ADR016/2704A/FD

CARIBBEAN FANTASY

Crankshaft investigation and adjustment program

1) Initial condition:

Ship' Staff has reported a significant alteration of the first web deflection along the past 6 months increasing from 0,23 mm to 0,31 mm at arrival in Tunisia. More than the absolute value the alteration has been considered and investigation were have been started in order to justify and stop the alteration phenomenon.

This particular situation happens exactly 21 months after the last damage repairs from July 2014. At that time the in situ repair company GOLTENS has been involved on repair affecting bearing n° 9 of both engines and leading to a grinding operation down to – 5 mm on port side and – 1 mm on starboard side.

Repair carried out on port side only results from a compromise in between crankshaft lift and deflection maximum value. Unfortunately this operation has only partially fixed the problem but also introduce more difficulties to fix it on permanent bases as the shaft alignment reference was destroyed during this operation.

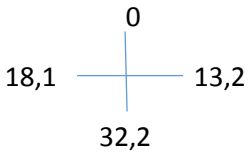
On top of that Control room monitoring system gives information about main bearing temperature from Bearing 1 to bearing 9 and thrust bearing… We were especially disappointed discovery that the thrust bearing is not the one of the engine but the propeller shaft thrust bearing. Nothing to see with engine thrust.

In other terms the 2 engines already heavily damaged in the past were both operated without any protection on their most important bearing: the bearing supporting the flywheel and also keeping alignment of the engine in front of the gearbox.

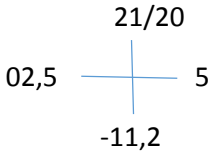
1) Analysis of the situation at ship arrival in Bizerte :
   - Hot engines
   - Measurements taken by March 31st 2016

Engine	Vertical deflection	Measurement gauge	Tendency	Comments
Starboard engine	11,8 / 100 mm	Electronic	Steady	Reference engine
Port Engine	31,2 / 100 mm	Electronic	Altering	Damage(s) to identify and fix.

2) Port engine situation by April 12th 2016
   - Cold engine
   - All cylinders dismantled
   - Vulkan coupling dismantled



Electronic tool



Mechanical tool

3) Relation between the vertical position of the flywheel and maximum deflection
Port engine:

Nota:

- Vulkan coupling disconnected. The flywheel has moved down by 0.95 mm while disconnecting.
- Flywheel mass is estimated to 5 tons making reference of the design and the 4.4 tons of the 48/60 flywheel.

Step	Flywheel lift	Deflection
1	**0.30 mm**	**- 5/100**
2	**0.90 mm**	**0 /100**
3	**1,15 mm**	**+ 2 / 100**
4	**1,55 mm**	**+5/100**

The crankshaft has been moved vertically by the mean of the engine room crane. This crane is rated 3 tons and only limited stress has been applied on it.

Considering the position of the last bearing n° 10 and the distance between bearing n° 10 and flywheel a lift above 1 mm is impossible unless we consider that bearing n° 10 is out of order. This measurement completed by the engine alignment here after led to confirm the damage on baring n° 10.

4) Relation between deflection and alignment:

Engine	Alignment	Web deflection
Starboard engine	Engine is 0.60 mm below gearbox axe	11,8 / 100 mm
Port engine	Engine is 1,50 mm below gearbox level	31,2 / 100 mm

Immediately after this sequence port bearing n° 10 has been dismantled and found destroyed justifying the possible lift of the flywheel.

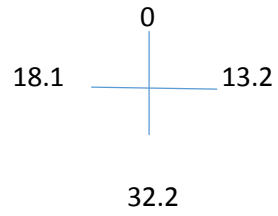
5) Relation between Baring n° 9 situation and the deflection:

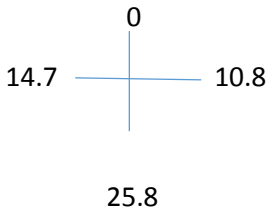
Bearing n° 9 vertical studs were loosed in order to inspect journal and shells – See general report.

In this sequence we start from Bearing n° 9 free and tighten it.0

Bearing n°9 loosed

Bearing n° 9 tightened





The horizontal deflection results from the barring gear tooth reaction pushing the flywheel. This reaction has been considered in the design of the flywheel roller support.

Conclusion: The bearing n° 9 has a limited influence on the maximum value of the web n° 8 deflection. Considering the repeatability of the deflection measurement we can conclude that bearing n° 9 has not influence on deflection.

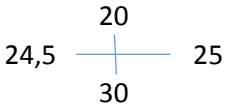
6) Validation of the port engine crankshaft behavior with the starboard engine:

Considering the damage discovered on July 2014 on bearing n° 9 of the starboard engine that led to grinding – 1 mm on journal and the lack of temperature monitoring on bearing n° 10 we have decided to inspect starboard engine as well. Bearing n° 10 has been opened and found in very poor condition requiring grinding operation. Bearing n° 9 has been opened as well found heavily scratched. Bearing n° 9 requires a minimum of mechanical polishing with vibrant stones and maybe more.

The damage on the journal results from the oil pollution they are impressive however they do not significantly affect the crankshaft alignment in its bearings. At least it does not significantly change what can be measured in situ.

Initial deflection of the web n° 8

- Engine is dismantled and cold condition
- All bearing are tightened
- Vulkan coupling is removed:



6-1) Action 1 releasing bearing n° 9 vertical studs:

- Crankshaft moves down 7 / 100 mm at bearing level
- No significant influence on the web deflection, less than 1 / 100 mm

6-2) Action 2 tightening bearing n° 9 vertical studs by hydraulic means:

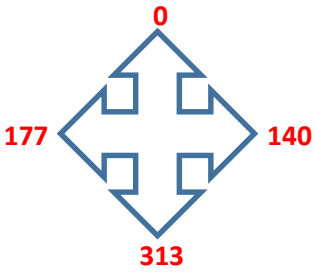
- Back to the original data

6-3) Action 3 Releasing bearing n° 10:

- Crankshaft moves down by 0,23 to 0.25 mm (several attempts done to validate)
- Flywheel moves down by 0.40 mm

6-4) Action Starboard engine web deflection measurement – Web n°8

- Main bearing n° 10 loosed – no contact between journal n° 10 and saddle (clearance = 0,25 mm)



The web deflection measured on the starboard engine web n° 8 is more or less exactly the same than the web deflection measured on web n° 8 of the port engine in similar conditions.

6-5) Conclusion:

- Only the bearing n0 10 directly and heavily influence the web deflection on web n° 8
- Both engines show the same web deflection when bearing n° 10 are disconnected.
- The tightening of the bearing n° 10 generates a crankshaft lift of 25 / 100 mm
- The tightening of the bearing n° 9 generates a crankshaft lift of 7 / 100 mm
- When bearing are tightened as per the specification the clearance below journal is nil.

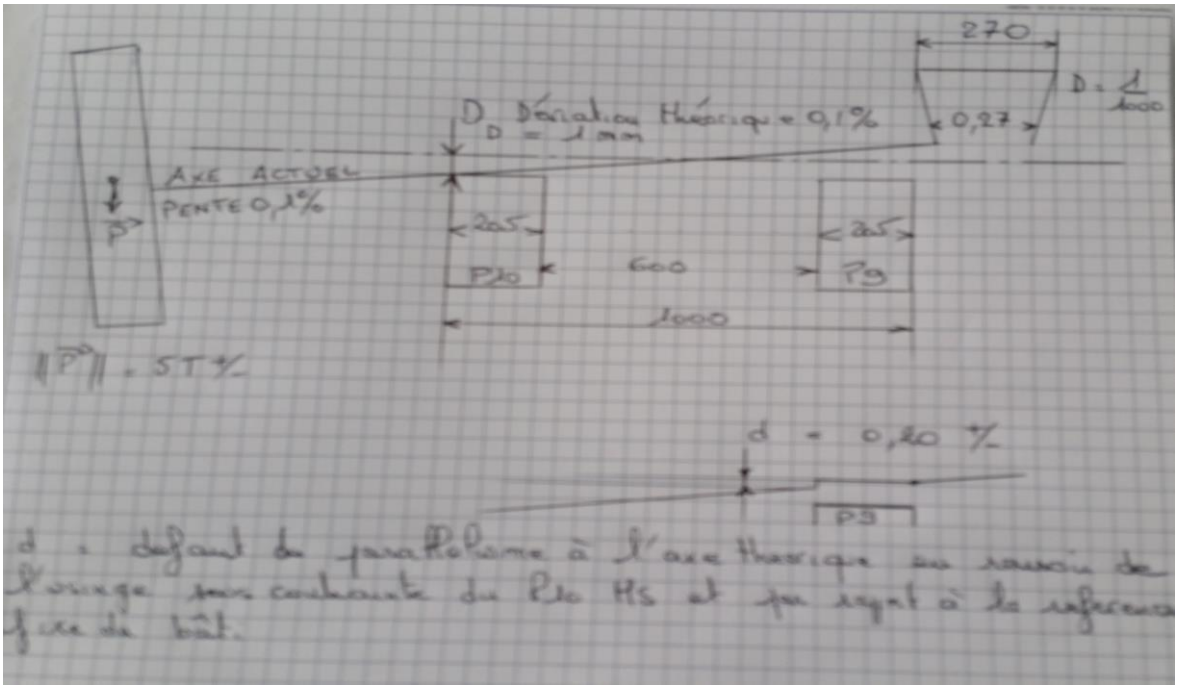
Examination of the starboard side engine gives us the key of the port engine adjustment.

7) Port engine adjustment:

The port engine has completely lost its center axle reference at bearing n° 9 and bearing n° 10 level because:

- Bearing n° 10 geometry has been altered by the overheating resulting from the bearing failure. This situation exist at least since 2 years.
- Journal n° 9 has been machined with deflection reaching 25 / 100 mm on web n° 8 causing misalignment
- The saddle n° 9 has been machined during the same intervention in order to find a compromise between the crankshaft lift and the web deflection.

The sketch here below summarize situation during July 2014 intervention.



8) First attempts for port engine crankshaft alignment:

Note: As n° 10 bearing shell has been found destroyed we have been obliged to use a spare (used) lower bearing shell in order to test alignment. This has been done with journal n° 10 in very poor condition and it of course introduce deviations. On top of that bearing n° 10 saddle has suffered significant overheating as per the marks in the center of the bore. This also introduces distortions.

The various attempts were tested in order to verify the response of the crankshaft and its possible bending effect. Knowing that port crankshaft reacts as starboard one does not allow concluding that it is not bended however it is a positive step before machining.

At the end foils introduced do not cover the whole surface of the saddle vertical landing surfaces. This also introduce deviation. It is not in our purpose to consider foils as a permanent repair solution however it is the only way to make adjustment which such a big saddles.

The objective of the tightening is to verify that bringing the port crankshaft in the same condition than the starboard on leads to the same results in terms of deflection, alignment / lift and clearance under journal.

We have defined our objective to a web deflection of 12 /100 mm similar to what we have measured on starboard crankshaft in the same tightened conditions.

Step	Tightening 100 bar	Foils at cut level	P10 lift	M8 deflection	M7 deflection	Clearance below shaft 10	Clearance below shaft 9	Clearance below shaft 8	Comments
1	Yes	0	0.95	5/100	2/100	0	25/100	18/100	Too high

2	Yes	0.40	0,35	8/100	2/100	0	6/8	0	Too high
3	Yes	0.45	0.35	8/100		0	4	0	Too high
4	Yes	0.50	0.30	9.5/100	3/100	0	0/4	0	optimized

Considering the out of round resulting from the machining done in July 2014 and the condition of both journal surface we can consider that here above results are rather positive and allow to conclude that the adjustment applied to the starboard engine can be copied on the port engine with the same correct result.

Only the out of round cannot be tested in such arrangement however considering that machining is realized using the engine block as reference we can conclude that situation is acceptable to proceed to the next step meaning the machining of the journals by GOLTENS.

9) Adjustment of the starboard crankshaft in order to start journal grinding and machining:

Machining of the crankshaft has been subcontracted to GOLTENS by Ship's Owner.

9-1) Starboard engine:

a) Flywheel adjusted on its roller support – shims welded by spots
b) M8 deflection < 4 /100 mm
c) Clearance under journal = 0 at P10 - P9 - P8 level
d) Vertical out of round checked by dial gauge and found nil +/- 0.03 mm
e) Horizontal out of round checked by dial gauge and found nil +/- 0.03 mm
f) Permanent follow up of the out of round in position
g) Barring gear supplied by 60 hz electric power
h) Bearing n° 10 removed without influence.

Fulfilling those conditions allows giving green light to GOLTENS. This has been made from Tuesday the 26th noon time.

9-2) Port engine:

Considering the distortions affecting the port engine we are obliged to consider an adjustment of the vertical position by steps:

a) Bearing saddle n° 10 tightened with its s0.50 mm shims
b) Flywheel adjusted + 0.10 mm lift
c) M8 deflection measurement if deflection < 4 / 100 mm go to step i)
d) Flywheel adjusted + 0.10 mm lift second time
e) M8 deflection measurement deflection must be < 4 / 100 mm
f) Do not lift flywheel more than 0.25 mm
g) Check clearance under journal bearing n° 8 – must be Zero
h) Check clearance under journal bearing n° 9 - must be < 0.10 mm
i) Flywheel adjusted on its roller support – shims welded by spots
j) M8 deflection < 4 /100 mm
k) Clearance under journal = 0 at P10 - P9 - P8 level

l) Vertical out of round checked by dial gauge and found nil +/- 0.03 mm
m) Horizontal out of round checked by dial gauge and found nil +/- 0.03 mm
n) Permanent follow up of the out of round in position
o) Barring gear supplied by 60 hz electric power
p) Bearing n° 10 removed without influence.

10) Port engine : Adjustment of bearing n° 9 and n° 10 after journal machining by GOLTENS:
a) Manufacturing of steel foil shims from 0.10 mm to 0.50 mm, every 0.10 mm exactly corresponding to the surface of the vertical landing surface
b) Checking geometry of the bearing n° 10 then n° 9 of the starboard engine – this is the reference even considering that bore position can be slightly different from one engine to the other. (Specific inspection procedure already given on site)
c) Main bearing n° 10 lift adjustment to 0.25 mm +/- 0.03 mm
d) Main bearing n° 9 lift adjustment to 0.07 mm +/- 0.03 mm
e) Validation of the expected deflection of crankpin n° 8: 0,10 mm < D < 0,15 mm
f) Machining of the bores if needed to remove adjustment shims
g) Final tightening
h) Final check of deflection and clearance under journals

Note:

- Due to the vessel situation the whole repair intervention is realized with ship on dry dock.
  Considering the very strong structure of the ship we expect that this will not influence engine crankshaft alignment after refloating however complete check must be done after ship refloating in order to give final validation of the operation
- Machining of the journal, crankpin, block, saddle and several other components of the engine are realized with 3/100 mm tolerance. Considering engine manufactured in 1988 we are obliged to consider that the acceptable tolerance of each measurement is at least equal to 0.03 mm.

Final conclusion:

It has been shown that existing engine temperature monitoring system is not efficient: an engine correctly protected cannot suffer such damage on its bearings.

In parallel with the restoration of the shaft line, the engine monitoring must be renewed and the oil temperature adjusted to the correct level as per maker specification.

Considering their current conditions the 2 propulsion of the Caribbean Fantasy definitively require a efficient monitoring system from bearing n° 1 to bearing n° 10.

The machining of the journal has started today Wednesday the 27th the next step of the restoration will start after machining to define correct geometry of the port engine saddles n° 9 and n° 10.

Staying at your disposal for further information regarding investigation findings and repair process applied.

Done in Saint Nazaire Wednesday the 27th 2017

François DELTOUR.