TECHNOLOGY MACHINERY ENGINEERS NEED TO KNOW TO WORK EFFECTIVELY SUBSEA

SESSION 1 AND SESSION 2
More and more equipment is being installed subsea. These include valves and manifolds, chokes, pumps, compressors, separators, etc. These installation are needed to effectively produce underwater oil and gas deposits. As water becomes deeper, it becomes less effective to install all the equipment above the water’s surface. These applications are occurring in almost all the waters of the world.

The skills required to work subsea in this manner are a combination of the basic mechanical skills of machinery equipment specialists coupled to the skills of subsea engineers. Either subsea specialists have to learn hardware engineering skills, or vice versa.

This tutorial attempts to present a part of subsea engineering skills to machinery specialists in order to both educate them in some of these skills and to enlighten them to the required additions to their skill set. References are provided. Liberal use is made of graphics, figures, and animations.
Tutorial Organization

• There are two sessions of this tutorial.
• Dr. Zenon Medina-Cetina of Texas A&M will start each with a “Big Picture” view of the issue.
• Session 1 will be presented by Dag Elvebakken and Jonah Margulis of Aker Solutions.
• Session 2 will be presented by Michael Mancuso of OneSubsea.
Content

• The presentation of the 2 Sessions will be somewhat different.
• The overall content will contain the same or similar features.
Topics

• A “Big Picture Walk Through on” Offshore Deepwater E&P Systems
• History of Subsea and the importance of the growth of subsea as a source of oil and gas moving forward.
• What does a typical subsea entire system look like? Size, scale, weight.
• Video, animations, and pictures of installation sequences, view of reservoir and entire system.
• Describe pumps and pump systems, including different pump technologies. Marininized units, pump modules.
• Typical standards and testing required for meeting subsea customer demands and regulatory requirements.
• What separates subsea equipment and equipment form topsides, show examples.
• Emphasize focus on reliable, robust and redundant systems. Modularization, simple and robust interfaces, ROV access.
• Educational Road Map to Subsea.
OFFSHORE DEEPWATER SYSTEMS
A "Big Picture Walk Through"

Stochastic Geomechanics Laboratory
SGL at Texas A&M University
Zenon Medina-Cetina

- Dr. Medina-Cetina is Assistant Professor in the Civil Engineering Department at Texas A&M University, with a joint appointment in the Petroleum Engineering Department.

- He leads the Stochastic Geomechanics Laboratory SGL, where both probabilistic and geomechanical applications are explored for improving the uncertainty quantification inherent to mainly energy-based projects, both onshore and offshore.

- He is a fellow of the Society for Underwater Technology SUT, and is Chair of the Offshore Site Investigation and Geotechnics of SUT, which gathers a geo-leaders in Oil & Gas E&P.
Offshore Deepwater Systems: The Big Picture
Offshore Deepwater Systems

Key Areas of Offshore Deepwater Systems

• Site Characterization
• Metocean
• Flow Assurance
• Design of Infrastructure
Offshore Deepwater Systems - Exploration: Geo-Science and Geo-Engineering

• What is the Geo-Scientist’s and Geo-Engineer Role in Site Characterization?
  • We want to assess the structural integrity of the ground-structure interaction of subsea facilities

• Why?
  • To minimize Risk

• What technical specialties are involved?
  • Survey Specialists, Geophysicists, Geologists & Geotechnical Engineers
  • Familiarity with other specialties helps: Marine Archeology, Environmental Studies and Oceanography
Offshore Deepwater Systems - Exploration: Flow Assurance

• Flow Assurance can be characterized as:
  – The ability to produce fluids **reliably** & economically from the reservoir to a production facility over life of the field in any environment
  – Assurance that well fluids can be delivered from the wellhead to the final production facility under all operating conditions.
  – Also the ability to deliver produced fluids via export lines, trunklines or transportation lines to process facilities

• This ability is influenced by:
  – Pressure
  – Temperature
  – Fluid composition

• We really mean: “Flow Assurance and Operability”
Offshore Deepwater Systems

Educational Road Map to Subsea Engineering
Offshore Deepwater Systems

- Reservoir Analysis
- Site Characterization
- Field Architecture
- Risk Assessment: Social, Economical, Environmental
- Controls
- Flow Assurance
- Subsea Facilities
- Floating Systems
- Pipelines
- Moorings
- Risers
- Safety
- Installation and Commissioning
- Monitoring Integrity
- Decommissioning
- Risk Management
TECHNOLOGY MACHINERY ENGINEERS NEED TO KNOW TO WORK SUBSEA EFFECTIVELY

INTRODUCTION TO

ROTATING MACHINERY SUBSEA
Dag Elvebakken

Dag Elvebakken is a mechanical engineer (Msc.) who has been working with subsea pumps for Aker Solutions the last 8 years. Since his start with the company he has been working within all of Aker Solutions boosting and compression projects delivered out of Norway. His main focus areas are pump system design and testing. Currently he is working as a Technology Lead for Aker Solutions Pump Systems department, located at Tranby a few miles west of Oslo, Norway. You can reach him at dag.elvebakken@akersolutions.com.

Jonah Margulis

Jonah Margulis is the Director of Business Development and Sales for Aker Solutions. He obtained his engineering degree from Lafayette College in Easton, Pennsylvania and MBA with an Energy Management certificate from the University of Houston. He has worked in the pump industry since 2001 and been involved in subsea multiphase pump technology development since 2008. Jonah serves as an active member of the API 17X and 17S working groups. He currently resides in Houston with his wife Milena and young daughter Rose. You can reach him at jonah.margulis@akersolutions.com.
Tutorial Scope

Focus

- Introduction
  - Background for boosting/injection
  - High level overview of subsea production system
- Rotating machinery located at the seabed, with main focus:
  - Centrifugal seabed pumps
  - Enabling systems
- Briefly cover subsea compression
- Pumps inside well (downhole) are not included
Subsea Production System

natural flow production

$P_{WH}$ = Flowing well head pressure
$P_{WH \text{ critical}} = $ Pressure limit where flow stops (or becomes too small)

UTA= Umbilical Termination Assembly
FLET= Flow Line End Termination
Subsea Production System

Boosting

\[ P_{WH} \]
\[ P_{WH \ start} \]
\[ P_{WH \ critical} \]

\[ P_{WH} = \text{Flowing well head pressure} \]
\[ P_{WH \ critical} = \text{Pressure limit where flow stops (or becomes to small)} \]

Note: Figure is a simplification. In a real application many other factors must be considered and will influence system and philosophies.

UTA= Umbilical Termination Assembly
FLET= Flow Line End Termination
Subsea Production System

Boosting & Water Injection

- **Master Control Station (MCS)**
- **Variable Speed Drive (VSD)**
- **Electrical Power Unit (EPU)**
- **Hydraulic Power Unit (HPU)**
- **Barrier Fluid HPU**

Note: Figure is a simplification. In a real application many other factors must be considered and will influence system and philosophies.

UTA = Umbilical Termination Assembly
FLET = Flow Line End Termination
WI = Water Injection

**Equations:**

- $P_{WH} = $ Flowing well head pressure
- $P_{WH\text{ critical}} = $ Pressure limit where flow stops (or becomes too small)

```
<table>
<thead>
<tr>
<th>P_{WH}</th>
<th>P_{WH\text{ start}}</th>
<th>P_{WH\text{ critical}}</th>
</tr>
</thead>
<tbody>
<tr>
<td>head</td>
<td>start</td>
<td>critical</td>
</tr>
<tr>
<td>P_{WH}</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```
Subsea Production System

- XMT
- Well jumper
- Umbilical
- Umbilical (power)
- Manifold
- Pump Station
- Flowline
Background - Why & Where

- Rotating machinery subsea in the form of pumps and compressors are used to increase recovery of hydrocarbons
  - By adding energy to the well stream (Boosting / Compression)
  - By adding energy to a fluid (water or gas) so it can be injected into the reservoir. (Injection)
  - In combination with subsea processing equipment, e.g. down-stream a separator or scrubber
Easy oil is gone; huge values remains

- 1% IOR on NCS = USD 50 BN value creation
- Short pay back: 30 days @ 20 000 bopd increase

IOR Examples

- Tordis: RF ~ 60%
- Tyrihans: RF ~ 35%
- GOM single phase potential: 40%
- GOM multi phase potential: 60%

Increased Subsea Recovery Factor

Source: Aker Solutions; Chevron; OD "Økt Utvinning På Norsk Kontinentalsokkel"; IntecSea poster 2011; Oistein Bøe "DOT IOR Workshop"
Why install subsea boosting?

- Increased production through life
- Increased production late life
- Reduced development cost
- Enables development and production of low pressure reservoirs
- Makes deep water development possible

![Enhanced Production (Early Boosting)](image)

![Extended Production (Late Boosting)](image)
Background - Why & Where

WORLDWIDE LOCATIONS FOR SUBSEA PUMPING, COMPRESSION, AND SEPARATION SYSTEMS (As of Feb., 2014)

- **Barents Sea**: Shtokman (Compression), Snocvit (Compression)
- **North Sea**: Columbia E. (W), Brenda & Niciel (Boosting), Lyell (Boosting), Machair/ETAP (Boosting), Highlander (Separation), Argyll (Separation)
- **Norwegian Sea**: Tordis (Separation, Boosting, WI), Troll C. Pilot (Separation, WI), Tyrhans (W), Draugen (Boosting), Draugen - Expansion (Boosting), Aassgard (Compression), Gulflaks (Compression), DEMO 2000 (Compression), Ormen Lange (Compression), Troll (Compression)
- **South China Sea**: Lufeng (Boosting)
- **Mediterranean**: Montanaz & Lubina (Boosting), Pireu, Prezioso (Boosting)
- **Abu Dhabi**: Zakiun (Separation)
- **Angola**: Pazflor (Sep, Boosting), CLOV (Boosting), GirR (Sirassol) (Boosting)
- **Congo**: Azurite (Boosting), Meha Phase 1 BIS (Boosting)
- **Campos Basin**: BC-10 - Phase 1 (Separation, Boosting), Espadarte (Field Trial) (Boosting), Berracuda (Boosting), Marlimba (Separation, Boosting), Marlim SSAO - Pilot (Separation), Alhacora L’Este (WI), Marlim (Boosting), Congo (Separation, Boosting), Corvina (Separation, Boosting), BC-10 - Phase 2 (Separation, Boosting)
- **Espirito Santo Basin**: Jubarte - Phase 2 (Boosting), Golfinho (Boosting), Jubarte - Phase 1 (Boosting), Jubarte EWT (Boosting), Canepu (Separation), Atlanta (Boosting), Parque das Baleias (Boosting)
- **Norwegian Sea**: Tordis (Separation, Boosting, WI), Troll C. Pilot (Separation, WI), Tyrhans (W), Draugen (Boosting), Draugen - Expansion (Boosting), Aassgard (Compression), Gulflaks (Compression), DEMO 2000 (Compression), Ormen Lange (Compression), Troll (Compression)

**GOM**: Pardido (Separation, Boosting), Navajo (Boosting), King (Boosting), Cascade & Chinook (Boosting), Jack and St. Malo (Boosting), Julia (Boosting), Stones (Boosting)

**Western Australia**: Mutineer/Exeter (Boosting), Vincent (Boosting)

**Equatorial Guinea**: Topacio (Boosting), Calba FFD (Boosting), Calba C3+C4 (Boosting)

**South China Sea**: Lufeng (Boosting)

**Norway**: Tordis (Separation, Boosting, WI), Troll C. Pilot (Separation, WI), Tyrhans (W), Draugen (Boosting), Draugen - Expansion (Boosting), Aassgard (Compression), Gulflaks (Compression), DEMO 2000 (Compression), Ormen Lange (Compression), Troll (Compression)

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**Congo**: Azurite (Boosting), Meha Phase 1 BIS (Boosting)
The Subsea Challenges

Long Distances
step-out from a few up to above 100 miles

Deep Waters
down to 10 000 ft
external pressures above 4000 psi

Environmental
Generally zero-tolerance for emissions

Complex Reservoirs
High pressures, up to > 15 000 psi
High temperatures, up to > 350 °F
Deep wells, Heavy oil
Corrosive fluids, Solids, Low permeability
Challenges of going subsea with rotating machinery…

- Reliability is key!
  - Cost of intervention is very high
  - Cost of lost production may be even higher
  - Reliability challenges
    - Target of 5 years or more between interventions
    - Design life 20 – 30 years
    - Demanding process fluids -> corrosive, solids
    - High temperatures and pressures in process fluid
    - Control and monitoring; remote location and demanding environment
    - Range of operation
  - Maintainability
    - Only access by ROV (Remote Operated Vehicle). Divers are used in a few cases
    - Need to mobilize expensive surface vessel to inspect by ROV or replace failed units
  - Environmental
    - Risk of emissions of hydrocarbons (or other toxic fluids) to sea
    - Consequences may be catastrophic and unacceptable
    - Generally zero-tolerance for hydrocarbon emissions (even for very small volumes)
What – Pump Technologies for use subsea

- Centrifugal (Roto-dynamic) Pumps
  - Single phase
    - Radial impellers, multi-stage
  - Multiphase
    - Multi-stage, mixed flow impellers
    - Helico-axial
  - Hybrid
    - Multi-stage, combination impellers of different technologies
    - Medium gas tolerance

- Positive displacement
  - Twin-screw (Multiphase)

What – Pressure generation vs GVF - capabilities

![Graph showing pressure generation vs GVF for different boosters: LiquidBooster™, HybridBooster™, and MultiBooster™](image)

- **LiquidBooster™**
- **HybridBooster™**
- **MultiBooster™** 8-Stage

<table>
<thead>
<tr>
<th>Pump differential pressure [bar]</th>
</tr>
</thead>
<tbody>
<tr>
<td>350</td>
</tr>
<tr>
<td>300</td>
</tr>
<tr>
<td>250</td>
</tr>
<tr>
<td>200</td>
</tr>
<tr>
<td>150</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

![Graph showing GVF (%) at Pump Inlet](image)

- GVF [%] @ Pump Inlet
  - 0
  - 10
  - 20
  - 30
  - 40
  - 50
  - 60
  - 70
  - 80
  - 90
  - 100
What - Centrifugal multi-stage single phase pump

Parameter | Value
--- | ---
Operating speed | Typ. 2,000 - 4,000 rpm
Pressure generation | Up to 4,500 psi
Shaft power | Up to 5.5 MW
Capacity | Up to 60,000 bpd
GVF | 0 – up to 10%
Maximum pressure | 15,000 psi (shut-in, non-operating)
Design standard | API 610 (as far as relevant for subsea)

Figure shows Aker Solutions LiquidBooster™
Radial impellers only
Back-to-back design
What - Centrifugal multi-stage single phase pump
What - Centrifugal multi-stage hybrid pump

Figure shows Aker Solutions HybridBooster™

Radial flow impellers - Mixed flow impellers
Opposed impeller design
Capable of up to ca 50 % GVF
What - Centrifugal multi-stage multi-phase pump

Figure shows Aker Solutions MultiBooster™

Mixed flow impellers
Back-to-back design

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating speed</td>
<td>Typ. 3000 - 6000 rpm</td>
</tr>
<tr>
<td>Pressure generation</td>
<td>Up to 200 bar/ 2900 psi</td>
</tr>
<tr>
<td>Shaft power</td>
<td>Up to 5.5 MW</td>
</tr>
<tr>
<td>Capacity</td>
<td>Up to 220,000 bpd</td>
</tr>
<tr>
<td>GVF</td>
<td>0 – above 95%</td>
</tr>
<tr>
<td>Maximum pressure</td>
<td>15 000 psi (shut-in, non-operating)</td>
</tr>
<tr>
<td>Design standard</td>
<td>API 610 (as far as relevant for subsea)</td>
</tr>
</tbody>
</table>
What - Centrifugal multi-stage multi-phase pump

MULTIBOOSTER VIDEO
## What – Subsea Pump Motors

- **Typical design parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated speed</td>
<td>3000 - 6000 rpm (2-pole) 1800 rpm (4-pole)</td>
</tr>
<tr>
<td>Rated power</td>
<td>&lt; 0.5 - 6 MW</td>
</tr>
<tr>
<td>Rated voltage</td>
<td>3.3 kV or 6.6 kV</td>
</tr>
<tr>
<td>Operation</td>
<td>Variable speed (VSD topsides)</td>
</tr>
<tr>
<td>Design</td>
<td>Cartridge design, liquid filled</td>
</tr>
</tbody>
</table>

Example: 3 MW shaft power subsea pump motor

VSD = Variable Speed Drive
What – Subsea Pump Motors

- Subsea motors are generally of cartridge design
- For subsea pumping applications, both induction motors and permanent magnet motors are used
- Both form wound and fully insulated cable wound stators are used
- Typically twin-screw pumps use 4-pole motors while the faster rotating centrifugal pumps use 2-pole motors
- To provide lubrication, cooling and preventing ingress of process fluid, subsea pump motors are liquid filled
What – Subsea Pump Motors

- The hydraulic losses in a liquid filled motor are considerable in particular at high speeds
  - \( P_{\text{loss}} (\text{kW}) \sim \text{speed}^3 \)
  - \( P_{\text{loss}} (\text{kW}) \sim \varnothing_{\text{rotor}}^4 \)
  - In order to maintain efficiency this generally leads to long and slender subsea motors

- The liquid used inside the motors is called Barrier Fluid

- One or more mechanical shaft seals are used to separate the Barrier Fluid in the motor from the process fluid inside the pump

- In general two types of Barrier Fluid are used
  - For motors with form wound stator windings typically some oil with dielectric properties is used
  - For motors with fully insulated stator windings (cable wound) a water/glycol mix is used
### What – Subsea Pump Motors

**Example: High speed subsea motor**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Liquid filled (Water/Glycol) induction motor</td>
</tr>
<tr>
<td>Number of poles</td>
<td>2</td>
</tr>
<tr>
<td>Rated Voltage</td>
<td>6600 V</td>
</tr>
<tr>
<td>Rated Frequency</td>
<td>100 Hz</td>
</tr>
<tr>
<td>Rated Power</td>
<td>6000 kW</td>
</tr>
<tr>
<td>Rated Speed</td>
<td>6000 rpm</td>
</tr>
<tr>
<td>Stator technology</td>
<td>Cable wound</td>
</tr>
<tr>
<td>Maximum Pressure</td>
<td>15 000 psi (shut-in, motor at stand-still)</td>
</tr>
<tr>
<td>Temperature rating</td>
<td>Class H (180°C, IEC 60085)</td>
</tr>
</tbody>
</table>

**Diagram:**
- **Stator winding**
- **Stator**
- **Barrier fluid from cooler (cold)**
- **Barrier fluid to cooler (warm)**
- **Circulation pump**
- **Bearing Housing**
- **Tilt-pad radial bearing**
- **Rotor**
What – Pressure casings

- Pressure casings
  - Main barrier between sea water and process fluid
  - Typical design pressures from 5 kpsi to 15 kpsi

- Example: Design and qualification of High Pressure (HP) pump & motor casing
  - Design pressure 13 500 psi = 931 bar
  - Test pressure = 20 250 psi = 1396 bar
  - Internal diameter 30 inches
  - Wall thickness ca. 7 inches
  - Weight ca. 15 tonne/casing
What – Subsea Pressure Casings

- High pressure casing manufacturing/testing

Forging  Pre machining  Cladding
Welding  Final machining  Assembly for test
Inspection  Painting  Final assembly

Design pressure 13 500 psi = 931 bar
Test pressure = 20 250 psi = 1396 bar
API 6A, API 17D and EN13445 (1,5x)
What – Subsea Pump & Motor assembly

Motor cartridge → Motor pressure casing → Motor assembly → Pump & Motor Unit

Pump cartridge → Pump pressure casing → Pump assembly
What – Pump Module schematic (Single phase pump)
What – Pump Module

- The subsea pumps are generally integrated into a module.
- The module has interfaces which allow operation by a Remote Operated Vehicle (ROV) and for installation and retrieval.
- The figures show examples of main units and interfaces.
What – Pump Module
What – Barrier Fluid System

Objective

- Lubrication and cooling of motor
- To prevent ingress of process fluid into motor
- Maintain controlled pressure difference over mechanical shaft seals
- Re-supply of barrier fluid to motor due to leakage over mechanical seal and dumping by pressure regulating valve (PVR)
- Schematic below shows high-level principle of system

PVR= Pressure Volume Regulator
(Mechanical hydraulic pressure regulating valve)
How - Barrier Fluid System working principle (example)

- Event: Pressure is decreasing in pump
- Action: Barrier fluid in motor is dumped to pump

Requirement (typ.):
- \( P_{\text{motor}} = P_{\text{pump}} + 100 \, \text{psi} \)

\( P_{\text{umbilical}} >> P_{\text{motor}} \)

PVR = Pressure Volume Regulator
(Mechanical hydraulic pressure regulating valve)
How - Barrier Fluid System working principle (example)

- Event: Pressure is increasing in pump
- Action: Barrier fluid is supplied from umbilical to motor

**Requirement (typ.):**
- \( P_{\text{motor}} = P_{\text{pump}} + 100 \text{ psi} \)

\( P_{\text{umbilical}} \gg P_{\text{motor}} \)

**PVR=** Pressure Volume Regulator
(Mechanical hydraulic pressure regulating valve)
What – Pump station

- Pump station with main interfaces
What – Pump station modularisation

Pump Module

Transformer Module

Manifold Module

Base frame and suction anchor
Pump Station process flow

Example shows typical process flow diagram for a Multi Phase Pump system

- Generally centrifugal MPP’s require a Flow Conditioning Unit (FCU) upstream to buffer slugs and level out the variations in GVF before the pump
- There is also typically a re-circulation loop with a choke valve for (typ.) start-up and adjustment of operating point

FCU = Flow Conditioning Unit
GVF = Gas Volume Fraction
What – Subsea interfaces

Process connections

Example: Clamp connectors

- Mono or multi bore
- Horizontal or vertical assemblies
- Metal to metal seals
- ISO 13628-4/7 & ASME VIII div 2

Example: Clamp Connector Sizes

- 6in clamp – bore size 2” to 6”
- 12in clamp – bore size 6” to 12”
- 16in clamp – bore size 12” to 16”
- 22in clamp – bore size 16” to 22”
- 28in clamp – bore size 22” to 28”
What - Umbilical

- The subsea system is connected to the host facility through umbilical(s)
- This allows for the supply of:
  - Controls power
  - Communication
  - Chemicals
  - Hydraulics
  - High-voltage power for pumps/compressors (and other applications, e.g. heating of pipelines)
  - Barrier fluid to subsea motors
What – Pump Control and Condition Monitoring

Example architecture

- **TOPSIDE HOST**
  - DCS
  - PSD/ESD

- **SUBSEA**
  - VSD
  - BF HPU
  - HPU
  - EPU
  - **TUTA**

- **CMC**
  - CPM

- **ON-SHORE**

**COMMENTS/POWER**
**HV-POWER**
**PSD/ESD SIGNALS**
**HYD/BARRIER FLUID**

**ABBREVIATIONS**
- **BF** BARRIER FLUID
- **CMM** CONDITION MONITORING MODULE
- **CPM** CONDITION & PERFORMANCE MON.
- **DCS** DISTRIBUTED CONTROL SYSTEM
- **EPU** ELECTRICAL POWER UNIT
- **ESD** EMERGENCY SHUT DOWN
- **HPU** HYDRAULIC POWER UNIT
- **MCS** MASTER CONTROL STATION
- **PM** PUMP MODULE
- **PSD** PROCESS SHUT DOWN
- **SCM** SUBSEA CONTROL MODULE
- **TUTA** TOPSIDES UTA
- **UTA** UMBILICAL TERMINATION ASSEMBLY
- **VSD** VARIABLE SPEED DRIVE

**FROM WELL(S)**

**PUMP STATION**

**TO HOST**
Control System - Topside Equipment

Subsea Production System Control

Electrical Power Unit (EPU)  Master Control Station (MCS)  Hydraulic Power Unit (HPU)

Pump System Control addition

Barrier Fluid HPU (BF HPU)
Control System Subsea Equipment

Subsea Control Modules (SCM)

Subsea Distribution Unit (SDU)

SCM Mounting Base
What - Low speed sensors subsea (typ. 1 Hz bandwidth)

- Pressure & Temperature
  - In process fluid
  - In barrier fluid
  - In MEG/MeOh

- Single phase flow meter
  - V-cone or Venturi

- Multi phase flow meter
  - Cross-correlation of several inputs
  - Venturi, electrical impedance & gamma ray
  - Multi-variable output

- Earth fault

- Line Voltage & Current
  - Average values (RMS)

- Motor stator winding temperature

- Leak detectors
  - Acoustic
  - Capacitive

MEG = Ethylene Glycol
MeOh = Methanol
What - High-speed sensors: Accelerometers

Technology:

• Accelerometers are located outside the pressure casings
• Aker Solutions was first to include accelerometers on subsea pumps and motors in 2005.

Location typical:
Motor NDE bearing: 1 axis, radial
Motor DE bearing: 1 axis, radial
Pump DE bearing: 2 axis, radial + axial
Pump NDE bearing: 1 axis, radial
What – Subsea interfaces

- Wet-mate connections for control system
  - Control system power (typ. < 1kV)
  - Communications
    - Electrical
    - Optical
  - Hydraulic couplers
Subsea Interconnection Flying Leads (Jumpers)

Hydraulic Flying Lead – showing ROV stab-plates (MQC plates)

Electrical Flying Lead – showing ROV connectors

Stabplate

MQC = Multiple Quick Connect
Multiplexed Electro/Hydraulic Control

MCS – Master Control Station
EPU – Electrical Power Unit
HPU – Hydraulic Power unit
SCM – Subsea Control Module
SEM – Subsea Electronics Module
XMT – Xmas Tree
PT – Pressure Transmitter
TT – Temperature Transmitter
What – Subsea Power long step-out systems

Type 1 (Lyell, King)
- Topside VSDs

Type 2 (Tyrihans, Åsgard)
- Topside VSDs
- Subsea transformers

Type 3 (Ormen Lange Pilot)
- Subsea VSDs
- Subsea Switchgear

Type 4 (RotoConverter)
- Low Frequency AC
- 4a - Subsea VSDs
- 4b - Topside VSD, RC
- 4c - Variable RC, VRC

HVDC – not covered
- No connectors
- No switchgear
- Large / heavy
- N/A next 5-10 years
What – Subsea Power systems

Power System Type 1

Supply: 4160V / 60Hz

Topside

Subsea

24km

28km

VSD

2.5MVA

8kV

M

P

Qualified for 2000m & 3000m

BP King MultiBooster™

BP King MultiBooster

- 2x 1MW - 6.6kV
- 2x 2.5MVA VSDs
- 24km & 28km
- 1600m and 1700m

VSD

Container

Onboard

Marlin TLP

Marlin TLP

D3/D5 Pump Station

D6 Pump Station

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What – Subsea Power systems

Power System Type 2

Asgard Subsea Compression

Supply: 11kV / 50Hz

Simplified SLD

Topside

18MVA 6.6kV

VSD

33kV

Subsea

1.2MVA 3.3kV

VSD

1.3MVA

VSD

300m w.d.

19MVA

M

M

M

M

300m

1.5MW

43.5km

43.5km

Compressor 6.6kV 11.5MW

Pump 6.6kV 750kW

Qualified for 300m & 3000m

VSD Building 40MVA total power

Subsea Compression Station

Compressor Trafo

Pump & CPDU Trafo

CPDU (control power distribution unit)

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What – Subsea Power systems

Power System Type 3

Supply: 132kV / 50Hz

Simplified SLD

Topside Subsea

30MW / 22kV Circuit Breaker Module
16MVA Compressor VSD Module

Qualified for 1000m

160kVA UPS Modules A & B

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What – Subsea Power systems

Power System Type 4

RotoConverter™ & Low Frequency

Patented RotoConverter™

- Electromechanical “gearless gear”
  - 10-50Hz transmission
  - 50-200Hz motors
- More MW longer step-out
- Works as harmonic filter
- Low weight/size
- Pressure compensated
- Robust due to low mech. speed
- Low frequency reduces cable ageing
What – Subsea interfaces

- Wet-mate connections for Power Systems
  - Allows connection of High-Voltage power by use of ROV at depths down to 3000 m (10 000 ft)
  - Smaller connectors can be 3-phase
  - Larger connectors are 1-phase
  - Capacities:
    - Current: typ. from 100 A up to 1600 A
    - Voltage: typ. from 2 kV up to 30 kV
What – Subsea Transformer (example)

Subsea Transformer Design and Monitoring

- Liquid-filled & pressure compensated
  - Basically similar as topside, except pressure
  - Pressure compensators fro each chamber
- Single / double barriers from core to seawater
- HV/LV terminations:
  - Bushings between inner chamber and outer chamber
  - Penetrators / seawater bushings to sea
  - No differential pressure
- Monitoring:
  - Earth fault
  - Currents / voltages
  - Water in oil content
  - Temperature

Diagram details include:
- Transformer Oil
- Pressure Compensating Bellow
- Boot Seal
- Internal cabling
- Transformer Winding
- Primary Side
- Secondary Side
- Insulation monitoring
- Oil & Winding Temp.
- 3x Current & Voltage Transformers
- Termination chamber
- To Controls
- To compressor motor

Diagram credit: Aker Solutions
What – Work Class ROV

How is a ROV equipped?

- Hydraulic or electrically driven thrusters (usually 4 to 8)
- Surveillance equipment:
  - Sonar
  - Transponder/Responder
  - Dimmable lights
  - Video cameras (fixed and pan and tilt)
  - Gyro
  - Compass
  - Altimeter
  - Optional pipe /cable trackers
  - Two manipulators (5 and 7 function)
  - Additional hydraulic circuits for tooling
  - Additional communication paths for tooling specific instrumentation or control
What – Work ROV tooling and interfaces

- Examples:
  - Cleaning tools
  - Override tools
  - Torque tools (hydraulic)
  - Hot Stabs
Åsgard Subsea Compression

Topside Equipment

Riserbase Transformer Station

Subsea Compression Station

Subsea Compression Manifold Station
What – Subsea Gas Compressors

- Proven pipeline compressor that are adapted to subsea application (“marinzed”) and subjected to extensive qualification testing
- Large field gas compressors require an upstream scrubber to remove liquid (condensate) from gas
- Main components (typ.) (for large field gas compression)
  - Compressor cartridge
  - Motor cartridge
  - Pressure casings
  - Active Magnetic Bearings (AMB)
  - Penetrators & wet-mate connectors (HV-power & controls)
  - Coolers (for some designs)
  - Auxiliary systems (washing/drainage, etc.)
- Typical compression ratio for is 2:1
  - (Åsgard and Ormen Lange application)
What – Subsea Gas Compressors

- Motors and bearings are cooled by process gas
  - By continuous bleed-off from compressor
    - Dried gas, circulated through motor/bearings and then returned to compressor inlet
  - By closed loop cooling
    - Dry gas circulating in closed loop with external cooler
    - Replenished by bleed-off from compressor
- Units are oil-free and uses active magnetic bearings

- Both vertical and horizontal configuration used

- Closed loop control subsea required
  - Active magnetic bearings
  - Anti-surge control

- Auxiliary systems for e.g. washing of internals
What - Subsea Compressors

Subsea Compressor Modules with Magnetic Bearings

Asgard Horizontal Machine

- Aker GasBooster™ Module
- Motor-Compressor:
  - MAN Diesel & Turbo
  - M43 Single-HOFIM
  - 11.5MW
  - 6.6kV

Ormen Pilot Vertical Machine

- Aker GasBooster™ Module
- Motor-Compressor:
  - GE Nuovo Pignone
  - Blue-C
  - 12.5MW
  - 6.6kV

Illustration: Courtesy of MAN D&T

MAN Diesel & Turbo
What – Subsea Compression

Process Flow Diagram
What – Subsea Compression

Compressor Module

Separator Module

Inlet & Antisurge Cooler

Train SCM
What – Compact Subsea Compression

- Further development to: Reduce system investment and operation cost while increasing reliability, availability and maintainability (RAM)

- Investment
  - Reduced size/ weight (>50%)
  - No pump VSD or Barrier fluid HPU
  - No barrier fluid tubing
  - Reduced cable cost due to Low frequency/ high voltage transmission
  - 30-40% cost reduction for a dual train system

- Operation
  - Reduced module retrieval weight

- RAM
  - Simplified system functionality
  - No booster pump → no level control, no barrier fluid control
Subsea Industry Trends

- Larger units (higher capacities and pressures)
- Subsea power distribution
- Simpler units / standardisation
- Subsea factory
- Longer step-outs – >100 miles
  - Enabling Arctic & subsea to beach developments
- Barrier fluid less systems
- Dual boost
  - Multiple in-well pumps + seabed pump
- Low salinity & low sulphur sea water treatment
- Ultra high pressure water injection with sea water treatment
- Condition monitoring
- All-electric actuators
Trends - Subsea Factory

Subsea animation
Drivers of future field developments

Deeper waters, complex reservoirs, harsh fluids

Longer subsea step-outs (distance from well to process facility)

Drive for increased oil recovery from existing fields

Reduce costs to drive marginal developments
REFERENCE INFORMATION & ACKNOWLEDGEMENTS

- Selected relevant papers
  - OTC 20078-PP Tyrihans Raw Seawater Injection
  - OTC-21516-PP Development and Testing of a Hybrid Boosting Pump
  - OTC 20030 Ormen Lange Subsea Compression Pilot – Subsea Compression Station
  - OTC 20146 BP King – Deep Multiphase Boosting made Possible
  - OTC 16447 An Efficient Wellstream Booster Solution for Deep and Ultra Deep Water Oil Fields

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- Subsea animation
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INTRODUCTION TO SUBSEA

MICHAEL MANCUSO

OneSubsea
A Cameron & Schlumberger Company
Michael Mancuso – Director of Technology, OneSubsea

Michael Mancuso is currently the Director of Technology for OneSubsea. He leads the global R&D activities. Prior to his current role and formation of OneSubsea, Michael served 13 years with Cameron in several positions including Senior Engineer for several subsea projects, Director of Marketing, management in finance (mergers and acquisitions) and product management in both corporate and the Valves & Measurement division. He holds a Bachelor of Science in Mechanical Engineering from the University of Notre Dame and a MBA from the C. T. Bauer School of Business at the University of Houston.
Agenda

- Defining Subsea
- History
- Importance of Deepwater Growth
- Mega Project Execution Model
- Subsea System Architecture
- Remote Operations
- Controlling the Infrastructure
- Quality and Materials Requirements
- Rotating Machinery Trends
OneSubsea Creation

Schlumberger
Leading oilfield services company

Leading provider of subsea production systems

CAMERON

Leading provider of subsea measurement, boosting and process systems

OneSubsea
A Cameron & Schlumberger Company

FRAMO ENGINEERING
A Schlumberger Company
OneSubsea Technologies and Services Offering

**Integrated Solutions**
- Field Development Planning
- Petrotechnical Services
- Production Assurance Consulting
- Early Engineering Engagement
- One-System Approach

**Production Systems**
- Trees
- Manifolds
- Connection Systems
- Wellheads

**Processing Systems**
- Multiphase Pumps
- Single-Phase Pumps
- Multiphase Compressors
- Multiphase Meters and Wet Gas Meters
- Sampling
- Separation

**Control Systems**
- Tree and Manifold Controls
- Multiphase Pump Controls
- Multiphase Flow Controls
- Topside and FPSO Controls
- Diamould Electric Connectors

**Swivel and Marine Systems**
- Swivel Stacks
- Turrets
- Submerged Loading Systems
- Offshore Cryogenic Transfer

**Services**
- Installation and Commissioning
- Life of Field
- Asset Management
What We Do

Not this.
An Integrated Approach from Reservoir to Surface
An Integrated Approach from Reservoir to Surface
An Integrated Approach from Reservoir to Surface
What is Subsea?

**Deep Sea Monsters**

Conventional drilling platforms, which rest on a solid concrete foundation or on a steel frame, as well as the mobile jack-up platforms, can only be used at moderate depths. In order to explore deep sea depths, special oil production ships as well as a variety of floating drilling and production platforms need to be used. These days, technologies exist that can drill beneath the ocean floor at a depth of more than 3,000 meters.
Example Quad 204

- https://www.youtube.com/watch?v=-wB-xljII Ms
Subsea Production System Overview

OneSubsea History

Paving the way in subsea innovation

OneSubsea Milestones

1960s
1970s
1980s
1990s
2000s
2010s

1962
OneSubsea designs and builds the first ever subsea tree

1979
OneSubsea installs first electro-hydraulic multiplex (E-H-MUX) production control system

1983
OneSubsea develops first 15,000 psi WP subsea wellhead

1991
OneSubsea introduces the STM-15 marine wellhead

2001
OneSubsea installs world's first 15,000 WP subsea tree and production manifold

2008
OneSubsea's MARS receives Hart's E&P Meritorious Award for Engineering Innovation

2009
DC System, the world's first all-electric (DC) subsea production tree, comes online
Development Overview
Components of a Subsea Production System

This diagram shows a typical drill center (an arrangement of wells that can be accessed from one mooring pattern). Please note the following:
Field Architecture Options

- Satellite
- Cluster
- Daisy Chain
- Template
Subsea Production System Overview
Tree Examples
What’s Inside of There?
Manifold Examples
Pump Stations
System Integration Testing (SIT)
How Big Is This Equipment?

- Trees: 40-90 tons
- Manifolds: 100-500 tons
- Jumpers: 50-200 feet
- Umbilicals and Flowlines: Up to 100 km
How Do These Get Installed Offshore?

- Installation videos
- Vertical monobore tree installation video
• ROVs, accessibility studies
What Are The Conditions Down There?

- 1-4 deg C
- 10,000 ft = <5000 psi
- Dark
- Can be muddy
- Seaflife
- Geohazards – Mudslides, slope, gas domes

- Video of subsea life next to subsea tree
  https://www.youtube.com/watch?v=Lt4fPT7Xdok
Typical Jumper Loading Cases that may be Considered

- Metrology/Fabrication error
- Vortex Induced Vibration
- Fatigue Life
- Temperature
- Bending limits of connectors
- Torsion limits of connectors
- Forces from pipeline growth
- Manifold settling in soil
- Wellhead thermal growth
- Self weight
- Insulation mechanics
- Buoyancy added
- Thermal cooldown times
- Installation dynamic loads
- Internal pressure
- External pressure
- Test pressure on land
Typical Subsea Project Timeline (PSVM)

- 2002-2004: Discoveries in Deepwater Angola
- 2005: Field Development Planning
- 2006-2007: FEED
- 2008: Award of Subsea EPC Contract to OneSubsea
- 2008-2010: Engineering and Procurement
- 2009-2012: Installation of Equipment and Facilities
- 2013: First Oil
Wells Taking Longer to Complete

Rig Efficiency [Days/Well]

- Exploration
- Development
- Average

Rystad Energy 2014
Cost per day in deepwater rising

Chart 1: Historical dayrates for Ultra-deepwater rigs

Source: Saxo Bank and Seadrill, Energy-Power Conference presentation
Forces Facing Operators (Our Customers)

E&P capex per barrel

$0 $5 $10 $15 $20 $25


0.9% CAGR (1985-1999)

10.9% CAGR (1999-2013)

Source: IEA, Barclays Research
Pre-Salt Challenging Scenario

- Pre-Salt – a New Scenario
  - Ultra-Deepwater Conditions
    - Risers
    - Flow assurance
  - Logistics
    - 300 km from shore
    - Lack of infrastructure
  - Fluids with Contaminants
Defining the Subsea Factory

Statoil’s Subsea Factory Menu
Potential subsea factory developments
Major Play – Lower Tertiary

- High Shut-In Pressures (>15K)
- Low Permeability
- Long Tiebacks
- Long-Term Dedication to Developing GoM (Many Long-Term Contracted Floaters)
Overall Longstanding Themes

- AVAILABILITY….. (Including Reliability)
- More Than 25 years of Life
- Maximize Recovery
- Environmental
- Tooling and Life-of-Field Support Teams
- Redevelopment of Maturing Fields
- Intervention Costs are HIGH
- Size and Complexity Increases
The Future
Separation? Reinjection? Storage?
Compression Technology

**Developed in Phases**

- Build the Offering
- Become a Leader in Integration
- Create the “Subsea Factory”
- 5MW and Above
- Ability to Handle Wet Gas