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Failure Analysis and Evaluation of a Six Cylinders Crankshaft for Marine Diesel Generator

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Abstract. This paper discusses the failure of a diesel engine crankshaft of a four stroke 6 cylinders, used in a marine diesel generator. A correct analysis and evaluation of the dimension of the crankshaft are very essential to prevent failure of the crankshaft fracture and cracks. The crankshaft is liable to deformation due to misalignment of the main journals bearings. This article presents the result of crankshaft failure analysis by measuring the mean diameter of the rod journal and the main journal, on the wear, out of roundness, taper, etc. The measurement result must be compared with the acceptable value in the engine specification and manual service and also should follow the American Bureau of Shipping (ABS) guidance notes on propulsion shafting alignment. The measurement results of this study show that the main journal diameter of the third cylinder exhibits an excessive wear, 1.35 % above the permissible lowest rate. It also has a taper for 0.23 mm and out of roundness of 0.13 mm. The diameter of the rod journal indicates excessive wear, 1.06 % higher than the permissible lowest rate, the taper of 0.41 mm and out of roundness of 0.65 mm. The crankshaft warpage or run-out journal, the analysis of the crank web deflection are also evaluated and presented in this paper.

Keywords: crankshaft failure, deformation, misalignment, taper, crank web deflection

INTRODUCTION

Transportation is a very important factor in the economy of every country, as every business transaction is frequently used by means of sea transportation due to its low operational cost and large carrying capacities. Therefore, marine industry played a significant role in economic development of any nation in the areas of transportation for the raw materials and finished goods inter-and intra-nations. Improved performance of the transportation sector, therefore, will have positive effects on the national economy [1].

The electrical power generation are especially sensible to outage events. In the case of a crankshaft failure, the cost of the reparation includes, not only the crankshaft, but also the cost of other parts of the engine affected by crankshaft failure (connecting rod, piston, cylinder, and bearings). The maintenance period for repairing the crank takes a long time due to the crankshaft location inside the engine [2].

The most common reason for crankshaft failure is fatigue. For fatigue to take place, a cyclic tensile stress and a crack initiation site are necessary. Diesel engines crankshafts in power plants run with harmonic torsion combined with cyclic bending stress due to the radial loads of combustion chamber pressure transmitted from the pistons and connecting rods, to which inertia loads from pistons and connecting rods have to be added. Although crankshafts are generally designed with a high safety margin in order to not exceed the fatigue strength of the material, the high cyclic loading and local stress concentrations allow cracks to grow even when fatigue strength does not exceed in values, limit [3].

The bending fatigue can occur in fracture of the crankshaft, by torsional fatigue or a combination of both. Misalignment raises bending loads on main journals fillets and can lead to bending fatigue fractures. The torsional

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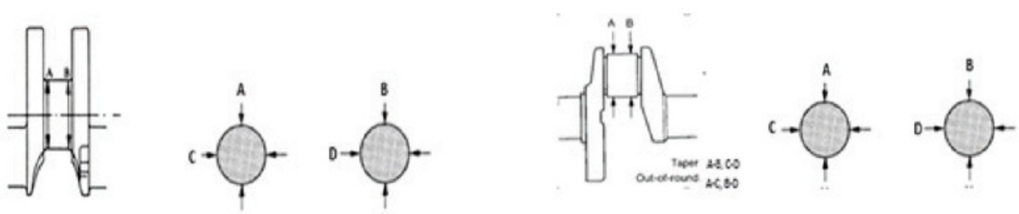
and bending fatigue cracks have similar features such as smooth flat fracture faces with ductile final fractures. The other features of bending and torsional fatigue cracks are beach marks (arrest lines) radiating away from crack initiation site. The fracture of the crankshaft is generally fatigue fractures produced by bending loads on the fillets and or torsional loads on main journals [4]. This paper discusses the failure of a diesel engine crankshaft of a four stroke 6 cylinder, used in a marine diesel generator. A correct analysis and evaluation of the dimension of the crankshaft are very essential to prevent failure of the crankshaft fracture and cracks. This article presents the result of crankshaft failure analysis by measuring the mean diameter of the rod journal and the main journal, on the wear, out of roundness, taper, etc.

EXPERIMENTAL METHOD

The failed crankshaft was subjected to be measured: the wear, the out of roundness measurement, the taper measurement, the warpage measurement and evaluated the data result of the crank web deflection. The damaged of main and rod journal were cleaned and examined with the measurement tools: micrometer, dial gauge with stand and appropriate support for both end journal to evaluate the straightness of crankshaft.



(a). Connecting rod journal (b). Main journal

FIGURE 1. Measurement Point of Connecting Rod and Main Journal [5]

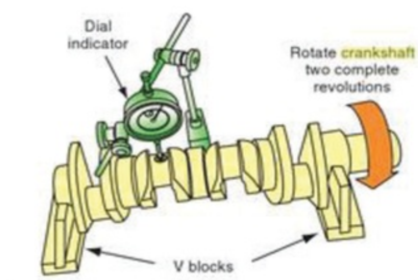


FIGURE 2. Warpage / Runout Measurement [6]

Figure 3 shows that the examination of warpage on this method by using a dial indicator with stand. Installation of the crankshaft lathes has also done the alignment of the crankshaft position prior to this warpage measurement. Warpage Measurement is not only done in the middle of the crankshaft but carried on each main journal.

RESULTS AND DISCUSSION

Wear of the Main Diameter and Connecting Rod Journal

Measuring the main diameter and connecting rod journals for wear, out-of-roundness and taper were conducted using a micrometer. The measurement is carried out, at least, at 4 places around each journal and compare all of the findings with the journal diameter specifications. Wear on the main crank journal and crank pin journal can be analyzed by measuring the diameter of each section. Minimum allowable diameter for the main crank journal is

82.962 mm and for the crank pin journal 68.962 mm. The out of round crankshaft should not exceed 0.05 mm, and the taper of the crankshaft should not exceed 0.013 mm [5].

Measurement Diameter of Main Journal

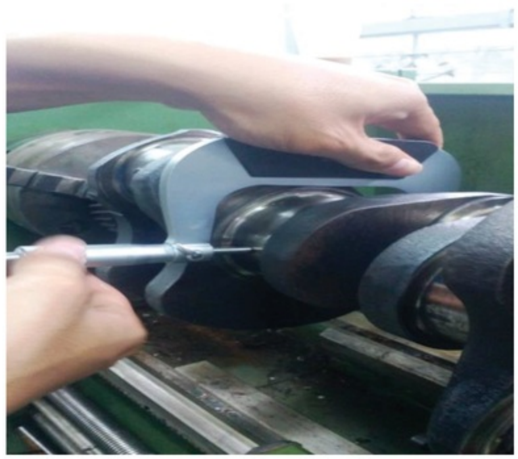


FIGURE 3. Measurement Diameter of Main Journal

TABLE 1. Limits the Size of Main Journal [5]

Diameter Main Journal		
mm		**in**
83	STANDART	[3.2677]
82.962	MIN	[3.2662]
83.013	MAX	[3.2682]
0.050	OUT OF ROUNDNESS	[0.0019]
0.013	TAPER	[0.0005]

TABLE 2. Measurement of Main Journal Diameter

Main Journal No	Diameter of Main Journal [mm]			
	ϕ A	**ϕ B**	**ϕ C**	**ϕ D**
1	82.03	82.09	81.99	81.98
2	81.97	81.95	82.06	82.00
3	82.07	81.84	81.94	81.95
4	81.88	81.96	81.89	82.01
5	81.96	81.98	81.93	81.97
6	81.99	81.99	82.02	81.97
7	82.40	82.42	82.48	82.47

Table 2 shows that all of the main journal diameters were experienced wear and showed that the main journal diameter of the third cylinder exhibits an excessive wear, 1.35 % above the permissible lowest rate.

TABLE 3. Result of Taper and Out of Roundness Value of Main Journal

Main Journal No	Taper [mm]		Out of Roundness [mm]	
	ϕA - ϕB	ϕC - ϕD	ϕA - ϕC	ϕB - ϕD
1	0.06	0.01	0.04	0.11
2	0.02	0.06	0.09	0.05
3	0.23	0.01	0.13	0.10
4	0.08	0.02	0.11	0.05
5	0.02	0.04	0.03	0.01
6	0	0.05	0.03	0.05
7	0.02	0.01	0.08	0.05

Table 3 shows that most of the measurement results of the taper and out of roundness is more than the limit prescribed limits, especially for no.3 where the measurement value is highest among others.

Measurement Diameter of Connecting Rod Journal

FIGURE 4. Measurement diameter of connecting rod journal

TABLE 4. Limits the Size of Connecting Rod Journal [5]

Diameter Connecting Rod Journal		
mm		in
69	STANDART	[2.7165]
68.962	MIN	[2.7150]
69.013	MAX	[2.7170]
0.050	OUT OF ROUNDNESS	[0.0019]
0.013	TAPER	[0.0005]

TABLE 5. Measurement of Connecting Rod Journal Diameter

Connecting Rod No	Diameter of Connecting Rod Journal [mm]			
	ϕ A	ϕ B	ϕ C	ϕ D
1	67.98	67.97	67.93	67.98
2	68.00	67.99	67.99	68.00
3	66.87	67.09	67.33	67.74
4	67.94	67.93	67.97	67.93
5	68.05	68.01	67.98	67.98
6	67.99	67.99	68.01	67.99

Table 5 shows that all of the connecting rod journal diameter were experienced wear and showed that the main journal diameter of the third cylinder exhibits an excessive wear, 1.06 % above the permissible lowest rate.

TABLE 6. Results of Taper and Out of Roundness Value of Connecting Rod Journal

Connecting Rod No	Taper [mm]		Out of Roundness [mm]	
	ϕA - ϕB	ϕC - ϕD	ϕA - ϕC	ϕB - ϕD
1	0.01	0.05	0.05	0.01
2	0.01	0.01	0.01	0.01
3	0.22	0.41	0.46	0.65
4	0.01	0.04	0.03	0
5	0.04	0	0.07	0.03
6	0	0.02	0.02	0

Table 6 shows that of the measurement results of the taper and out of roundness for no.3 is more than the limit prescribed limits.

Crankshaft Warpage / Runout

Measuring the crankshaft warpage by installing the front and rear upper bearing inserts, then placing the crankshaft into the V block or lathe machine. Set a dial indicator to measure the middle journal. Install a dial indicator on the middle main bearing journal where the plunger is positioned in the three o'clock position on the journal. Rotate the crankshaft one revolution while observing the dial indicator. The amount of crankshaft warpage is 50% of the total indicator reading (TIR) [6-7]. The warpage limit for bending of the crankshaft is 0.05mm.

(a). Crankshaft on the lathe machine (b). Measurement by dial indicator

FIGURE 5. Measurement of Crankshaft Warpage / Runout

TABLE 7. Measurement Result of Crankshaft Warpage / Runout

Main Journal No.	Crankshaft Warpage [1:100mm]			
	A			
	P	S	P + S	A / 2
1	18	3	21	10.5
2	21	4	25	12.5
3	35	9	44	22
4	20	14	34	17
5	24	5	29	14.5
6	18	2	20	10
7	8	4	12	6

P means that the needle on the dial indicator moves counter-clockwise
S means that the needle on the dial indicator moves clockwise

Table 7 shows that warpage measurement is performed on all the main journal from No. 1 to No. 7. The measurement results showed that the No. 3 main journal is greatest among others that are equal to 0.22 mm.

Evaluation Result of Crank Web Deflection

Crank web deflections are an indirect confirmation of the stress level in the crankshaft. However, the crank web deflections can be utilized as an indication of the crankshaft bearing loading as well. The crank web deflections are important to be verified as a part of the alignment procedure. Therefore, when the alignment procedure is performed, and if the bearing offset is changed, the crank web deflections need to be confirmed to be within the engine manufacturer-required limits [7-9]. Crankshaft deflection measurement is conducted with a dial indicator being placed at a predefined location between crank webs. The crankshaft is then rotated, and the readings are taken at the prescribed angular locations. Web deflections between each cylinder are measured. Crank web allowable deflection is 0.033 mm.

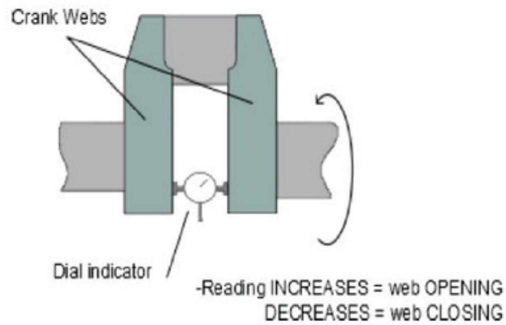


FIGURE 6. Dial Indicator to Check Crank Web Deflection [8-9]

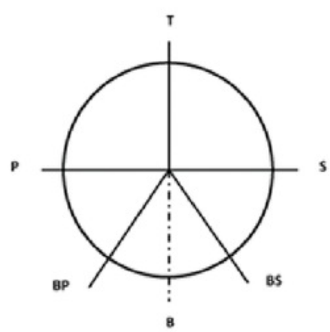


FIGURE 7. Measurement Point of Crank Web Deflection [10]

TABLE 8. Result of Crank Web Deflection

Crank Pin Position	Crank Web Deflection [1:100mm] Cylinder No.					
	1	**2**	**3**	**4**	**5**	**6**
BP	0	0	0	0	0	0
P	-2	3	-3	-4,5	-4	2
T	-4	4	-9	-8	-5	4,5
S	-3	2	-4	-2	-2	3
BS	-2	1	2	2	-3	2,5

TABLE 9. Evaluation Result of Crank Web Deflection

Crank Pin Position	Crank Web Deflection [1:100mm] Cylinder No. 1	2	3	4	5	6
B = (BP + BS)/2	-1	0,5	1	1	-1,5	1,25
Vertical = T - B	-3	3,5	-10	-9	-3,5	3,25
Horizontal = P - S	1	1	1	-2,5	-2	-1
Horizontal/100[mm]	0,01	0,01	0,01	-0,025	-0,02	-0,01
Vertical/100[mm]	-0,03	0,035	-0,10	-0,09	-0,035	0,0325

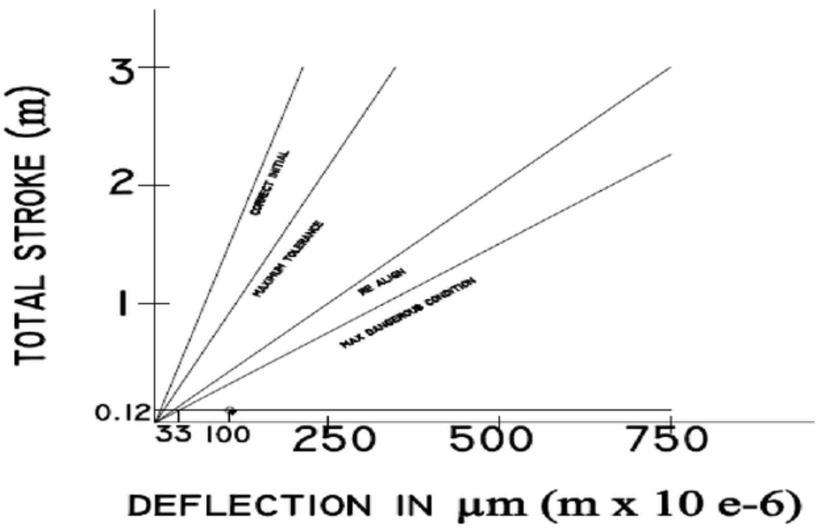


FIGURE 8. Crank Web Allowable Deflections [10]

To determine the value of crank web allowable deflection by looking in Fig. 9 is the piston stroke of 120 mm, the value of crank web allowable deflection of 0,033 mm or 33 µm. To see the results of Table 9, the value of deflection (vertical = T - B) on the cylinder No. 3 is 0,10 mm or 100 µm, where the value of this deflection is already at the maximum dangerous condition.

An excessive torsional vibration of rotary components like crankshafts is an important matter in defining the operational reliability of rotary equipment. The current industry approach to document crankshaft alignment is to measure static web deflections. The crankshaft bending failures are usually related with the misalignment. The measurement of deflection on crankshaft measurements at each crank web are until now an empirical process to assess and control the misalignment of crankshafts [11-12].

The system of lubricating also deserves special and care attention in the crankshaft. Low oil pressure and abnormal wear of shell bearings will cause a higher oil clearance, which can lead a misalignment of the crankshaft. Inspections to the damper and special attention to screws tightening of main engine, with the specific torque applied, can prevent premature damages. Failures can also occur due to improper engine operating and deficient maintenance. Some of these damage sources include oil absence or defective lubrication on journals, the disequilibrium of pressures in the cylinders, the inadequate clearance between journals and bearings, crankshaft vibrations, etc. [13].

CONCLUSIONS

The measurement results of this study indicate that the third cylinder of main journal diameter is experienced wear, a 1.35 % higher than the lowest permissible rate, the taper of 0.23 mm and the out of roundness of 0.13 mm. The diameter of rod journal has experienced the wear, 1.06 % higher than the lowest permissible rate, the taper of 0.41 mm, the out of roundness of 0.65 mm. The measurement result of crankshaft warpage was 0.22 mm. Crank web deflection result was found on crankshaft number 3 (0.10 mm) and number 4 (0.09 mm).

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