Thrusters

The Reliability of Mechanical Thruster for Offshore Operations

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On the reliability of a mechanical steerable thruster for offshore operations

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Introduction

• Reliability is the ability of the equipment unit to perform its stated duty without a forced (unscheduled) outage in a given period of time

By William E Forsthoffer (Reliability optimization through component condition monitoring and root cause analysis)

Content of this paper:

design aspects mechanical thrusters
failure analysis
condition monitoring system
Why apply steerable thrusters

Steerable thrusters comply with maritime market demands for:
Generating full thrust over 360º steering angle:
- Improved manoeuvrability
- Accurate Dynamic Positioning
- Effective braking / stopping power (90º - 180º steering angle)

- Creating compact propulsion arrangements

Additional benefits:
- Saving machinery space / increasing cargo volume (short shafting, no gearboxes)
- Saving cost of rudders, stern tubes and shaft brackets
Design requirements for offshore thrusters

- high bollard pull requirements
- safety and reliability aspects
- dynamic positioning: most of the time low power operation

- Mission profile thruster with CPP
Two ranges of LIPS steerable thrusters:

- **LIPS Modular Thrusters (LMT):**
  - power range 800 -- 7,000 kW
  - composed from adaptable main modules
  - custom made solutions / special requirements
  - Bolted stem

Existing since 1967
Product Design

Gearwheel / bearing arrangement

• Pinion supported by roller bearings at both sides

• Separate axial and radial bearings

• Precise and stable tooth contact pattern under variable loading (thrust)

• Teeth are finish-machined after hardening: cyclo-palloid HPG process
Design (Housing)

- Pinion and Ring Gear shapes
  - integral
  - shrunk
  - bolted

- Housing design
  - Straddle-mounted
  - Pinion & Gear
  - Bearings on each side
Reliability aspects in design

Reliability and durability are ensured by first class and well dimensioned key components:

- Premium quality roller bearings
- High Power Gear wheels
- Durable triple Viton seals, ceramic liner
- Rigid and vibration free thruster structure

Infinitive lifetime

Min. 25,000 h lifetime: full continuous load
Design

- Separate bearings for axial and radial load → better predictable loading → higher lifetime

- Bearing load depends on: - torque (power + speed)
  - thrust

- double sided anti-friction bearings near gearwheels → less deformation = (thermal elongation)
  → higher lifetime

- Effect of load profile

- Oil contamination / water ingress / temperature
Shaft Seal JMT Triple viton MK2

- Triple Viton lip type running at liner with ceramic coating

- Sealing rings are exchangeable without propeller or shaft de-mounting
- Survey interval period at least 5 years
• Protector Ring is strongly pressed to the liner by Protector spring and rotates with the liner.
• Fishing lines can not be caught between the P-ring and the liner!
AC CoastGuard System Pollution Free Seal
AC CoastGuard System Pollution Free Seal

- Face seal
- Vented Air Space
- Lip Seals
Applications

Some offshore references

Pipe Laying Vessel “Solitaire”
8 x 5550 kW - FS/NU

Semi-sub Heavy Lifting/Pipe Laying Vessel “SAIPEM 7000”
4 x 3000 kW - FS/ CNR
2 x 5550 kW - FS/ MNR
Applications

Some sea-going references

Cable laying Vessel “Knight” and “Baron”
2 x 4500 kW - FS / MN
2 x 2000 kW - FS / MNR

Oceanographic Survey Vessel “Pathfinder” (T-AGS 61-65)
2 x 3100 kW – FS / BO
1 x 1100 kW – FS / MNR
Applications

Some heavy lift references

Dockwise Heavy Lift 2 x 5,5 MW

Covered by Lips Modular Thruster

Thialf 6 x 5,5 MW Retractable
What can go wrong

- Seal damage; more than 0.5% water content in lub oil reduces the life time of gears and bearings significantly.
- Inadequate lubrication due to late filter / oil change
- Overloading of the Thruster
- Propeller induced shocks as a result debris in the water

THE HEALTH OF THE THRUSTER SLOWLY BUT STEADILY DETERIORATES

- Oil contamination eventually results in pitting of gears and bearings.
- Wear particles spread through the unit and affect other “healthy” bearings and gears
Consequences

- Loss of hire > 250,000 USD / Day
- Docking > 1 Milj USD
- Replacement parts
- Mounting / De-mounting
- Loss of redundancy (Class)
- Loss of Confidence

It is therefore important!
Reliability is therefore also related to feedback from actual experience

- The components to be considered
  - The seals
  - The hydraulics
  - The lubrication system
  - The bearings
  - The gears
  - The propeller
  - The controls
  - The vessel structure/ thruster foundation
  - The shaftline/elastic coupling

Based on experience with existing thruster installations the failure modes were identified.
Assessing reliability

General model of failure analysis

The main concept of this model has evaluated from the revision of the past registrations and their counting's
Definitions

- **Symptom** – visible (possible to be experienced) occurrence in the working environment of a propeller,
- **Sub symptom** – detailed specification (if necessary) of a general problem (symptom),
- **Assembly** – secondary level in the product structure,
- **Defect location** - third level in the product structure and, at the same time, LRU (the Last Replaceable Unit),
- **Root Cause** - describes what the source of failure start was
- **Sub root Cause** - distinct in details what exactly caused the break down (after previous specifying the source (root cause) of a failure),
- **Frequency** – counting (it should be sum!!!) of all exactly the same cases of breakdowns of particular location,
- ***Failure rate* - could be defined by means of descriptive terms, i.e.
  - S (significant) 50% and more cases,
  - I (important) 30% - 50%,
  - W (weak) 10% - 30%,
  - IS (insignificant) – less than 10% (but described in details in order to show unusual or abnormal situations).
Steerable thruster symptoms

ST symptoms pool:

- Vibration,
- Noise,
- Oil track (on the water),
- Dropping oil level,
- Seal leakage,
- Temperature changes,
- Oil contamination,
- Misalignment,
- Leakage,
- Floating mechanical seals,
- Broken wire,
- Changes in the pressure,
- Free – wheeling E – motor,
- Clogged filter,

- Changes in the pitch movement,
- Abnormal rpm (acc. to the regular operations),
- Steering problems,
- Smoke,
- Different indications of mechanical & electrical devices,
- Grease spilling,
- Gear wear,
- Large “dead band”,
- Failure on HMI,
- Failure of HMI,
- No light on all test lamps,
- No reaction of all buttons,
- Reduced load on propulsion,
- Misindication.

Note: all based on experience in service, not obtained via formal FMEA analysis
Overall relations ships diagram for ST system

30 symptoms defined
74 defect locations defined
**Example: External observation leakage**

<table>
<thead>
<tr>
<th>Internal Water Leakage</th>
<th>Oil Leakage</th>
</tr>
</thead>
<tbody>
<tr>
<td>N8150 (Intermediate vertical shaft)</td>
<td>N8750 (ST stem section)</td>
</tr>
<tr>
<td>Clamps</td>
<td>N8500 (ST powerpack steering)</td>
</tr>
<tr>
<td>N8550 (Lubrication powerpack)</td>
<td>N8580 (ST pitch powerpack)</td>
</tr>
<tr>
<td>N8700 (ST upper gearbox)</td>
<td>N8750 (ST stem section)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Leak Type</th>
<th>Cause</th>
<th>Action</th>
<th>Life Cycle</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil leakage</td>
<td>8703 (Seals)</td>
<td>C2929 (Maintenance actions)</td>
<td>C2929 (part lifetime)</td>
<td>1</td>
</tr>
<tr>
<td>Oil leakage</td>
<td>8763 (Retraction parts)</td>
<td>C6100 (Work cause)</td>
<td>C6100 (Wrong measurement)</td>
<td>1</td>
</tr>
<tr>
<td>Oil leakage</td>
<td>8763 (Retraction parts)</td>
<td>C6400 (Assembly fault)</td>
<td>C6400 (Old or revision drawing)</td>
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</tr>
<tr>
<td>Oil leakage</td>
<td>Total: 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil leakage</td>
<td>8506 (Hydraulic pump)</td>
<td>C6700 (Machine fault)</td>
<td>C6700 (Machine breakdown)</td>
<td>3</td>
</tr>
<tr>
<td>Oil leakage</td>
<td>8552 (Oil cooler)</td>
<td>C6600 (Handling fault)</td>
<td>C6600 (Carelessness in handling)</td>
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<tr>
<td>Oil leakage</td>
<td>8557 (Hydraulic pump)</td>
<td>C6400 (Assembly fault)</td>
<td>C6400 (Fault in working method)</td>
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<td>Total: 1</td>
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<td>8558 (Lubrication pump)</td>
<td>C5700 (Machine fault)</td>
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<tr>
<td>Oil leakage</td>
<td>Incomplete registration</td>
<td>Total: 6</td>
<td></td>
<td></td>
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<tr>
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<td>8766 (Steering motors)</td>
<td>C6400 (Assembly fault)</td>
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**Oil Leakage**

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**Return to Session Directory**
Example: External observation oil contamination

- **Oil Contamination**
  - Metal particles in a lubrication oil
  - N8500 (ST powerpack steering)
  - N8550 (lubrication powerpack)
  - N8580 (ST pitch powerpack)
  - N8750 (ST stem section)
  - N8780 (ST lower gearbox)

- Changes in a temperature
  - 8763 (retraction parts)
  - 8782 (bearings)
  - C2929 (Maintenance)
  - C2929 (scheduled inspection)
  - C2929 (contamination of lub. Oil)
  - Complete registration
  - Total: 7
• Results:
  – Many occurrences in commissioning phase related to auxiliary systems
  – Seals remain a sensitive issue
  – Data too scattered to predict life expectancy
  – More data needed to validate life time predictions
Typical Maintenance cost development

Bathtub curve

- Infant mortalities
- Normal aging
- Product leaving factory
- End of commissioning period
- End of Guarantee period
- Random failure
- End of economical lifetime

Nr of machine failures vs Machine life
Case study on maintenance cost

- Reference: offshore vessel
- Medium power thrusters (not WP) and transverse thruster
- Evaluation carried out at owner site:
  - Reveal main maintenance cost
  - Find root cause of maintenance cost
  - Recommend improvements
Ship case study on maintenance cost

Three ships with same equipment:
Large variation in cost
Not good for statistics: incident driven?
Main issues on the propulsions equipment (not W supply) was with the seals
Failure analysis data

• Experience
  – Report ‘facts’ not opinions (avoid generalizations such as “technical problems”)

  – Tool also serves as helpdesk support to
    • Relate external failure to find possible defect location
    • Use for quick response
    • Knowledge management: new issues can be added and introduced

  – Training revealed
    • Sharp definitions are required
    Facts sometimes missing in reports

  – Statistic still too scattered for prediction purposes
  – Large variations in cost per ship

• Solution: Use Monitoring System to more accurate data
Condition monitoring

• Today: alarms
  – periodical maintenance
  – alarms

→ actions too early / (too) late

• Tomorrow: monitoring:
  – early detection of deteriorating components
  – less unplanned dry-docking
  – decrease down time
  – decrease stock

→ less “surprises”, saving money

• Diagnostics/prognostics: in future

• This will provide a better basis then long term statistics
from alarming ..

- temperature alarms
  - lubrication
  - steering

- pressure alarms
  - pumps
  - steering motors
  - filters

- level
  - gearboxes
  - header tanks

- Rely on expertise on board, Wärtsilä service
- Alarm: (too?) late, not source related
… to monitoring…

- Add sensors to system
  - Accelerometers
  - Moisture sensors
  - Particle detector

With signals:

- Detect early changes in behavior
- Establish trend lines
- Use fuzzy logics to determine optimal use of thruster
sensors

• Accelerometers:
  – damage to race way / roller element
  – damage to gearing
  – Vibration
  – determine frequencies → relation to damaged element
  – signal analyzing
sensors

• Moisture sensors:
  – detect water
  – rate of change

• Particle detectors:
  – ppm
human interface

- Off-line monitoring
- Robust software
- Fit to purpose
- Easy to use
- Trend watching
**Monitoring**

- Monitoring can detect damage via vibration sensors in main components
Detect early damage

Bearing undamaged

Bearing damaged

Time signal

Envelope Spectrum

Envelope

fb = 1/T
Future: Online monitoring

- Online monitoring
- Health gears
- Health bearings
- Reports / recommendations
Reference to vibration criteria
Conclusions

- Reliability of mechanical thruster is based on the design safety and robustness
- But also on the integrity and the accuracy at which design loads are being predicted
- Based on symptoms, reliability studies can be made which serves as basic tool for rapid fault analyses
- Statistics need to grow, as the data is still too scattered, for life time assessments

- Active monitoring will be another tool which serves to improve system reliability by:
  - Early damage detection of main components
  - Optimising operating conditions

- Experience shows that most of the unreliability is in the sub systems
Bearing Lifetime

- $L_{10h}$-method

\[
L_{10h} = \frac{1000000}{60n} \left( \frac{C}{P} \right)^p
\]

- $C$: basic dynamic load rating
- $P$: equivalent load
- $p$: exponent: 10/3 for roller bearings
  - 3 for ball bearings
- $n$: speed