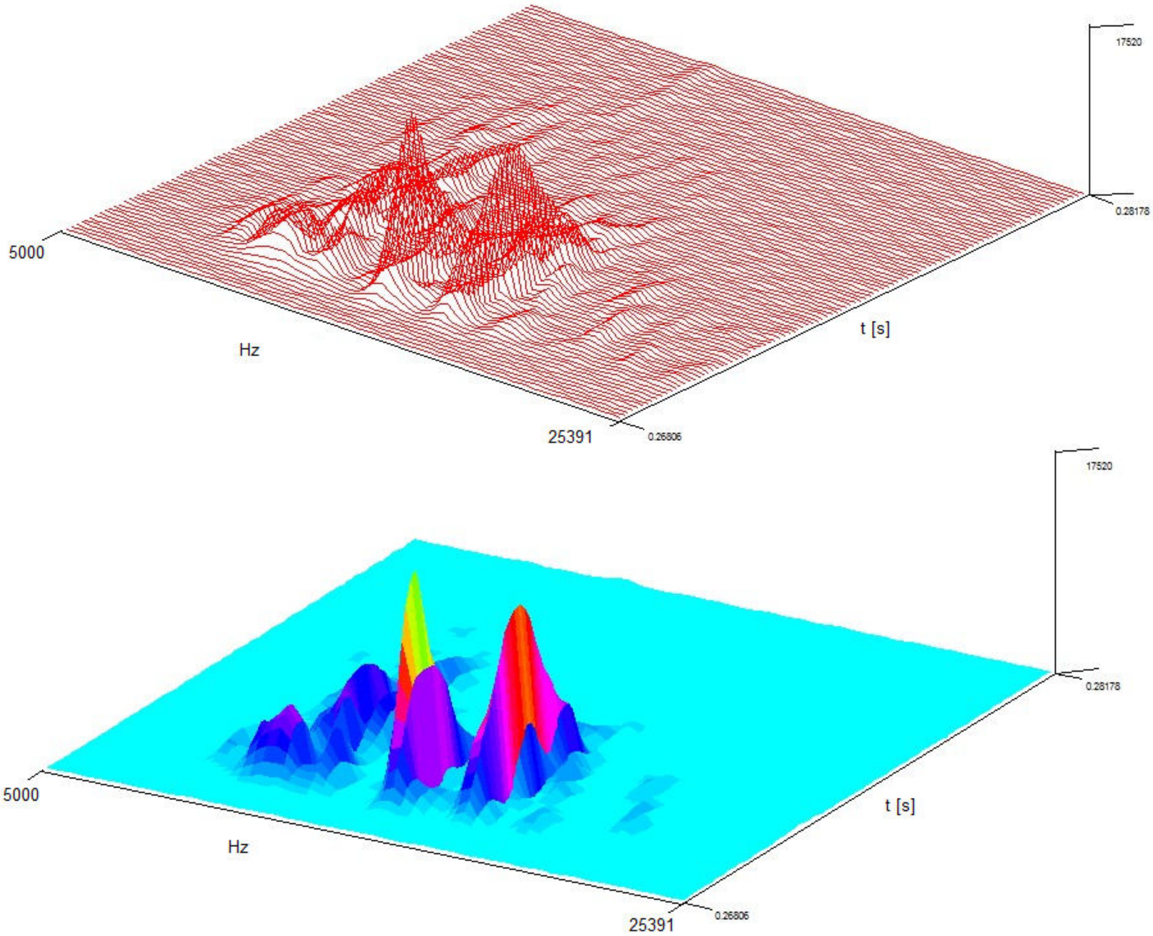

Figure 2. Spectral density of an injection process in a C-R engine for a new faultlessly operating injector (in the function of amplitude – frequency – time)

The flow of fuel through the injection holes, operation of injector needle, generates stress waves of acoustic emission. At a given moment during the injection process, the energy of the AE signal is strictly dependent on the condition of the injector. After a thorough analysis of the signal, one can spot all the changes connected with a particular fault (or wear). A diagnostic method for injection systems in ship engines has been developed for both the classical injection system and for the one with the Common-Rail. At the moment an application form for a patent, which accurately describes the way and the method of analysis for a non- invasive diagnosing of injecting systems, is being prepared. The term "a non - invasive method" means a study with no interference into the injection system. The detector is mounted on the outside available part of the system.

Spectral density presented in fig. 2 and fig. 3 is one of the simple tools which visualizes the difference in injector operation. The occurring change of frequency of the emitted wave is dependent on the condition of the injector.

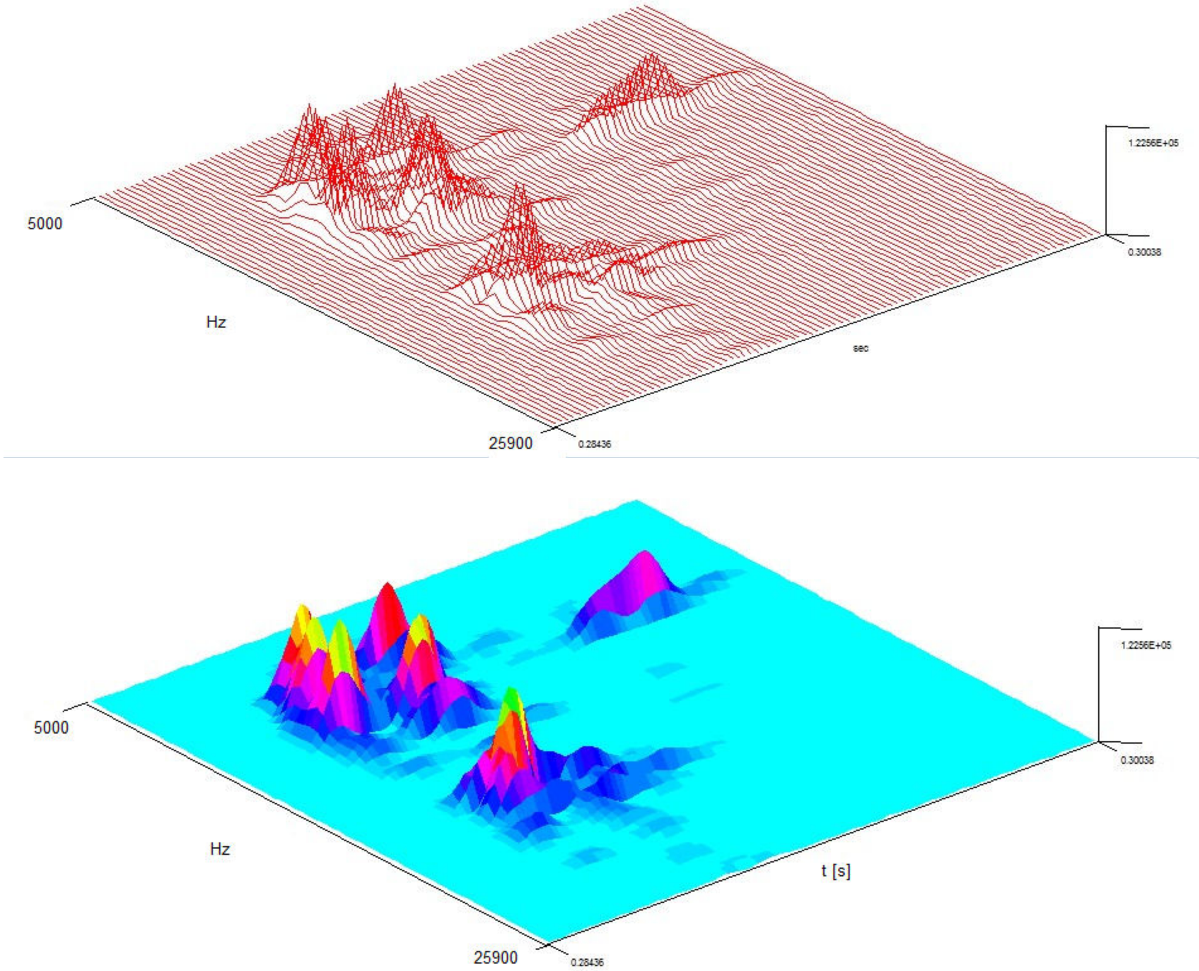

Figure 3. Spectral density of an injection process in a C-R engine for a faulty injector (in the function of amplitude – frequency – time)

Summary

An important value which should be taken into account from the diagnostic point of view in the considered analysed signals connected with the operation of a C-R engine injection system is an accurate extraction of a band of the signal frequency, its amplitude and shape distortion of the stress wave. Using a respective analysis of the acoustic emission signal of the injection process, one can distinguish the previously mentioned "electric" and "hydraulic" system faults. At present, the author of this study is preparing an application form for a patent referring to the application of an acoustic stress wave emission signal. It will also contain a thorough description of particular analyses important for particular failures like for example disturbances connected with the so-called multi-phase injection in engines with the Common-Rail injection system or injection hole blockage with coke.

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Zachodniopomorskie

The paper was published by financial supporting of
West Pomeranian Province