**TAEK Ankara**

**Pump Training for Inspectors**

**Agenda for a 3-day training course**

**Day 1**
Introduction / Basics / Preparation
Location: TAEK-Office
Morning: Basics of centrifugal pumps
Afternoon: Briefing for pump acceptance test according to ISO 9906

**Day 2**
Practical pump acceptance test
Location: LayneBowler Pump Company Inc. in Ankara
Test of a pump on LayneBowler’s test rig
Inspection report

**Day 3**
Debriefing / Discussion / Questions / Conclusions
Location: TAEK-Office
Hydraulic Performance Acceptance Tests according to ISO 9906:2012

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Hydraulic Performance Acceptance Tests according to ISO 9906:2012

- international standard for hydraulic performance acceptance tests for:
  - CP:
    - Radial flow pumps
    - Mixed flow pumps
    - Axial pumps
- for CP of any size
- For tests at the manufacturer’s pump test facility or in laboratories
- not for field tests in a production plant
- three levels of acceptance (quality grades) are defined for:
  - flow
  - head
  - power
  - efficiency rate
  - special rules are defined for small pumps with \( P \leq 10 \) kW
Hydraulic Performance Acceptance Tests according to ISO 9906:2012

Table of contents of ISO 9906

- Declaration of all terms, symbols and definitions
- Pump measurements and acceptance criteria
- Guarantees
- Measurement uncertainty
- Performance test acceptance grades and tolerances
- Default test acceptance grades
- Test arrangement
- Test procedure
- Test conditions
- NPSH-tests
- Testing equipment
- Records and report
- Analysis of measurement results
- Diverse appendices (normative and informative)
Remark:
Three principles for suction pressure reduction are generally available (NPSH-measurement):

a) Pressure reduction by lowering the water level in the tank
b) Reducing the air pressure by using the vacuum pump (connection „a“)
c) Throttling by using valve no. 6

If possible, principle a) or b) should be preferred because measurement accuracy is higher. Generally, principle c) results in higher (worse) \( NPSH_R \)-values.

If principle c) has to be applied, the straight suction pipe length in front of the suction nozzle should be at least 12 x D) or a flow straightening device should be used.

Which valve is necessary to shift the operating point \( (Q;H) \)?
Arrangement of pressure measurement devices (for grade 1)

Remark:
The pressure losses between \( p_{M1} \) and the suction nozzle and accordingly between the discharge nozzle and \( p_{M2} \) can generally be neglected.

If – in special cases – it has to be considered, the ISO 9906 gives rules for the calculation, see appendix (A.4.9).
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Example of a test-bench setup in a University’s laboratory
Other possible test-bench setups with open circuits for vertical pumps without suction line/pipe

1. Pressure reading \( p_{M1} \)
2. Pressure reading \( p_{M2} \)
3. Reference plane
4. NPSH datum plane
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**Guarantee point**

A guarantee point is defined by a flow rate $Q_G$ and a total head $H_G$.

Other features can be included if agreed by both parties (vendor and customer) like:
- efficiency factor $\eta$ for the pump or for the complete pump unit (pump plus motor)
- $NPSH_R$ at guarantee point

Other technical features can also be measured and verified during the acceptance test if defined by contractual agreement:
- Static head (zero flow head)
- Vibrations at bearing housing
- Noise emission
- Remaining axial thrust
- …
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What does a pump do?

Three things (but not always):

- Pressure increase
- Increase of flow velocity
- Lifting up the fluid

between section an discharge nozzle

The sum of these three parts is the pump’s total head

\[
H = \frac{p_D - p_S + \frac{v_D^2 - v_S^2}{2} + (z_D - z_S)}{\rho \times g} 
\]

- \( p_D \) = pressure at discharge side
- \( p_S \) = pressure at suction side
- \( v_D \) = flow velocity at discharge side
- \( v_S \) = flow velocity at suction side
- \( \rho \) = density of fluid
- \( g \) = acceleration of gravity
- \( z_D \) = vertical position of discharge side
- \( z_S \) = vertical position of suction side
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Physical definition of hydraulic pump power

\[ P_{hy} = \rho x g x H x Q \]

Pump power at coupling

\[ P_K = \frac{\rho x g x H x Q}{\eta} \]

Efficiency factor

\[ \eta = \frac{\rho x g x H x Q}{P_C} \]

Principally identical equations
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Suction capability - NPSH<sub>A</sub>

\[
\text{NPSH}_A = \frac{p_{SS,\text{abs}} - p_V + \frac{v^2_S}{2}}{\rho \times g} = \frac{p_b + p_{SS} - p_V + \frac{v^2_S}{2}}{\rho \times g}
\] [m]

- \(p_{SS,\text{abs}}\) = absolut static pressure at suction side
- \(p_{SS}\) = relative static pressure (gauge pressure or overpressure) at suction side
- \(p_V\) = vapor pressure of fluid depending on fluid temperature
- \(p_b\) = atmospheric pressure
- \(v_S\) = flow velocity at suction side
- \(\rho\) = density of fluid
- \(g\) = acceleration of gravity
Generally, only one guarantee point \( (Q_G/H_G) \) at a guarantee speed is in the focus (if not otherwise agreed between vendor and buyer).

This guarantee point \( (Q/H) \) is in the center of the guarantee-cross defined by the tolerances:

### Table 8 — Pump test acceptance grades and corresponding tolerance

<table>
<thead>
<tr>
<th>Grade</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Guarantee requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta \tau_Q )</td>
<td>10 %</td>
<td>16 %</td>
<td>18 %</td>
<td></td>
</tr>
<tr>
<td>( \Delta \eta_H )</td>
<td>6 %</td>
<td>10 %</td>
<td>14 %</td>
<td></td>
</tr>
<tr>
<td>Acceptance grade</td>
<td>1U</td>
<td>1E</td>
<td>1B</td>
<td>2B</td>
</tr>
<tr>
<td>( \tau_Q )</td>
<td>+10 %</td>
<td>±5 %</td>
<td>±8 %</td>
<td>+16 %</td>
</tr>
<tr>
<td>( \tau_H )</td>
<td>+6 %</td>
<td>±3 %</td>
<td>±5 %</td>
<td>+10 %</td>
</tr>
<tr>
<td>( \tau_P )</td>
<td>+10 %</td>
<td>+4 %</td>
<td>+8 %</td>
<td>+16 %</td>
</tr>
<tr>
<td>( \tau_\eta )</td>
<td>≥0 %</td>
<td>-3 %</td>
<td>-5 %</td>
<td></td>
</tr>
</tbody>
</table>

**NOTE** \( \tau(x = Q, H, P, \eta) \) stands for the tolerance of the indicated quantity.

Tolerances for NPSH\(_R\):
- Positive NPSH\(_R\)-tolerances do not exist
- Negative deviations from NPSH\(_R\)-guarantee value are always allowed (unlimited)
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Procedure:
1. Set guarantee point
2. Set tolerance cross
3. Measure the Q-H-curve
4. Check, if the Q-H-curve touches the tolerance cross at least once. If yes, guarantee for Q-H is fulfilled, if not, guarantee is not fulfilled
5. Connect guarantee point with point (0/0)
6. Generate point of intersection between straight line and Q-H-curve
7. Drop a perpendicular line to the Q-η-curve
8. Check, if point of intersection is within guarantee range for η
9. Check the power-curve in the same way
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Figure 3 — Bi-lateral tolerance acceptance

Key
X rate of flow, Q
Y head, H

- curve 1: crosses the head tolerance, P = pass
- curve 2: crosses the flow tolerance, P = pass
- curve 3: crosses both the head and flow tolerance, P = pass
- curve 4: does not cross any tolerance, F = fail
- curve 5: does not cross any tolerance, F = fail
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Uni-lateral tolerance acceptance

Key:
- X: rate of flow, Q
- Y: head, H
- Curve 1: crosses the head tolerance, P = pass
- Curve 2: crosses the flow tolerance, P = pass
- Curve 3: crosses both the head and flow tolerance, P = pass
- Curve 4: does not cross any tolerance, F = fail
- Curve 5: does not cross any tolerance, F = fail
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If no tolerances (acceptance grade) are defined, the following default acceptance grades should be applied:

### Default acceptance grades

<table>
<thead>
<tr>
<th>Application</th>
<th>Shaft power of pump, $P_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&gt;10 kW and ≤100 kW</td>
</tr>
<tr>
<td>Municipal water applications</td>
<td>2B</td>
</tr>
<tr>
<td>Municipal wastewater applications</td>
<td>2B</td>
</tr>
<tr>
<td>Drainage pumps</td>
<td>3B</td>
</tr>
<tr>
<td><strong>Electrical power industry</strong></td>
<td>1B</td>
</tr>
<tr>
<td>Oil and gas industry</td>
<td></td>
</tr>
<tr>
<td>Pumps in accordance with ISO 13709</td>
<td>1B</td>
</tr>
<tr>
<td>Water Injection</td>
<td>N/A$^a$</td>
</tr>
<tr>
<td>Marine application</td>
<td>1B</td>
</tr>
<tr>
<td>Chemical industry</td>
<td>2B</td>
</tr>
<tr>
<td>Cooling tower applications</td>
<td>2B</td>
</tr>
<tr>
<td>Pulp and paper applications</td>
<td>2B</td>
</tr>
<tr>
<td>Slurry applications</td>
<td>3B</td>
</tr>
<tr>
<td>General industry applications</td>
<td>3B</td>
</tr>
<tr>
<td>Irrigation applications</td>
<td>3B</td>
</tr>
</tbody>
</table>

$^a$ N/A = not applicable.
**Tolerances for pumps with an input power of 10 kW and below**

If not otherwise agreed upon between the manufacturer and purchaser, the tolerance factors shall be the following:

- rate of flow $\tau_Q = \pm 10\%$
- pump total head $\tau_H = \pm 8\%$

The tolerance factor on efficiency, $\tau_\eta$, if guaranteed, shall be calculated

$$\tau_\eta = -\left[10 \left(1 - \frac{P_2}{10}\right) + 7\right] \%$$

where the pump power input, $P_2$, tallies with the maximum shaft power (input), $P_{2,\text{max}}$, in kilowatts, over the range of operation. A tolerance factor, $\tau_{P,\text{gr}}$, is allowed using Formula

$$\tau_{P,\text{gr}} = \sqrt{(7)^2 + \tau_\eta^2} \%$$
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The tolerances should not be mixed with permissible amplitude of fluctuation of measured values:

Permissible amplitude of fluctuation as a percentage of mean value of quantity being measured

<table>
<thead>
<tr>
<th>Measured quantity</th>
<th>Permissible amplitude of fluctuations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grade 1</td>
</tr>
<tr>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Rate of flow</td>
<td>±2</td>
</tr>
<tr>
<td>Differential head</td>
<td>±3</td>
</tr>
<tr>
<td>Outlet head</td>
<td>±2</td>
</tr>
<tr>
<td>Inlet head</td>
<td>±2</td>
</tr>
<tr>
<td>Input power</td>
<td>±2</td>
</tr>
<tr>
<td>Speed of rotation</td>
<td>±0,5</td>
</tr>
<tr>
<td>Torque</td>
<td>±2</td>
</tr>
<tr>
<td>Temperature</td>
<td>0,3 °C</td>
</tr>
</tbody>
</table>

Remark:
ISO 9906 defines much more specific parameters and requirements for the measurement's accuracy, but in practice that is not applied in most cases because the whole procedure is getting quite/too complicated.
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Pressure measurements for grade 1 and 2/3

For grades 2 or 3 the measurement nozzle on the discharge side should be aligned vertically to the impeller's rotational plane (purpose: Reduction of inaccurate pressure measurement).

For measurements in grade 2 or 3, the nozzle for the discharge pressure measurement should be in line with the pump shaft (parallel with the shaft).

Grade 1 — Four pressure tappings connected by a ring manifold
Grades 2 and 3 — One pressure tapping (or two in opposite position)

Key
1 vent
2 drain
3 connecting pipe to the pressure measuring instrument
If possible, pumps should be tested at guarantee conditions on the test-bench. That means, that

- Pump speed and
- Water temperature

should comply with the future application and the guarantee conditions.

But: ISO 9906 allows significant deviations for the performance test conditions:

- Head and Flow: Test speed from 50 % to 120 % of guarantee speed
- NPSH\textsubscript{R}: The speed from 80 % to 120 % of guarantee speed, provided that flow rate is between 50 % and 120 % of \( Q_{\text{BEP}} \)
- Pumps for hot water (for example 180°C, feed water pumps) are allowed to be tested with cold water

How to check the fulfillment of guarantee conditions/values?

=> By conversion of test conditions to guarantee conditions (by calculations)
Conversion/Translation of test results to guarantee conditions (deviating speed and/or deviating water temperature/density):

\[ Q_T = Q \frac{n_{sp}}{n} \]

\[ H_T = H \left( \frac{n_{sp}}{n} \right)^2 \]

\[ P_T = P \left( \frac{n_{sp}}{n} \right)^3 \cdot \frac{\rho_{sp}}{\rho} \]

\[ \eta_T = \eta \]

\[ (NPSHR)_T = (NPSHR) \left( \frac{n_{sp}}{n} \right)^x \]

Set \( x = 2 \) if not otherwise agreed between the two parties.

\( n_{sp} \) = specified speed (guarantee value)
\( Q / H / P / \eta \) = testing parameters (measured values)
Index T = true (at guarantee conditions)
Advantages of this procedure:

- Simple and unified test procedures
- Many operational (guarantee) conditions can not be tested on the manufacturer's test-bench setup (without excessive cost). Without ISO 9906’s regulations these pumps could not be tested at the pump manufacturer's test-bench setup.
- Comparability of test results from different test-benches
- Big pumps with high power input can be tested at the manufacturer because power requirement is significantly reduced and speed is reduced (speed reduction lowers the power demand by exponent 3)
- Test-benches can be used for many applications
- Water temperature is allowed to vary during a test as long as it is measured and influence to density is considered by calculations
Remarks to NPSH<sub>R</sub>-measurement

- If not otherwise agreed, the 3%-drop of head at constant flow rate is the criterion to determine NPSH<sub>R</sub>
- Other criterions (0% or 1%-drop of head, noise emission, vibrations) can be defined by agreement between the two parties
- For multistage pumps the 3%-drop of head refers to the 1. stage
- In the case of multi-stage pumps there should be a measurement nozzle between the 1<sup>st</sup> and the 2<sup>nd</sup> stage in order to measure with a sufficient accuracy
- Double suction pumps can be measured as single suction pumps
- NPSH<sub>R</sub>-measurements with cold water are generally conservative in comparison to hot water
- NPSH<sub>R</sub>-guarantee values have no positive tolerance
Remarks regarding the conversion/translation of test (measurement) results at deviating speed

- If a test is done with the test-bench motor, all deviations between test speed and guarantee speed have to be corrected by using the given formulas even if the deviations are small.
- If a complete pump unit (including the specified motor) is tested, a conversion of test results due to possibly deviating speed is not necessary.
- If a canned motor pump has been tested, a conversion of test results based on speed deviations is not necessary.
- If the test-bench’s water temperature deviates significantly from the guarantee conditions, a conversion of test results to the guarantee conditions (based on different densities) is required even if speed, voltage and frequency are correct. In this case only the power input is being influenced.
Test conditions and execution of tests/measurements:

- All measurements have to be done at constant operational conditions. Deviations of water temperature during the test (warming/cooling) are allowed as long as it is recorded and later considered by calculations.

- For all acceptance tests the complete Q-H-curve has to be measured with at least 5 measurement points distributed over the allowable flow range.

- In order to check the guarantee point \((Q_G/H_G)\):
  - one measurement point has to be in the range between 95% and 100% of \(Q_G\)
  - one measurement point has to be in the range between 100% and 105% of \(Q_G\)
  - one measurement point has to be near to the minimum flow rate \(Q_{min}\) (possibly zero flow head)
  - one measurement point has to be near to the max. allowable flow rate \(Q_{max}\)

- The pump to be tested on the test-bench setup should not be disintegrated from the test bench as long as the test results are not clear and possibly some measurements have to be repeated.

- For all measurement devices valid calibration certificates have to be available at the test bench and may be presented to the customer (3rd-party inspector) if required.

- A handover of copies of the calibration certificates is generally not required and not necessary.
Reporting of test results (see annex F of ISO 9906)

The following information should be included in the report (as applicable):

- test date;
- the tested equipment;
- test facility and location;
- the guaranteed data (flow, head, power or efficiency, as applicable);
- the guarantee given;
- ambient and water temperatures;
- barometric pressure;
- driver data;
- if witnessed, name and signature of all witnesses;
- if test point corrections are carried out, the correction method should be outlined;
- comments pertaining to anything noteworthy about the test.

- all relevant curves at guarantee conditions
- all raw datas
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For practical participation in Hydraulic Performance Acceptance Tests: Work with a check list (like the attached one)!

Checklist Acceptance Tests according to ISO 9906 07.08.18

1. General design of test rig
   1.1 General arrangement of components
   1.2 Calibration certificates
   1.3 Characteristics of test fluid
   1.4 Test conditions
   1.5 Test report
   1.6 Miscellaneous

1. General design of the test rig
   1.1 General arrangement of components
     • Is a drawing or a sketch available that shows/describes the test rig?
     • Is the straight length in front of the suction nozzle sufficiently long (min. 7 x ØDs if possible)?
     • Do pipe elbows in the suction line have internal guide plates?
     • In case of changing pipe sizes in the suction line in front of the suction nozzle: Is the cross section decreasing in the flow direction so that the flow will be accelerated? If yes, ok, in case of deceleration of flow velocity in front of the pump that’s adverse and should be avoided
     • Is the inflow to the suction pressure measurement and to the flow measurement undisturbed?
     • Is the distance between suction/discharge pressure gauge and the nozzles L = 2 x D?
     • Where is the flow measurement installed?
     • Where is the temperature measurement installed?
     • Can the gas content in the fluid be measured? (generally not required)
     • NPSHa-measurement: What is the principle to reduce the suction pressure? Evacuation/reduction of water level in the suction chamber/throttling?
     • What is the measurement class? Class 1, 2 or 3? Different pressure measurement arrangements have to be considered
     • Do the amplitudes of fluctuating measurement values exceed the given limits?
     • Is sufficient venting of the pipe system (of test rig) possible?
     • In case of having an open suction chamber: Is there a sufficient overlap between suction opening (pipe) and water level to avoid air vortices/swirls?
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Questions?