Typical wear mechanism of 2-stroke exhaust valves

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Abstract

Modern two-stroke exhaust valve components, especially the exhaust valve spindle, are operating more and more under extreme load conditions. The whole exhaust system is a cost intensive part of the engine and requires much service. So, the need is obvious to optimize service intervals as well as to perform the correct and necessary work. The aim is to reduce the operating costs over a period of several years by means of a high quality service program.

Service experiences show that different types of two-stroke exhaust valves display various, identifiable wear effects. The description and analysis of these wear effects and the presentation of solutions is given in this paper. Some of these solutions are already practiced in the market while some new developments are undergoing field-tests.

Introduction

The market demand for large container vessels, up to 8,500 TEU, as well as for tankers, is still showing significant growth. This demand for more vessels also im-pacts the propulsion system, where two-stroke engines with exhaust valves are being used. The engine popula-tion is continuously growing since the basic diesel en-gine design is known as reliable and cost effective with long running times. During the past decade, the engine manufactures have also focused on permanent design improvements, increasing the engine's efficiency and minimizing the pollution.

Increasing the engine power output per cylinder is a function of higher effective and firing pressure. From the thermodynamic aspect, the combustion temperature will increase with the increased pressure. Modern two-stroke exhaust valves, especially the valve spindles, are operating more and more under extreme load condi-tions. With firing pressures approaching 150 bar and more, the bottom side of the exhaust valve spindle reaches temperatures of about 650°C.

The business of Märkisches Werk GmbH (MWH) is developing and manufacturing gas exchange components for large two- and four-stroke diesel engines. MWH has been serving engine builders and users throughout the world with cylinder head components and services for more than fifty years. During the last fifteen years MWH has focused on the improvement and optimization of the gas load and efficiency of the two-stroke exhaust valve. The knowledge gained as a developer and manufacturer of cylinder head components, combined with the experience of remanufacturing exhaust valves, has lead MWH to extend the life time of the components and to prolong the time between over-hauls of the engine.

Two-stroke exhaust valve

This paper focuses on two-stroke engines with exhaust valves being designed by following engine manufactur-ers: MAN-B&W (MC-series), Wärtsilä-Sulzer (RTA-series) and Mitsubishi (UEC-series). Actually there is a population of about 8,000 MC engines, 2,000 RTA en-gines and 500 UEC engines running worldwide. The design of the exhaust valves of all three engine builders are different in details, but the general function is the same, see figure-01. The main components of MC, RTA and UEC are:

- Valve drive or hydraulic actuator
- Air cylinder
- Valve housing
- Valve guide
- Valve spindle
- Bottom piece or seat ring

Figure 01: Main components of an exhaust valve

The exhaust valve spindle can be made of different ma-terials. Standard valve spindles are manufactured out of heat resistance steel with a hard faced seat area. These are being used in all UEC- and part of the MC engines. Nimonic valve spindles are manufactured out of nickel-based material with higher mechanical properties and are being used in all RTA- and part of the MC-engines.

All exhaust valve spindles are equipped with a valve turning device. While UEC engines are equipped with a hydraulic device, MC and RTA valve spindles are fitted with a vane wheel (wing bush), which uses the exhaust gas to rotate the valve spindle.

The meaning of saving money

Nobody saves money with a cheap or bad repair. A good repair, lets say remanufacturing, changes an old part to a new one. As we will prove later, there are spe-cial methods of doing remanufacturing that make a re-pair more than just a repair. For example you can make a valve spindle with properties like Nimonic from a standard valve spindle, with the right method and the knowledge to do so.

Typical wear mechanism of two-stroke ex-haust valves

Some operating conditions, like the quality of fuel, have to be taken as they are. It's a fact that poor fuel in-creases components wear. Also, cheap fuel leads to re-duced component lifetimes. Wear to exhaust valve components is usually caused by the following mecha-nism:

Adhesion and abrasive wear

Adhesion and abrasive wear is very often found in the stem sealing area of hard chromed, MC valve spindles (see figure 02). Usually the limit of this stem diameter is reached after 12,000 - 18,000 hrs. MC valve spindles with HVOF-stem coating, as well as RTA- and UEC valve spindles with hard-chromed stems, reach a TBO (time between overhaul) of 24,000 - 36,000 hrs.

Figure 02: Physical adhesion and abrasive wear of a hard-chromed valve spindle (MC-type after 15,000 hrs)

Thanks to the favorable lubrication properties of the permanent luboilflow of the hydraulic system, piston and liner of valve drive and air cylinder show only minimal adhesion and abrasive wear. This leads to TBOs with more than 72,000 hrs for MC, RTA and UEC type engines.

Build up of deposits and dent marks

The deposits formed on an exhaust valve are from the reaction of fuel-borne contaminants and lubrication oil during combustion as well as the reaction of combustion products with valve material. The sulphur, vanadium and sodium content in the fuel oxidize during the com-bustion process. Solid products of combustion, slag par-ticles and hard particles of Al_2O_3 and SiO_2 (catalytic fines) are pressed into the valve seat, forming dents (NANDA 2003).

The probability and intensity of dent marks is directly related to the material combination of valve spindle seat and bottom piece. The hardness of the seat material of RTA- and UEC-type is about 400 HV for valve spindle and bottom piece, the hardness of the MC-types is about 400 HV for seat of valve spindle and about 500 HV for the seat of bottom piece.

Seating pressure and sealing velocity are also relevant factors for dent marks. The MC-type has a higher seat-ing pressure (>700 bar) than the UEC- and RTA-type (about 550 bar). Typically, 550 bar gives good sealing and low wear. (KINGSTON-JONES, THOMAS, RAD-CLIFF 1990)

Together with high seat pressure and a higher seat hard-ness of the bottom piece, the MC-type shows the highest probability and intensity of dent marks with TBOs of 6,000-18,000 hrs (see figure 03). The seats of RTA- and UEC-types require overhauls after 12,000 - 36,000 hrs.

Figure 03: Typical dent marks of the seat of a valve spindle (MC60-type Nimonic after 8,300 hrs)

Depending on the design of the valve guide, its inner diameter will display more or less deposit buildup. Ex-haust gas enters into the clearance between valve spin-dle stem and the inner diameter of the valve guide, which allows deposits inside the guide (see figure 04). Due to this, MC-types need a replacement of the valve guide between 6,000 - 8,000 hrs to minimize the risk of the valve spindle sticking in the guide.

The valve guide of UEC- and RTA-types will show the same deposits, but after a much longer period of time (TBO is 24,000 to 36,000 hrs).

To disassemble exhaust valves, hydraulic power is usu-ally necessary to remove the valve spindle from the valve guide. In some cases the sticking of the valve spindle is so extreme that the valve guide breaks during the operation (see figure 04a and 04b).

Figure 04a: Breakage of the valve guide during valve spindle disassembling Figure 04b: Typical deposits of inner diameter of valve guide (MC70-type after 8,200 hrs)

Low-temperature corrosion

Heavy fuel contains high amounts of sulfur (up to 5%). If there is an exposed surface where the temperature is below the dew point of sulfurous acid, the acid con-denses into liquid and can attack the metal surfaces. If a large amount of concentrated sulfuric acid condenses, it can attack the valve housing, bottom piece, valve guide and valve spindle stem. Sulfur acid has an extremely corrosive effect on cast iron (BEHRENS, GROTH 1990).

Nearly all components of the exhaust gas channel show some low-temperature corrosion (see figure 05-07).

Figure 05: Low temperature corrosion of valve housing (MC-type 43,700 hrs)

Figure 06: Low temperature corrosion of bottom piece (RTA-type after 28,420 hrs)

Figure 07: Low temperature corrosion (pitting corro-sion attack) of under head radius of valve spindle (MC60-standard / 22,700 hrs)

High-temperature corrosion

High-temperature corrosion in heavy fuel engines is caused by the presence of Sulfur, Vanadium and Sodium in the fuel. Vanadium and Sodium are contained in heavy fuels at ratios up to 600 ppm and 200 ppm re-spectively (ISO 8217, 2003). This can build up sodium-vanadyl-vanadates in different structures during the combustion process. These semi-liquid, sticky, low-melting point salts together with gases containing sulfur oxide are a definite cause of corrosion due to their oxy-gen transitions (HESSE 1981, BLUDSZUWEIT 2000).

As a result of the above-mentioned physical process, the following wear mechanism can be described. Hard salt deposits on the seat surfaces of the valve spindle lead to dent marks caused by each closing stroke of the valve spindle. This can lead to crucial micro gas channels, which will grow over the time (NANDA, 2003). Be-cause of the high temperature, the salt deposits reach their melting point, then the "cobble stone corrosion" starts (see figure 08) at the seat and finally leads to blow-byes (UMLAND 1975, RITZKOPF 1975). Result: The whole exhaust valve has to be replaced.

Figure 08: "Cobble stone corrosion" appearance of valve spindle failure through high-temperature corrosion (MC60 Standard-type)

The bottom of the valve spindle is mostly operating in the critical area of the high-temperature corrosion seen as "cobble stone corrosion". The wear rate is between 0,2 - 1,0 mm / 1,000 hrs. depending on valve material and type of engine. The limit for remanufacturing is only reached after 12 mm. This leads to a TBO of about 12,000 - 60,000 hrs. Figure 09 shows micro cuts of Ni-monic with high-temperature corrosion.

Figure 09: Micro cuts of Nimonic with high-temperature corrosion.

Low cycle fatigue

The valve spindle is the component with the maximum thermal stress. Most of fatigue problems are documented at the valve spindles. Figure 10 demonstrates a typical heat distribution across a Nimonic valve head.

Figure 10: Typical temperature distribution of a Nimonic exhaust valve head

The maximum thermal stress takes place during the warm-up period. During this period the temperature at the center of the valve bottom and the seat reaches the maximum difference. Under regular operating conditions the temperature distribution is much lower. The mechanical load of a valve spindle is nearly constant between warm-up and regular operating, see figure 11.

Figure 11: Mechanical and thermal load as function of running in and stationary operation

The RTA valve spindles are subjected to the highest operating temperatures. The MC and UEC valve spindles were designed for lower temperatures and me-chanical properties.

While standard valve spindles have disadvantages with respect to high- and low- temperature corrosion, they do have advantages regarding low cycle fatigue. The dis-advantages of standard valve spindles will seldom cause catastrophic failures. The quality of repair can be meas-ured by comparing the TBOs. The design of valve spindles usually takes into account the combination of mechanical and thermal load of the engine. But, the addition of residual stress, caused by non-professional forging, welding or heat treatment during the manufacturing process can be critical. Also, unprofessional repairs, including welding and heat treatment, can add further residual stress, leading to catastrophic failures. In particular, Nimonic valve spindles require excellent welding and heat treatment. There are two typical failure reasons. One is a crack that starts in the under head radius. After the micro cracks get to a critical length, the speed of the crack growth increases. A catastrophic failure follows, with parts of the spindle dropping down into the combustion chamber (see figure 12 and 13). *Figure 12: Catastrophic failure of a repaired valve spindle (RTA72 Nimonic-type 740 hrs after repair) Figure 13: Macro cut through the center of a valve head (RTA62 Nimonic-type 6,430 hrs after repair)* The second failure reason is: Micro cracks starting in the outer diameter of the valve bottom. After reaching the seat area blow-byes are created and the valve spin-dle is destroyed (see figure 14).

Figure 14: Failure of a valve spindle (RTA84 Nimonic type 5,270 hrs after repair).

Methods to reduce the operating costs

From remanufacturing to providing correct services - there are some ways to reduce the overall operating costs for two-stroke diesel engines.

One is to put emphasis on high quality overhaul services to ensure that engines are running reliably and effi-ciently. Another focus would be to improve the setup of running engines. This can be achieved by mobile diag-nostic systems and technical developments.

Qualified Remanufacturing

MWH uses the word “remanufacturing” instead of “re-pair” or “reconditioning” in order to distinguish its con-trolled process from typical reconditioning procedures available in the market. If engine users are to optimize the services they receive, they need to work with reli-able partners. These partners need to perform all kinds of remanufacturing processes with the same care and precision as the manufacturer. The solution is to have all engine components repaired by only qualified service centers that have production knowledge and long ex-perience in all areas of remanufacturing.

The two-stroke exhaust valve is a complex system. Any service activity affect all components (e. g. valve spin-dle, bottom piece, valve housing). In the following, we are focusing on the most sensitive component – the valve spindle.

Standard valve spindles

There are lots of companies who provide services and repairs for standard valve spindles. If the customer has no wish to extend the lifetime or optimize the compo-nent for the future, countless companies can to do the repair.

Nimonic valve spindles

Looking at the more costly Nimonic valve spindles is a completely different situation. Only few companies are competent to do repairs on Nimonic valve spindles. Most often, the engine user wants to get his Nimonic valve spindle repaired because of the premium material. To remanufacture Nimonic very special know-how is required. The usual wear effect on Nimonic 80A is low cycle fatigue. Cracks develop in the maximum stress area because of damage to the microstructure caused by the welding procedure or by insufficient post heat treatment processing. An inadequate repair leads to fatal failures with spindle pieces dropping down into the combustion chamber. **Nimalike-Procedure** Nimalike is the premium class of remanufacturing pro-cedures. MWH is one of the leading manufacturers and service centers that are able to work with Nimalike. Nimalike is used in two ways: To extend the lifetime of a standard valve spindle to a lifetime similar to Ni-monic, or to remanufacture Nimonic valve spindles in a way that leads to “close to new” conditions after the process (see figures 15 a/b). *Figure 15 a/b: Nimalike spindle before and after remanufacturing* The competence to perform this remanufacturing method is a combination of long-time experience in the field and manufacturing technology. The experience is coupled with continuous improvement of manufacturing processes and intensive R&D in the fields of metallurgy and welding processes (see figure 16). *Figure 16: PTA-welding*

Service: Mobile Diagnostic Systems

Whenever onboard diagnostics are necessary, it means a large investment of money and time. Online analysis is usually very complicated and they are only for large installations.

For this reason MWH provides the “Leakage Measure System”, a mobile diagnostic system which is able to detect leakages at the cylinderhead to prevent fatal fail-ures of a running engine. The principle is based on measurement of ultrasonic sound by using one simple and robust sensor (WEHNER, ALBERT 2001).

With this very compact measurement system, the engine user is able to find out what condition the engine is in and when the next actions have to be taken for service.

Figure 17: Leakage Measure System onboard in use

Figure 18: Documentation of the result of leackage detection and valvetiming/ignition

Two-stroke valve rotator (Turnomat®)

MWH developed and patented the valve rotator Turno-mat® for four-stroke diesel engines in 1983. Since then, countless engines have been fitted with the Turnomat® and TBO’s has been extended. Twenty years later, MWH has developed a valve rotator for two-stroke ex-haust valves that is performing much better than vane wheels. The aim of our engineers was to extend the TBO of MC-type two-stroke exhaust valves from 6,000 hrs to 18,000 hrs. The valve rotator forces an accurate, reliable valve turn-ing during valve closing. The Turnomat® principle is simple and surprisingly effective: The forced rotational movement causes a defined rotational energy for the valve at the instance of seating. This brings about the desired polishing effect, removing combustion deposits between valve spindle and valve seat and, at the same time, optimizing the heat exchange to the cooler valve seat. The rotation also prompts a balanced temperature distri-bution across the entire valve head, thereby reducing thermally induced strain. First field tests are ongoing with a MC70 engine. In-spections have proven that the Turnomat® works as de-signed (see figure 19). *Figure 19: Seat ring and valve spindle show no dent marks after app. 1,000 hours.* **Summary** The power ratings of modern two-stroke engines with exhaust valves have increased significantly along with a simultaneous deterioration of the fuel oil quality. The exhaust valves are operating under increasing thermal load and in a more corrosive environment. Based on our service experience of the last decade the typical wear mechanisms of exhaust valves of MC-, RTA- and UEC-engines have been investigated and discussed. Adhesion and abrasive wear was found at the valve drive, air cylinder and valve spindle stem. Build up of deposits in valve spindle guides reduces the valve spin-dle rotation and results in non-symmetric thermal load. Deposits and dent marks formed on the valve spindle seat can cause micro gas channels, which will grow over the time.. “Cobble stone corrosion” starts at the seat and finally leads to blow-byes. By using the new development of the two-stroke Tur-nomat, the critical build up of deposits between valve spindle and seat can be greatly reduced. Ongoing field tests have also proven the benefit of the Turnomat in preventing sticking of the valve spindle in the guide. Nearly all components of the exhaust channel have con-tact with sulfur acid coming from the condensation of the exhaust gas (low-temperature corrosion). In addi-

tion, the bottom of the valve spindle is subject to “cob-ble stone corrosion” (high-temperature corrosion) with a wear rate of 0,2 - 1,0 mm / 1,000 hrs.

Standard valve spindles can be upgraded with the Nima-like-procedure to achieve a lifetime similar to Nimonic. The procedures used to remanufacture Nimonic valve spindles (including welding and heat treatment) are cri-tical to preventing low-cycle fatigue. An inadequate repair leads to catastrophic failure. While standard valve spindles have disadvantages with respect to low- and high-temperature corrosion, they do have advantages regarding low-cycle fatigue.

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