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A Case Study on the Failure of Intake and Exhaust Valves for Marine Diesel Engines

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Abstract : Any failure of intake and exhaust valves of marine diesel engine must be regarded as serious, and any steps which can be taken to prevent such failure are desirable. The purposes of this study is to investigate and to analyse the failure causes of intake and exhaust valves for marine diesel engine during sea trial after completion of overhauling. In this study, to analyse the failure causes, we have carried out on board inspection, fractography test and discussion based on the specimen and repairing report provided by the ship owner. From the results of above inspection, test and discussion, it has been considered reasonable to conclude that the causes of damaged valves of the ship are as follow :

1) During operation, the stick or seizure of valve spindle occurred and hence the movement of exhaust valve spindle was to be resisted and subsequently the engine was to be operated under an unappropriated valve timing and the exhaust valve sustained the repeated loads exceeding the fatigue strength of valve material.

2) By the loads above described, the fatigue fracture was initiated at the structural noncontinuous part of exhaust valve spindle, and then the valve head was finally fractured and dropped in the cylinder.

3) The fractured exhaust valve head impacted the intake valve at various direction to be bent or damaged.

Key words : Marine diesel engine, Fatigue fracture, Valve spindle, Valve guide, Circular contour

1. Introduction

It was stated by the shipmaster of a ship that while the ship was under sea trial after completion of overhauling main engines, the intake and exhaust valves, the cylinder head, the piston and the push rods for A2 cylinder of No.1 main engine were damaged. The particulars of main engines are as follows :

- Engine type : 18RP200CM, 18 Cylinders Vee type, Four strokes, - Rating : 4050 BHP@ 1540 r.p.m, - Bore 197 mmΦ, Stroke 216 mm

The purposes of this study is to investigate and to analyse the failure

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causes of intake and exhaust valves for No.1 main engines of the ship during sea trial after completion of overhauling.

2. Tests and inspections

2.1 Onboard inspection

The nature and extent of damage on piston, cylinder head, intake and exhaust valves and push rods were ascertained while the ship was lying afloat alongside on a pier.

Fig. 1 shows the magnified view of the above cylinder head, and the tear of the valve guide was found to the direction marked as "I" in the figure.

Fig. 2 presents the exhaust valve for the above cylinder head and the stick marks are revealed on the parts as indicated "O".

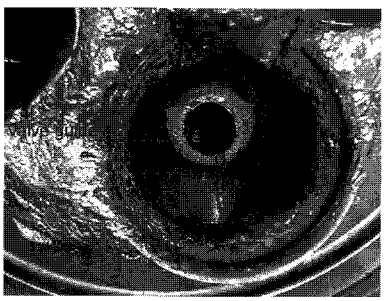

Fig. 1 Detail of No. 1 main engine A2 cylinder head

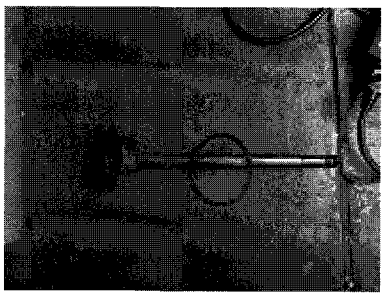

Fig. 2 A2 exhaust valve of No. 1 main engine

2.2 Fractography examinations

For the purpose of examining and analysing of the damaged intake and exhaust valves, they were identified as engine No.- kind of valve(intake valve : IN, exhaust valve : EXH)-serial number.

Fig. 3 displays the damaged No.1 main engine valves. In this figure, the valve spindles of both intake valves were bent, and the valve heads of inake vale (1-IN-02) and exhaust valve(1-EXH-01) were fractured without deformation of valve spindles. The stick problem was no found on the valve spindle of both intake valves. However, the stuck part as marked "O" in the figure was found on the valve spindle of exhaust valve.

Fig. 4 presents the intake valve head (1-IN-02) which was found in the damaged

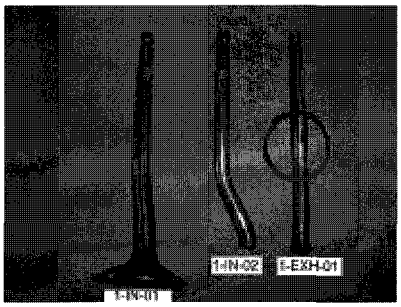

Fig. 3 The damaged valve of No. 1 main engine

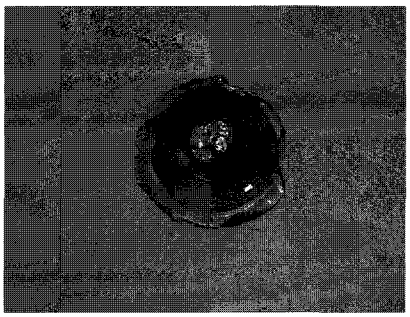

Fig. 4 The intake valve(1-IN-02) of No. 1 main engine

cylinder of No.1 main engine. As for this valve head, the plastic deformation is found but any mark of fatigue fracture is not observed.

Fig. 5 The Valve spindle of No. 1 main engine intake valve(1-IN-02)

Fig. 5 presents the magnified view of the valve spindle of intake valve (1-IN-02). In this figure, the plastic deformation which was accompanied with change of diameter and sectional area and the mark of ductile fracture were observed.

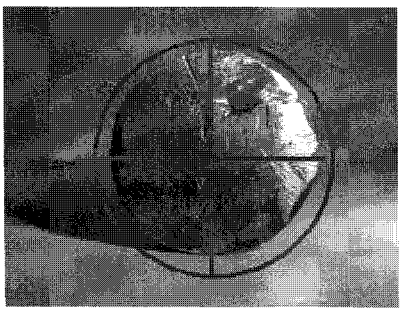

Fig. 6 valve spindle of exhaust valve(1-EXH-01)

Fig. 6 displays the magnified view and the sectional division of valve spindle of exhaust valve(1-EXH-01) for examining the fractured surface. As shown in Fig. 6, the valve spindle was flatly fractured without any change of diameter and sectional area. The above fracture is a

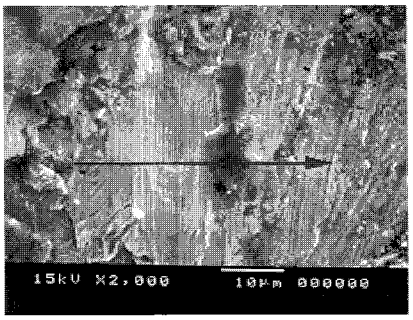

Fig. 7 1-EXH-01, Division I

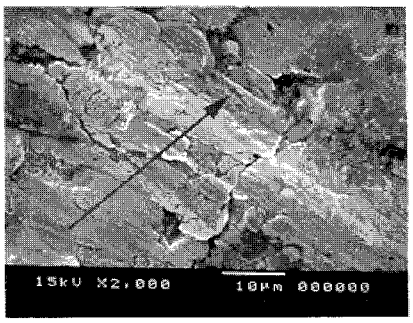

Fig. 8 1-EXH-01, Division II

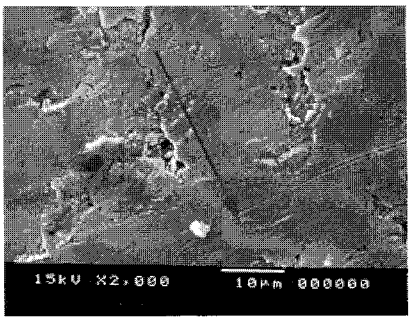

Fig. 9 1-EXH-01, Division III

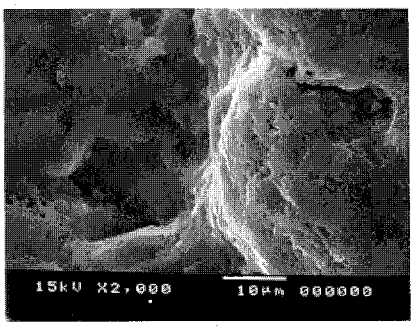

Fig. 10 1-EXH-01, Division IV

typical example of fatigue fracture which occurs when the material is subjected to cyclic loads below the yield strength.

Fig. 7-10 present SEM(Scanning Electro Microscope) fractograph of the valve spindle of exhaust valve(1-EXH-01) at 2,000magnification. Figs. 7-9 show striations which are a typical mark of fatigue fracture, and the propagation direction of fatigue crack is illustrated as arrow mark in the figures.

Fig. 10 shows a dimple which occurred at final stage of fatigue crack propagation.

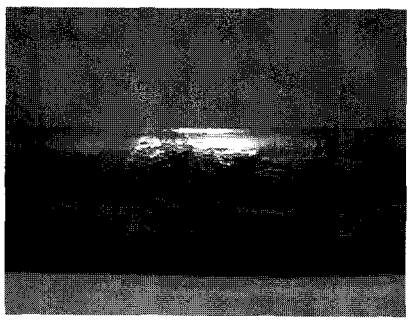

Fig. 11 Exhaust valve(1-EXH-01) spindle

Fig. 11 shows that the valve guide was fused into valve spindle due to the stick of valve spindle and valve guide. With a magnetic property test using the magnet, it is found that the valve guide is magnetic material and the exhaust valve spindle is non magnetic material, and hence the fused material on the valve spindle is originated from the valve guide.

According to the test results of chemical composition and micro structure of valve guide the material is ascertained to be gray cast iron classified as KS D 4301.

3. Discussion

From review results of reference[1]-[6], on board inspection, fractography test and the authors' experience, it has been considered reasonable to conclude temporarily as follow,

1) As for the fractured exhaust valves(1-EXH-01), there is not any change in the diameter and the sectional area. Therefore, the valve has been subjected to the cyclic loads below the yield strength of valve material. The track of fatigue fracture by the above cyclic loads is revealed to the fractograph of the fractured valve spindle.
2) As for the fractured exhaust valves(1-EX-01), it is found that the valve guide and valve spindle are stuck together.
3) As for the fractured intake valves(1-IN-01, 1-IN-02), their valve spindle are bent and hence it is evident that they have been subjected to loads which were not exactly act on the centroid of valve spindle.
4) As for the intake valve(1-IN-02) of which valve head was fractured, its fracture surface is different from that of exhaust valves(1-EX-01).
5) As for intake valves, they are found that the valve guide and valve spindle are not stuck together.

On the basis of temporary conclusion above mentioned, the probable situation when the valves were being fractured are classified as following two cases.

The case 1 is in the repeated excessive

loads during running, and the case 2 is in the impact loads by foreign materials at starting or during running.

3.1 CASE-1

The repeated excessive loads could be induced by the stick of valve guide and spindle, inappropriate clearance between valve guide and valve spindle, insufficient lubrication, inappropriate top clearance, inappropriate tappet clearance and etc.

3.1.1 The stick of valve guide and spindle

To determine whether the stick of valve guide and spindle was occurred at this accident, the dimension measuring of valve guides are done and the results are tabularized in Table 1.

Table 1 Measuring results of valve guides

Valve guide	Inner circular contour	Outer circular contour	Inner diameter	Remark
No. 1	0.004mm	0.0018mm	14.241mm	Standard
No. 2	0.010mm	0.004mm	14.250mm	Failed
No. 3	0.031mm	0.006mm	14.240mm	Failed

As seen in the table, the valve guides used for the failed valves at this accident illustrate a worse circular contour than that of the standard valve guide. It is presumed that the worse circular contour would result the stick or seizure of valve guide and valve spindle.

However the standard circular contour for circular shaped products is generally dependent on the object desired.

Therefore it is considered to be difficult that the circular contour of valve guide failed at this accident is out of standard. As for circular contour problem of the valve guide failed at this accident, the additional investigation and study are necessary.

However, in case the of manufacturing the valve guide without the design drawing, it is considered to be generalized process to adopt the standard dimension from the original valve guide.

3.1.2 Clearance between valve guide and valve spindle

As the standard clearance described in the main engine instruction book is 0.09 mm, it is considered that all valve guides have an appropriate clearance as shown in Table 1.

3.1.3 Top clearance and tappet clearance

On the basis of the repairing report, the top clearance and the tappet clearance are considered to be in order. If the tappet clearance had been small, the sound by impact of piston to the valve head would have been heard to persons who attended at the mooring trial and sea trial.

As no person witnessed the abnormal sound to be heard, the probability of unappropriated adjustment of tappet clearance was few.

3.2 CASE-2

The impact loads by foreign materials at starting or during running could be induced by the fractured exhaust valve head or the fractured intake valve head, foreign materials left in cylinder at overhaul and etc.

3.2.1 The exhaust valve head fractured and subsequently intake valve head fractured

Taking into followings phenomena into consideration, it is considered reasonable to presume temporarily that the valve head fractured in order of the exhaust valve and intake valve as follow.

1) The stick and fatigue fracture of exhaust valve spindle(1-EX-01).
2) The bent of intake valve spindle could be occurred by the load which was not exactly act on the centroid of valve spindle.
3) References and the authors' experience.

According to the summarized operating record of main engines on the basis of the engine log book and repairing report, the total revolution counters of No.1 main engine had been about 1.8×10^5 after overhaul, therefore the numbers of loading on exhaust valves of engines were about $1.8 \times 10^5 \div 2$ cycles.

Therefore the valve spindle will not be fractured in the mode of fatigue fracture under normal operation condition. its

However, if the valve guide and valve spindle are stuck together, the movement of valve spindle is resisted in the valve guide and then the engine is subjected to a condition under unappropriated valve opening and closing timing.

If the engine is operated under those condition, the valve spindle will sustain the loads exceeding the allowable stress or fatigue strength.

Under above condition the fatigue fracture would be initiated at the structural noncontinuous part of exhaust valve spindle, so called as stress concentration part.

3.2.2 The intake valve head fractured and subsequently the exhaust valve head fractured

As for one intake valve(1-IN-02) of which valve head was fractured, the fracture surface of it represents a typical ductile fracture and there is not any track of fatigue crack.

Therefore the intake valve has been fractured by the impact of foreign materials and subsequent load above yield strength of valve material and it shows no track of stick.

If the valve had been touched with piston during operation due to unappropriated tappet clearance or top clearance, the valve spindle should have been fractured showing the track of fatigue fracture when the total revolution reached at the cycles corresponding to fatigue strength under compressive loads.

From review of above discussion, it is considered reasonable to conclude temporarily that there is few probability that valve head was fractured in order of the intake valve and the exhaust valve.

3.2.3 The foreign materials in cylinder after overhaul

After completion of overhaul of diesel engine, the casualty by foreign materials left in cylinder is often reported.

However, as no person who attended at the mooring trial and sea trial witnessed the abnormal sound to be heard, the probability for this case is few.

3.2.4 The intake and the exhaust valves fractured at the same time

Taking above discussion and the operating condition of diesel engine into

consideration, there was no probability for this case.

4. Conclusions

From the results of above inspection, test and discussion, it has been considered reasonable to conclude that the causes of damaged valves of the ship during sea trial on completion of over hauling are as follow :

1) During operation, the stick or seizure of exhaust valve spindle for No.1 main engine occurred and hence the movement of exhaust valve spindle is resisted and subsequently the engine operated under an unappropriated valve timing of opening and closing.
2) In case where the valve timing was not coincided with the movement of piston, the piston would impact the exhaust valve.
3) By the impact above described, the exhaust valve sustained the repeated loads exceeding the fatigue strength of valve material.
4) By the loads above described, the fatigue fracture was initiated at the structural noncontinuous part of exhaust valve spindle, and then the valve head was fractured and dropped in the cylinder.
5) The fractured exhaust valve head impacted the intake valve at various direction to be bent or damaged.

5. References

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