Wave feed Forward DP and analysis of the effect on Shuttle Tanker operations

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MARIN
Background

**DP – JIP:** Joint Industry Project to develop Wave drift Force Feed Forward

**Analysis:** Quantify the effect on station keeping performance and fuel consumption

**Scenario Simulations:** Predict the effect on the actual operation
DP - JIP: 2000 - 2003

THE PROJECT

- Full scale measurement campaign
- Development of technology
- Model testing

OBJECTIVE

Enhanced positioning performance by use of wave drift force feed forward
DP - JIP

Technology application:

step 1   Estimate real time wave drift force
step 2   Let thrusters counteract this force
step 3   Give information to Kalman filter
          and to DP operator

- Decision support
- Better position filtering
How to estimate a wave drift force.....

Irregular wave drift forces ~~ Wave groups

Simple case: 2 regular waves with different frequency and phase

\[ \zeta(t) = \sum_{i=1}^{2} \zeta_i \sin (\omega_i + \epsilon_i) \]

\[ A^2(t) = \zeta_1(t) \cdot \zeta_2(t)^\ast = \zeta_1^2 + \zeta_2^2 + 2 \zeta_1 \zeta_2 \cos (\mu t + \Delta\epsilon) \]

with \( \mu = \omega_1 - \omega_2 \)

Apply Low Pass filtering of relative wave height squared
Time trace of wave squared and envelope filtering method
Real time estimator “RTEFE” available as plug-on module for DP control system
Why apply to shuttle tanker operation?

- Application of DP to harsh area Offshore Loading requires reliable positioning in high sea states
- On large DP vessels the wave drift forces are relatively high
- Drift forces increase with wave height squared …
- Heading windows get narrower in increasing sea states …
Heading set point:

- **High sea state**
- **Low sea state**
- **Positioning accuracy limit**
- **Optimum heading**

Positioning accuracy vs. Heading offset from optimum
Heading set point: improvement?

Positioning accuracy

Optimum heading

Heading offset from optimum

Positioning accuracy limit

High sea state

Low sea state

With Wave FF
Effect RTEFE on X-pos

Sea State 1: $H_s = 4.5 \text{ m} \quad V_w = 15 \text{ m/s}$

- Sigma_x
- Heading set point

- Conv
- RTEFE
**DP - JIP**

Positioning time trace with and without Feed Forward shows the benefit to reduce on the larger excursions.

- **Full DP**
- **Tandem DP**

4.5 m sea state

6.5 m sea state
DP -JIP Conclusions

• Wave feed forward for large ships improves positioning accuracy by better reaction to large wave group excitation

• Fuel consumption in the same sea state is equal or slightly less.

• With the same DP system the ship can increase its workability
DP-SHUTTLE TANKER APPLICATION

SCOPE

• Investigate and quantify the effect on the positioning capability

• Use of numerical tools: validation

• Scenario simulations: criteria and weather
Validation: DP simulation versus model test results

Conventional DP

- wave_modeltest
- wave_Simulation

- X_Modeltest
- X_Simulation

- Y_Modeltest
- Y_Simulation

- M_Modeltest
- M_Simulation
Validation

RTEFE-DP
Validation: Model tests versus Full Scale trial

6.5 m sea state with 15 m/s wind

<table>
<thead>
<tr>
<th>Signals (Sig = St. Dev.)</th>
<th>Full Scale measurement</th>
<th>Model test Conv.</th>
<th>RTEFE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sig_Rm</td>
<td>5.89</td>
<td>5.76</td>
<td>3.11</td>
</tr>
<tr>
<td>Sig_Psi</td>
<td>2.76</td>
<td>2.07</td>
<td>1.4</td>
</tr>
<tr>
<td>Sig_Y</td>
<td>10.72</td>
<td>6.22</td>
<td>4.69</td>
</tr>
<tr>
<td>Sig_BTs Corr</td>
<td>342</td>
<td>126</td>
<td>107</td>
</tr>
<tr>
<td>Mean BTs</td>
<td>-44</td>
<td>-24</td>
<td>-38</td>
</tr>
</tbody>
</table>

(Aborted)
Shuttle Tanker operations analysis

**SafeTrans**: Monte Carlo simulations
Shuttle Tanker operations analysis

**SafeTrans: Monte Carlo simulations**

- **Criteria development**
  - Weather: Start & Stop criterions
  - Vessel DP capabilities in weather

- **Time domain simulations**
  - 3-Hr time steps
  - Task plan
  - Historic weather 1995-1998
  - Captain’s decision mimic
  - Multiple operation simulations (250)
Scenario simulations

1. Approach manoeuvre & connect: 3 hr critical task of preparation of loading operation
2. Loading first phase: 6 hr critical task with Shuttle tanker in light draft
3. Loading second phase: 6 hr critical task of Shuttle tanker in intermediate draft
4. Wait and de-ballast: 60 hr task
5. Approach manoeuvre & connect: 3 hr critical task of preparation of loading operation
6. Loading third phase: 6 hour critical task with Shuttle tanker in intermediate draft
7. Loading fourth phase: 6 hour critical task with Shuttle tanker in deep draft
Scenario simulations: criterions

Shuttle tanker operation West of Shetlands

• Present operational criterions
  
  **Approach criterion** Hs 0 to 4.5m; W 0-40k
  **Load criterion** Hs 0-6m; W 0-60k
  Time schedule is important

• Can this be improved?
### Scenario simulations: criterions

<table>
<thead>
<tr>
<th>Task No. (see list above)</th>
<th>Criteria as is</th>
<th>Criteria with RTEFE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hs</td>
<td>Vw</td>
</tr>
<tr>
<td></td>
<td>(m)</td>
<td>(m/s)</td>
</tr>
<tr>
<td>1</td>
<td>4.5</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>6.0</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>6.0</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>No limits</td>
<td>No limits</td>
</tr>
<tr>
<td>5</td>
<td>4.5</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>6.0</td>
<td>30</td>
</tr>
<tr>
<td>7</td>
<td>6.0</td>
<td>30</td>
</tr>
</tbody>
</table>

$F_{BT}$ ~~ bow tunnel capacity, allowing a 25% dynamic load.  
$F_X$ ~~ wave drift forces.
### Operations simulations: Results

<table>
<thead>
<tr>
<th>RESULT 250 simulations</th>
<th>RTEFE</th>
</tr>
</thead>
<tbody>
<tr>
<td>90 -120 hrs (no loss)</td>
<td>189</td>
</tr>
<tr>
<td>121-150 hrs (1 day loss)</td>
<td>19</td>
</tr>
<tr>
<td>151-300 hrs (1 cycle loss)</td>
<td>30</td>
</tr>
<tr>
<td>&gt; 301 hr See Note</td>
<td>12</td>
</tr>
</tbody>
</table>

Note: Two bad weather periods, i.e. 12-26 Feb 1998 and 10-29 Dec 1997 caused long non-workable periods

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<tr>
<th>RESULT 250 simulations</th>
<th>Actual+</th>
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<tr>
<td>90 -120 hrs (no loss)</td>
<td>199</td>
</tr>
<tr>
<td>121-150 hrs (1 day loss)</td>
<td>15</td>
</tr>
<tr>
<td>151-300 hrs (1 cycle loss)</td>
<td>23</td>
</tr>
<tr>
<td>&gt; 301 hr See Note above</td>
<td>9</td>
</tr>
</tbody>
</table>

+ means that the connect condition has been increased to Hs=5 m instead of Hs=4.5 m
Operations simulations: Results

Assume 70,000 bbl per day production rate

Keeping the connect condition unchanged results in:
• About 3% greater regularity and about 4 days extra production yearly
• About 10 million US$ extra production

Changing the connect condition to Hs=5m (on basis of decision support):
• About 10% greater regularity and about 17 extra production days yearly
• About 40 million US$ extra production

Note: the improvements are largely obtained in the winter half year.
Operations simulations: conclusions

DP simulations with use of RTEFE can be used to compute criteria for offloading operations.

Scenario simulations in historic weather can be used to compute potential operations improvements in use of Wave feed forward DP.

For a harsh area shuttle tanker operation the economic benefits of using the RTEFE can be substantial.

Thank you.