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Remote Condition monitoring of subsea equipment
Norway is close to some very strategic areas.....

......This has made us very good listeners

A submarine can detect, identify and locate the coordinates of a hostile vessel very far away

But it can also be detected and identified from very far away itself
Technology Transfer
• Production of oil and gas is being moved from sea top to sea floor

• The development of subsea oil and gas fields requires specialized equipment

• Any requirement to repair or intervene with installed subsea equipment is normally very expensive

• Traditional Preventive scheduled shutdown is a poor solution

• Predictive Condition-based shutdown is preferred but currently not possible

• Combine acoustic and electric fieldsensors to give ears and eyes to the operator
Condition monitoring criteria

1. Sensor’s non-invasivity
2. Sensor and instrumentation’s system reliability
3. Diagnosis reliability
4. Fault severity quantification
5. Remaining life-time estimation
6. Cause of the fault prediction
Traditional condition monitoring

- Accelerometers mounted inside or on equipment to measure acceleration, velocity and displacement
- Proximity Probes mounted inside equipment to measure displacement or distance
- Tachometers mounted inside equipment to measure rotational speed
- Motor current sensors enclosing phase-lines to measure current flowing into and out of the engine
- Search coils mounted inside and on equipment to measure electromagnetic fluxes

WHAT DO THEY HAVE IN COMMON?
They are all hooked on!
Electromagnetic emission:

Galvanic contact between Electromotive force and seawater cause electric currents in the water.

The UEP sensors measure $U=RI$ (Ohms lov)

Properties of salt water:

- $ho \sim 0.25\ \Omega\text{m}$
- $\lambda(50\text{Hz}) \sim 220\ \text{m}$
The electric environment surrounding a subsea installation will be characterized by emission from all electric components.

Even at healthy conditions the signal level is considerable.

Recognition of faults require experience with the machinery and prescience of machine parameters.

Additional feature: Connector breakdown detection.

\[
\overline{E} = i\omega\mu_0 \overline{A} + \frac{\nabla(\nabla \cdot \overline{A})}{\sigma}
\]
• Vibrations in machinery and structures propagates at approx. 1500 m/s in seawater

• Hydrophone arrays placed at specified locations are used to detect these vibrations

• High level of noise means signal conditioning is necessary

• Beamforming algorithms used to spatially separate different vibration sources

• Frequency domain analysis performed to estimate system condition
Fault types

• Bearings (41%)
  - Relationship between vibrational and electric frequencies (Schoen et al.):
    \[ f_{bng} = f_s \pm f_b \]

• Stator related faults (37%)
  - Winding insulation failure result in a rise in some frequency components (Penman)

• Rotor related faults (10%)
  - Broken rotor bar detection, sidebands at \( f_s (1 \pm 2ks) \) (Thomson)
  - Additional spectral components related to rotor-cage faults (Delroi):
    \[ f_s \left[ \left( \frac{k}{p} \right)(1 - s) \pm s \right] \]

• Other fault types (12%)
Connector breakdown

Ground fault, connector leak
Cross-section of 3-phase TML embedded in seawater
Cross-section of screened 3-phase TML embedded in seawater
3D Representation
Simulations
The AECM module
The AECM module

Ø 1m
H 1.7 m
Vekt 230 kg
Titan gr 2
Field measurements

Raw data

Electric potential vs time
Field measurements

Raw data analysis

Electric Amplitude vs Frequency

PSD

WiP
MPP
WiP 2.harm
WiP 3.harm
Field measurements

Startup of the Tordis Multiphase Pump
Raw data analysis

Frequency analysis (zoom), Water Injection Pump

- Slip ratio

\[
\text{Speed} = 39.59\text{[Hz]} \cdot 60[\text{sec/Hz}] = 2375\text{RPM}
\]

\[
SLIP = \frac{39.71 - 39.59}{39.71} \cdot 100\% = 0.3\%
\]
Ball valve operation
User interface under development
Provides information on the rotational condition of machinery, pumps, compressors through measurements of:

- RPM
- Slip
- Harmonic Frequencies
- Transient behavior
Provides detection of leakages in high pressure flanges, valves and weldseams
Provides information on operation of valves and chokes.
Provides information on structural integrity through vibration and stress monitoring.

WELLHEAD, HIGH PRESSURE PIPING

VALVES

STRUCTURAL INTEGRITY

WATER INJECTION PUMP
The AECM features:

- Multifunction and remote condition monitoring.
- Spatial and directional resolution.
- A combination of audible feedback and advanced analysis and processing.

The AECM concept provides simultaneous monitoring of multiple sub-systems:

- Rotational machinery, pumps, compressors
- Valve-operations,
- Pipe-line leakages,
- Structural integrity and vibrations
Thank you for your attention 😊