Moisture Condensation Effect on Turbine Performance Tests

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Moisture Condensation Effect on Turbine Performance Tests

- Ambient Humidity and Condensation
- Test Rig Model
- Test Case
  - Condensation Prediction
  - Measurements Correction
- Condensation Avoidance
- Conclusions
Moisture Condensation Effect on Turbine Performance Tests

Moisture fraction is a function of ambient pressure, temperature and relative humidity

**Ambient Humidity**

![Graph showing moisture fraction as a function of relative humidity for different temperatures and pressures.](image)
Humidity, Condensation and Temperature Rise

- Homogeneous and Heterogeneous Condensation
- Water droplets appear and two-phase flow with heat and mass transfer between water and the gas mixture occur.
- Release of the latent heat of vaporization produces a temperature rise of the gas mixture.
- Condensation is a thermodynamically irreversible process, resulting in loss of stagnation pressure.
Temperature Rise

Heating of dry air by the latent heat of vapour.

Vapour quantity corresponding to various ambient conditions

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**Turbine Efficiency Determination**

**Thermodynamic Method**

\[ n_{T, is} = \frac{T_{t1} - T_{t3}}{T_{t1} \cdot 1 - \left( \frac{p_{t3}}{p_{t1}} \right)^{\gamma - 1}} \]

- Temperature Measurement
- Pressure Measurement
- Gas Composition

**Mechanical Method**

\[ n_{T, is} = \frac{\tau \cdot N}{c_p \cdot n_{fT1} \cdot 1 - \left( \frac{p_{t3}}{p_{t1}} \right)^{\gamma - 1}} \]

- Flow Measurement
- Torque Measurement
- Shaft Speed Measurement
- Gas Composition

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Condensation during Expansion

Phase Diagram for Water

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Test Rig Model

Typical Measurements

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Test Rig Model

Objective

Evaluation of isentropic efficiency as if no condensation occurs

Steps

Prediction of condensation

Calculation of condensed water

Calculation of the exit conditions as if no condensation occurs
Test Rig Model

Calculation of Condensed Water

Assuming Equilibrium Saturation at Turbine Exit

Condensate Quantity Calculated based on Static Conditions

Conservation of enthalpy (total to static)

Conservation of entropy (total to static)

Conservation of mass
Test Rig Model

Calculation of “Dry” Exit Conditions

- Assuming Instant Condensation
- Calculation of Exit Conditions as if no Condensation had Occurred
  - Conservation of Energy
  - Conservation of Momentum
  - Conservation of Mass
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Test Facility

Typical Test Rig with two additional measurements at duct exit (RH, Tt)
Raw measurements

Deviations of measured efficiency from no condensation speedline

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Test Case

Variation of Measured Temperature and Relative Humidity at duct exit

Operating point variation during test

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Condensation Prediction

Correlation of erroneous efficiency calculations with condensation

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Condensation Prediction

Correlation of erroneous efficiency calculations with condensation

“dry” speedline
Condensation Prediction

Correlation of measured Relative Humidity with Condensation

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Measurements Correction

Calculated Isentropic Efficiency corrected for Condensation

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**Measurements Correction**

Calculated Isentropic Efficiency corrected for Condensation

F Speedline 2
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Condensation Avoidance

Test case used isolines

Minimum Temperature at Expansion Start

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Conclusions

- Condensation in cold flow turbine testing alters significant the measurements
- Condensation regions may be predicted accurately without additional measurements
- The efficiency corrected for condensation is consistent with the efficiency calculated from dry measurements
- The implementation of the method is possible to assure condensation free tests