A continuous hydraulic jacking system
High Performance Turbine Installation Vessel (HPTIV)

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Product Responsible, Offshore Jacking Systems
1. Introduction

Aker Solutions has developed a new concept of a **Jacking System** for a Jack-Up vessel for installation of offshore wind turbines.

- Using a combination of: **truss legs**, and **hydraulic pin&hole**.
- A joint-venture agreement with Wartsila, as the ship designer, a concept of a **High Performance Turbine Installation Vessel (HPTIV)** is designed.
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2. Success factors and advantage:

- Truss legs is a more *light weighted* structure, compared to tubular legs of similar strength for leg sizes approx. 6x6x6 and upwards, and also easy scalable.
- For smaller legs than approx. 6x6x6, tubular legs might be more optimal.
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- A hydraulic pin&hole system is very *reliable, robust, and cost optimal* compared to a rack and pinion system, especially for frequent use of the jacking system. The design is based on the experience from our drilling technology.

- In this case we have chosen design criteria for jacking to be 280 times/year). This is *not* the case for oil&gas rigs.

Hydraulic cylinders:

Rack & Pinion:
3. Jacking concept

3.1. Animation HPTIV
Animation 2: 8of12 (new)

3.2. Cylinders:

Cylinder sequences: Total 12 cylinders per leg

- **4:12 System** *(Leg Handling, leg up/down)*
  - Double speed is then possible compared to 8:12, decreasing lifting capacity – but we need to lift “only” the weight of legs.

- **8:12 System** *(Jacking, vessel up/down)*
  - 2 levels, 2 or 4 cylinders lifting at each corner

- **12:12 System** *(Parking)*
  - Increasing system holding capacity with 50% compared to lifting with 8:12 – giving $48/32 \times 26\,717 = 40\,106$ tons.
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3.3. 8:12 System info:

- By using 8 of 12 cylinders at all times a greater total lifting force of 33% is then available, compared to for instance 6 of 12.

- Cylinder info:
  - cylinder bore Ø550mm
  - rod diameter of Ø330mm
  - 250 bar working pressure
  - 345 bar design pressure

- => 605tons lifting capacity pr cylinder.

- => Total lifting capacity of 605x32 = 19360 tons.

- 345 bar is available as capacity for impact loads in «opposite direction», =345/250*19360 = 26 717 tons,

- Loads above 345 bar will bleed of with a PSV (Pressure Safety valve) – protecting the hydraulic cylinders from pressure above 345 bar.
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3.4. RPD: Rack Phase Differential

- Measuring RPD, is a good indicator of brace loading for slender truss legs.
- The HPTIV is designed with a plated structure in between the chords instead of braces on the top part of the legs that are never exposed to wave slamming – eliminating any RPD issues.
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3.5. Footing:
Independent Spud can is chosen, instead of mat footings, having an advantage to be used on several types of seabed's. One spike in center of the spud can intended for rocky seabed, and a large taper surface for medium dense sand (soft soil) around the spike.
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3.6. LBU detail:
A specially designed Locking Bolt Unit is designed for the purpose.
The LBU is transferring the forces between the LEG and the GUIDING TOWER.
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3.7. Chord cross section:

T=100mm

T=140mm
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4. HPU: **Hydraulic Power Unit**
Integrated HPU and hydraulic piping:

- HPU’s at each leg, no piping in hull
- 2 HPU’s pr leg is chosen, totally 8.
- Guiding tower unit to be installed and tested before installation at yard, reducing fabrication time.
- One HP system (for working cylinders), and one LP system (for returning cylinders) + drain line to tank.
- Main components:
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4.1. Simplified calculation of HPU Power:

Lifting speed: 1.0m/min = 16.67mm/s

Energy = Work / Time = (Force x Length) / Time

Energy [W] = Force [N] x Speed [m/s], \( P = F \times v \)

Total HP HPU Power needed:

(incl efficiency 0.6=energy loss in pumps,piping, valves, friction)

\[
P_{TOT} = \frac{19360 \times 1000 \times 10}{0.6 \times 1.0 / 60} = 5.38\text{MW}
\]

HP Power each leg (2HPU’s): 1.34MW (670kW pr HPU)

Assuming 10% LP Power, increasing total consumption to 1.5 MW pr leg, or 0.75 MW pr HPU, or

375 kW pr motor.

If working pressure is increased above working pressure of 250 bar to achieve extra lifting capacity, then the hydraulic flow (and jacking speed) needs to be reduced similar.

Energy [W] = Pressure * Flow
4.2. Hydraulic calc. of HPU’s:

Energy = Pressure x Flow, Energy [W] = Pressure [Pa] x Flow [m³/s]
Flow = Speed x Area, Q = v [m/min] x A [m²]

\[ Q_{\text{in-Lifting}} = 8 \times Q_{\text{jacking1.0-piston}} + 4 \times Q_{\text{return3.0-rod}} = 8 \times 237 + 4 \times 456 = 1896 \text{(HP)} + 1824 \text{(LP)} = 3720 \text{l/min. pr. leg} \]

Energy = \( \frac{P}{10} \text{[bar]} \times \frac{Q \times 1000}{60} \text{[l/min]} \)

Energy \( \text{HP} \) = \( \frac{250}{10} \times (4 \times 1896) \times \frac{1000}{60} \) = 3.16 MW

Energy \( \text{LP} \) = \( \frac{50}{10} \times (4 \times 1824) \times \frac{1000}{60} \) = 0.62 MW (LP-flow=3xHP-flow)

Energy \( \text{HP+LP} \) = 3.16 + 0.62 = 3.78 MW for the total vessel

Total HPU Power pr. vessel = 5.2 MW pr. Vessel (incl efficiency HP=70%, LP=90%)

Energy \( \text{VESSEL} \) = \( \frac{3.16}{0.7} + \frac{0.62}{0.9} \) = 4.51 + 0.69 = 5.2 MW

Energy \( \text{LEG} \) = \( \frac{5.2}{4} \) = 1.3 MW pr leg

Energy \( \text{HPU} \) = \( \frac{1.3}{2} \) = 0.65 MW = 650 kW pr leg

With 2 engines for HPU,

325 kW pr motor.

Hydraulic flow diagram,
Cylinders of Test Model 1:6:
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4.3. Guiding tower:

■ LBU at each chord, pinned to guiding tower and

■ guided towards leg chords, removing horizontal forces between guide tower and legs.

■ Only VERTICAL forces are therefore taken by hydraulic cylinders and guiding tower.
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4.4. Guiding tower support structure:

- Guiding tower are boxed in with a plated guide tower support structure, taking all horizontal forces at upper and lower guide points.
- 2 purposes, weather shield AND strength
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5. Maintenance:

Guide support structure will be equipped with suitable openings to be able to replace cylinders and HPU pumps/motors within 24 hours.
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6. Video film and Test Model 1:6

Link
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7. Hydraulic & Control system

Test Model HMI:
A *servo valve* controls the hydraulic flow from the HPU to each side of a pair of jacking cylinders, (handling 1 LBU). A pair of locking bolt cylinders is locking the LBU to the leg with locking bolts. The servo valve is controlled by a servo controller integrated in a Siemens PLC. (Siemens SIMATIC Step 7 programming software). The HMI runs on a Siemens SIMATIC WinCC Flexible platform on a panel PC with touch screen.
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Virtual Master curve: (Simplified)

3 LBU* are «slaves», following a virtual master time curve, by position. All 3 LBU’s is moved in vertical direction by 2 hydraulic cylinders. One LBU is pushing (stroking out) 0%-50% stroke, Second LBU is pushing (stroking out) 50%-100%, Third LBU is pulling (stroking in) 100%-0%.
Main Regulating Parameters:
Input parameters are cylinder pressure (force) and cylinder absolute position (stroke).

Proximity switches:
Proximity switches reading physical vertical location of holes in the legs (when to insert the locking bolt), and prox’es reading physical horizontal location if the locking bolt is inserted in the leg or not (in/out).
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Full size vessel, HPTIV

Control center:
• The central Jacking HMI and PLC is located at the bridge.
• Each leg shall have a setup with also local panels and PLC on each leg
• A challenge for our system is to handle the variable direction of load at touch down, when vessel is going afloat, and cylinders switching between pull and push!

Redundancy:
Redundancy of E&I hardware and signals will also be an important part of the setup, having safety as top priority when doing detailed control system development for full size vessel with 4 legs.
8. HIL-simulation (Hardware-in-the-Loop)

- Real time simulation is used to reduce **cost** and **failure** related to testing of our Jacking system. We can vary the system algorithm and easily test the system response with different parameters – tuning the system to meet function requirements.

- With **Sim-X** software we have built a **virtual physical model** of the test model size 1:6, controlled by the PLC developed for the purpose.

- In workshop we are verifying our virtual Sim-X model, in order to scale the virtual system up to a full size HPTIV vessel!
9. Operation criteria

- 1 meter/min jacking speed might not be that important - because pre-loading is a large portion of the total jacking time.
- Power consumption is proportional to jacking weight & speed, and must be evaluated up against vessel case by case.
- $H_s$ (Sign. Wave Height) and $T_p$ (Time Period) at specific location (Depth max 50m), defining percentage 1-year operation criteria is more interesting.
- The HPTIV is designed to operate and install wind turbines in $H_s=5$, and if needed, jacking further up to Survival position (18m air gap) in $H_s=6$, instead of going to safe location (meaning jacking down and going afloat in $H_s=2.5$) that would reduce the operating weather window.

Approx. 70%
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10. Global strength analysis

Design conditions: *Basic code used is DNV-OS-J301*

- Installation condition \((H_s=2.5, T_p \text{ max 7sec})\)
- Operation condition \((H_s=5)\)
- Transit condition \((H_s=6.5)\)
- Survival condition \((H_s=10)\)

Design software:

- SESAM *for* package for all linear analyses
- GTSTRUDL/SELOS *for* Non-linear dynamic installation analysis
- TOWER *for* Time history dynamic analysis based on irregular and random sea
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10.1 Survival

Plated field in top of legs requires the vessel to be jacked up to maximum height to withstand a SURVIVAL condition.

Self frequency of the system is approx. 8s, and should preferably be outside 70% operations of scatter diagram.

For $H_s = 2.5 \text{ Max } T_p = 7\text{sec}$. 

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**Table:**

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<th>$H_s$ (m)</th>
<th>0-0.5</th>
<th>0.5-1</th>
<th>1-1.5</th>
<th>1.5-2</th>
<th>2-2.5</th>
<th>2.5-3</th>
<th>3-3.5</th>
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<tr>
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10.2 Installation

In the calculations it is assumed that the impact loads are governed by the rolling and pitching of the jack-up and that no roll and pitch damping devices are present.

DNV-RP-C104 is basis,

But GTSTRUDL/SELOS is used for Non-linear dynamic installation analysis, resulting in a more realistic approach to the impact loads – and not that conservative.

The analytical expressions for the impact loads are derived under the assumption that the rotational kinetic energy of the jack-up (associated with the roll or pitch motion) shall be absorbed as elastic strain energy by the leg and porting structure at the barge (it is assumed that only one leg touches the bottom). The horizontal and vertical components are given as:

\[
P_h = \frac{2\pi}{T} \cdot \theta \cdot \sqrt{\frac{I_w k_H}{1 + \frac{k_p}{k_H} \left( \frac{d}{h} \right)^3}}
\]

and

\[
P_v = \frac{2\pi}{T} \cdot \theta \cdot \sqrt{\frac{I_w k_F}{1 + \frac{k_p}{k_F} \left( \frac{h}{d} \right)^3}}
\]

where:

- \( k_H \) = overall lateral stiffness of the leg
- \( k_F \) = overall vertical stiffness of the leg
- \( I_w \) = mass moment of inertia of the jack-up with respect to roll or pitch motion
- \( T \) = period of roll or pitch
- \( \theta \) = amplitude of roll or pitch (angle)
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11. Strengths & weakness (pro’s & con’s)

PRO’s:
- Reliable and Robust system for frequent jacking (280 times/year)
- Cost optimal and easy scalable for truss legs 6x6x6m-18x18x18m
- Fabrication friendly, HPU to be fabricated and tested before yard.
- Operational friendly, to withstand rough weather conditions.
- Maintenance friendly (24h time limit for critical parts)
- No fixation system needed
- Aker Solutions Drilling expertise and mindset in delivery

CON’s:
- No previous vessels (except one in late 70’s, but no info is available) delivered with this type of combination.
- A conservative mindset (=R&P) regarding the choice of jacking system.
12. Where are we, and what to do ahead?

Status of technical solution:
We have established the concept for the mechanical design and developed a master/slave control philosophy (sequence 8:12) for the hydraulic system, and executed preliminary tests in workshop of the same.

Planned work ahead:
More tests are necessary to log and verify the test model up against our Sim-X simulation, to be able to scale the system doing simulations for a full size vessel and manipulating the system for worst case scenarios.

This is planned finished by end of Q4 2013
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13. Separated Installation and Supply

- A new concept in addition to HPTIV is developed.
- **J-LASH** is one Installation vessel, with several Barges and Tug boats, for independent Supply of foundation structure, monopiles, and wind turbines, severe reducing downtime for installation.
14. Marked and planned activities in 2014:
The need of installation vessels is varying a lot and is up to clients!
We need a cooperation with a serious player or client, to continue further into a basic/detail phase for a specific vessel?

2012 Douglas Westwood

Indicated 10 – 15 new installation vessel / year
Indicated Overcapacity until 2018?
Thank you!
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