Control

Power Optimal Thruster Allocation

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WORLD CLASS – through people, technology and dedication
Power Optimal Thruster Allocation

- Basic optimisation task
- Minimize the total squared thrust used to fulfil the thrust demand

\[ g_0(t) = \frac{1}{2} \cdot \left( \sum_j w_j \cdot t_j^2 \right) \]

subject to

\[ g_1(t) = \sum_j t_j \cdot \cos(\alpha_j) - d_1 = 0 \]

\[ g_2(t) = \sum_j t_j \cdot \sin(\alpha_j) - d_2 = 0 \]

\[ g_3(t) = \sum_j t_j \cdot \left( \sin(\alpha_j) \cdot p_j^y - \cos(\alpha_j) \cdot p_j^x \right) - d_3 = 0 \]
Power Optimal Thruster Allocation

- Thruster constraints
  \[ T_j^{\text{min}} \leq t_j \leq T_j^{\text{max}} \]

- Power constraints
  \[ \sum_j p_j \leq P_i^{\text{max}} \]
  - Power phase back (traditional)
  - Power consumption included in the optimisation
Power Phase Back

- Percentage wise distribution of phase back power according to the rated power of each thruster

\[ \Delta p_i = \frac{\Delta P \cdot (p_i - p_i^0)}{\sum_j (p_j - p_j^0)} \]

- Sequenced phase back where least efficient thrusters or pair of thrusters are reduced first
  - Sorting according to moment arms \(1/ |A_i|^m\)
  - Sorted according to efficiency \(r^n\)
  - Combinations \(r^n / |A_i|^m\)

- Weighted reduction according to thruster efficiency

\[ \Delta p_i = \frac{\Delta P \cdot (p_i - p_i^0)}{\sum_j (p_j - p_j^0) \cdot \sum_j 1/ |A_j|^m} \]
Example

- 6 tunnel thrusters each 2,500kW
- Power available 8,000 kW
- Thrust demand
  - 100 tonnes
  - (would require 9,500 kW online power)

<table>
<thead>
<tr>
<th>Phase back procedure</th>
<th>Lateral force (tonnes)</th>
<th>Moment (tonnes*m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage phase back</td>
<td>84</td>
<td>835</td>
</tr>
<tr>
<td>Armed weighted phase back</td>
<td>83</td>
<td>935</td>
</tr>
<tr>
<td>Armed based sequencing</td>
<td>81</td>
<td>832</td>
</tr>
</tbody>
</table>
Power optimisation

Power phase back

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Additional Features

- Equal percentage load on each switchboard (*Even Lode* mode)
- Operator specified max load on one switchboard (*Reduced Bus Load* mode)
- Minimum bus tie current with connected switchboards (*Zero Bus Tie Current* mode)
Special Features

*Reduced bus load – Start generator*

- **Numeric**
  - **Power Bus Consumption/Nominal**
    - Main Bus A
    - Nominal
  - **Maximum load**
  - **Generator connected**
  - **Power bus load**

- **Numeric**
  - **Thruster Force**
    - BowMidAzi1
    - BowPortAzi2
    - BowStbdAzi3
    - AftPortAzi4
    - AftStbdAzi5
    - AftMidAzi6
Special Features

Zero bus tie current

Closed bus tie

Open bus tie
Special Features

**Zero bus tie current - scenario**

- Redistribution of power among the generators when the bus tie is
  - closed
  - and reopened

- The bus tie operation has no effect on the thrusters (lowest part of graph)

- When the *Zero Bus Tie Current* is selected necessary redistribution to minimize the bus tie current if the two halves should be connected

- At closing the bus tie there is no change in neither power distribution (generators and thrusters)