The Analysis of an Internal Combustion Engine Breakdown - Case Study

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Abstract. The paper concerns with the general assembly conditions and circumstances that could cause fatal damage to an internal combustion engine during operation. In the first part, the focus is on identifying the majority of dysfunctions that may result in the connecting rod destruction. Possible causes of the connecting rod destruction that led to engine failure are presented sequentially, starting with those of conceptual nature (the right choice of material, constructive solution and cross-sectional design from a geometric-dimensional point of view), then passing through issues related to operation (the severity of thermal and mechanical operation - and lubrication regimes) and last but not least, the effects of accumulated fatigue and potential structural defects of the material. This review of possible causes takes into account the particularities induced by the ignition engines and by the type of equipped machinery. The synthesis contains a case study on a 6-L medium displacement diesel engine in which the damage cause is accurately identified and which has been investigated with a scanning electron microscope (SEM).

1. Introduction

The general issue of internal combustion engines failure is very complex and comprehensive. In principle, an analysis of such failure must take into account the way the constructive/functional requirements are met by the engine’s mobile organs, the particularities of the operating regime of the equipment (specified by speed, load, the corresponding thermal regime and engine cooling conditions), lubrication regimes of the engine friction couples and the quality of the used lubricant.

It is also necessary to take into account the wear accumulated during the engine operating, as well as possible internal discrete defects of the engine’s parts. The systemic approach to this complex of conceptual, functional and intrinsic problems involves, on the one hand, the multidisciplinary engineering analysis and the polyvalent training of the operator team and, on the other hand, requires specific investigation equipment. This paper is in fact an application of analysis techniques in a particular case [1,2].

The subject of this case study is a 4-stroke compression ignition engine with 6-cylinder in-line, turbo-compressor medium-turbocharged and liquid-cooled. The engine is an older generation of the Case IH family and has equipped a grain-harvesting combine. Its cylinder capacity is 8.7 [liters] and runs at 230 [HP] at a nominal speed of 2300 [rpm]. The engine compression ratio is 18.
This engine failed during operation, the engine running in full load. At the time of the damage, the engine was about 1200 hours of operation since the last major repair and about 100 hours since the last oil change.

2. Experimental investigations to identify the cause of engine failure

The engine is of the direct injection type and uses the Meurer principle for self-ignition of the mixture. Consequently, in spite of overcharging, the load of such an engine is medium; the engine is fitted with only two valves per cylinder and is medium-speed. The use of the pellicular burning principle gives the engine a certain functional insensitivity to fuel quality.

Internal combustion engines with piston which equips agricultural aggregates have as functional particularity very high thermal regimes, due to low speeds and consequently low relative speed between the engine and the ambient air flow - on one hand - and the high loading regimes specific to the operation, on the other hand. Under these circumstances it is possible that such an engine may fail as a result of compromising engine lubrication functions, as a consequence of the extremely severe thermal regime applied. It is well known that under such severe conditions the viscosity of the lubricant, the strength of the lubricating film under the shear stress, and even the flows circulated in the engine lubrication system decrease, and the lubricating medium may degrade as a consequence of oxidation reactions accelerating.

In the first phase, the lubricant problem was removed from the list of possible causes of engine failure. A degree of oxidative degradation of 47 [%] was determined for the lubricant by the SKF technique of measuring the dielectric constant of the lubricant. It is appreciated that the degradation of oil is acceptable considering its accumulated use time and the seasonal specificity of the operation of the equipped machine.

The engine was damaged as a result of the failure of the connecting rod from engine cylinder no. 1, positioned in the cylinder line at the end of the engine, opposite to the power outlet.

Given the destructive effects of the damage in the context of the general casualties of engine breakdown and their causes, the experimental investigations to identify the possible causes of the failure in the present case have focused on the engine’s connecting rod from cylinder 1 and the sensing points of it, respectively the two bolts and the connecting rod small end sections.

Such an analysis should take into account some constructive/functional solutions used by the engine manufacturer to design the connecting rod. Thus, the piston pin type is full floating. The full-floating pin is free to rotate in the connecting rod and in the bosses, while plugs or snap-ring locks prevent it from working out against the sides of the cylinder. The solution is also common in the case of medium power engines with aluminum alloy pistons.

This solution takes into account that the piston pin material often has a lower thermal expansion coefficient than that of the piston material. Starting the engine is ensured by providing a functional clearance between the piston pin and the rod bushing. At the operating regime, this clearance tends to decrease, due to the increased dilatation of the bushing, but has no dangerous effects. To ensure sufficient lubrication in the piston pin bearings, oil access holes are provided both in the piston bosses and the connecting rod small end eye, corresponding to the oil hole in rod bushing.

The rod bushing for the cylinder 1 connecting rod is deeply deformed (its initial cylindrical shape degenerates into a quasi-flattened one), it has numerous blows, tears caused by shock. It is noted the break-through of the bushing in the direction of the generator, in an area disposed approximately diametrically opposed to the corresponding oil hole. By analyzing the inner working surface of the bush, it is found that it is not affected by pitting (wear of surface fatigue contact), there are no dislocations of the anti-friction layer and no adhesive wear marks, that emphasize that the rod bushing has fulfilled its functional role and has not initiated the dangerous situation that eventually led to the destruction of the engine.

The rod cap shows superficial blows on its outer surfaces. There are no significant changes to the geometric-dimensional configuration of the cap. The holes for fixing the cap to the body have been found free from the bolt remains.
The rod body is broken by tearing into two parts, the rupture being produced approximately halfway of the beam.

The upper part (towards the connecting rod small end) is strongly deformed and lacks a piece of the connecting rod small end eye. A fragment of the piece emitted from the rod eye was found in the engine crank when dismantling the engine, and was analyzed separately. The lower part of the rod body is also strongly deformed in the oscillation plane, the tear section indicating that the rod has been loaded at uniform bending stresses in the above-specified plane, above the breaking limit.

Comparing the recovered sections of the bolt with other bolts from the other cylinders, it is noted the elongation of this bolt remain (by about 0.48 [mm] or 0.63 [%] at the beginning of the thread ), and thinning it (with 0.11 [mm] or 1.2 [%] in the middle of the third section) indicating unequivocally that rupture of this bolt occurred under predominantly stretching effort.

Applying the free lubrication solution of the bearing formed by the connecting rod small end bushing and the piston pin by using the oil access hole has the great disadvantage that the bore is an important stress concentrator by decreasing the active section of the connecting rod eye under the bending load.

In the case of the present engine the free lubricating solution is taken to the extreme, in the sense that the oil access hole has along its length two sections of approximately equal lengths; the section disposed to the outer fiber is essentially an enlargement, in order to capture an increased flow of oil. This enlargement towards the outside of the oil access hole accentuates the character of the orifice stress concentrator. Taking into account these observations, the analysis of the end sections of the cut-off zone of the connecting rod eye becomes a priority.

Last but not least, the solution of connecting rod screw discharge from lateral shear stresses in the separation plane between the cap and the rod body is of an old type. The screws are provided with median sections (adjacent to the plane of separation between the cap and the rod body) which are mounted without clearance in the corresponding cap and rod body locations. The solution is disadvantageous because it allows additional loading of shear stressing on screws and it is not very reliable over time.

Regarding the mechanism of connecting rod failure from the engine cylinder 1, two scenarios can be developed:

A - The destruction of the connecting rod was initiated by the failure of the connecting rod small end eye’s dangerous sections, thus the movement of the rod was not anymore guided by the evolution of the piston in the cylinder. Subsequently, in a second phase, rupture of the bolts and of the rod body took place, as a result of the stresses induced by the impact of the rod body with the side walls of the engine block.

B - The destruction of the connecting rod was caused initially by the failure of the bolts and later of the rod’s small end and body, as a result of the impact of the body against the side walls of the engine block. In this case, the movement of the rod big end was no longer synchronous with the rotation of the crankshaft throw corresponding to the cylinder 1. The rupture of the connecting rod small end eye occurred in a second phase of destruction.

The investigations were deepened on the basis of electron microscopy analysis for the fracture sections of the two bolts and the rupture section of the rod’s small end eye containing the oil hole. This last section was identified at the ruptured piece of the rod’s eye found in the inferior crankcase of the damaged engine.

For analysis, a high-performance electronic microscope [3-5] (the TESCAN brand equipped with BEKER electronic cannon) was used, which allows, besides macro- and microscopic analysis of metal surfaces, also the analysis of the chemical composition at well defined points on the analyzed surfaces, with the detection of substances deposited on surfaces by assessing the energy potentials of relatively new chemical bonds, usually of a metallic nature.

Figures 1 and 2 show the photographic results of the electron microscope investigation of the cut-off part from the connecting rod small end eye, at the level of the surface that contains in its median area the oil hole. It is noted that the surface positioned to the inner fiber (the contact area with the rod
bushing) has preserved its cylindrical shape after rupture. The breaking surface captured in the photograms is positioned along the direction of the rod’s eye generic cylinder generator.

Figure 1. The rupture section of the rod’s eye.

Figure 2. Detail from the rupture section of the rod’s eye.
Results interpretation should take into account the connecting rod’s material, respectively steel alloyed with manganese and chrome. In the photograms one can notice the existence in the breaking surface of two distinct areas:

- a more flat but smaller area with a "fresh" appearance of metallic luster arranged to the outer fiber (zone 2, as shown in figure 3);
- another area, larger, disposed to the inner fiber of the rod’s eye (zone 1, as shown in Figure 3).

This area, remarkable in terms of breaking surface (fibrous, drawing in "lines", "faults" or "waves") reveals the fatigue breaking of the material.

This type of steels rupture highlights the progressive propagation (according to the drawing lines) of an initial microfissure, with the evolution of rupture over time during the operation, initiated by a possible endogenous factor. Such a rupture can be initiated even by a microscopic defect of the crystalline structure of the steel and occurs at exploitiation of the analyzed component at fatigue under high loading of the resistant section. This kind of rupture can be initiated and propagated reaching catastrophic break even after several hundred hours of cyclical fatigue.

The flat and metallic luster appearance zone 2 occurs in the load cycles immediately preceding the catastrophic breakage. It is even possible that the specific appearance of the surface is partly due to the “beating” (micro-vibrations) of the surface with a conjugated metal surface over the last few functional cycles of the engine in the area of total rupture, when, although the section under analysis is pierced by tearing, the embedded section of the connecting rod’s eye is still sufficiently strong to guide the piston pin. These findings are clear arguments in favor of scenario “A” of engine destruction. Also, the microfissure could not be initiated by mounting the piston pin in the rod bushing because - as we have already mentioned, the solution used in this engine is with the piston pin freely mounted in the eye of the rod’s small end.

A chemical analysis of the surface composition was carried out for the rupture area, revealing the following: first of all, the basic elementary composition of the steel from which the connecting rod is made (oxygen, carbon, iron, manganese and chromium). Secondly, the chemical analysis emphasized the fixing of four metallic elements (aluminum, sodium, magnesium and calcium) and an organic polymeric compound (silicone polysiloxane) originating from insoluble substances contained in the engine lubricating oil, which penetrated the microfissure during the operation of the engine.

![Figure 3](image_url). The cut-off piece from the rod’s small end.
This last aspect highlights the different "ages" of the two areas of rupture. The formation of metallic bonds with high energy potential, needed to fix the metal atoms (aluminum, sodium, magnesium, calcium) to the base metallic material of the connecting rod does not occur instantly, and shows that the rupture in zone 1 was made before the rupture in zone 2 (which did not have the time required for contamination with various metals).
The chemical analysis of the rupture surface validates the theory of rupture in time, by fatigue of this section, with the obvious propagation of the rupture from the inner fiber to the outer one of the rod’s small end eye.

Figure 4 shows the breakage section of the bolt 2, with the typical appearance of rupture by dynamic loading with shock, under a combined effort of eccentric tightening with bending, favored by course thread tension concentrators.

Figure 5 shows the rupture surface of the bolt 1 and which, in qualitative terms, detaches itself from the rupture of the bolt 2. The irregular surface appearance with peaks of material alternating with material squeezes and excavations reveals the occurrence of rupture by dynamic loading with shock under pure bending effort. In this case, the presence on the bolt body of threaded tension concentrators plays an insignificant role.

3. Conclusions

Engine failure was caused by the fatigue rupture of the connecting rod small end’s eye from the engine’s cylinder no. 1 along the direction of the generator, in the section of the rod’s eye that contained the oil hole, and which favored breaking by concentrating the stresses.

The rupture section was strongly stressed by bending in the oscillation plan dynamically, in asymmetric alternating fatigue cycle. Weakness of the breakage section was generated by a structural intimate defect which led by exploitation over time to the initiation of a microfissure on the inner fiber of the rod’s eye. This microfissure progressively propagated to the outer fiber as the engine was operated until the whole section was penetrated, culminating in catastrophic breakdown.

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