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TUTORIAL HANDOUT
PRACTICAL FIELD PERFORMANCE TESTING FOR CENTRIFUGAL COMPRESSORS

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OBJECTIVE

The objective of this tutorial is to provide practical guidance useful when conducting field performance testing for centrifugal compressors.

TUTORIAL OUTLINE

Slide Topic Summary
1 Title Page

2 Outline
- Motivation
- Principle of Operation and Main Components
- Performance Testing Instrumentation
- Basic Thermodynamics and Performance Calculations
- Test Overview
- Uncertainty Analysis

3 Motivation
4 Benefits of Testing
Compressor Operators
- Evaluate performance deterioration in aging equipment
- Quantify performance deficits
- Audit internal test procedures

Manufacturers
- Independent validation of product performance: Support manufacturer's own claims, Dispute competitor claims, Resolve internal disputes (R&D lab vs. production testing, etc.), Resolve performance related disputes with customers (warranty issues)
- Audit internal test procedures
- Identify equipment components for product improvement

5 Principle of Operation and Main Components
6 Operating Principles -In a Nutshell
- Shaft power from gas turbine is transmitted to impeller rotation.
- Impeller imparts energy to the gas.
- Energy input results in pressure and temperature rise, and also in high velocity flow at impeller exit.
- Stationary components downstream of impeller diffuse flow and remove swirl giving rise to

further pressure increase.

- Compressor designers strive to make this process as near to isentropic (no entropy change) as possible – i.e. high efficiency.

7 Single Stage Centrifugal Compressor
8 Multi-stage Centrifugal Compressor
9 Beam Style vs Overhung Compressor
10 Solid vs Modular Rotor
11 Parts of a Centrifugal Compressor Stage
11 Compressor Discharge Components
12 Performance Testing Instrumentation
13 Required Measurements
14 Measurement Types and Sensors

- Pressure
- Temperature
- Flow
- Speed
- Gas Composition

15 Pressure Transducers

- Strain Gauge
- Piezoelectric

16 Thermocouples
17 RTDs and Thermistors
18 Temperature Sensor Comparison
19 Differential Pressure Flow Meters

- These meters use pressure differential across an obstruction to determine flow rate
  Based on Bernoulli's Equation
- The equation provides an ideal flow rate for incompressible flow that is higher than the actual flow rate.
- There are several factors that are typically used to adjust the equation so that it reflects the actual flow rate. Two of the most common are: Discharge Coefficient Cd accounts for viscous losses: Orifice Typical Value is 0.6, Venturi Typical Value is 0.94-0.99
- Calibrate for increased accuracy
- Expansion Factor Y (<1.0) accounts for density difference between tap and orifice plate

20 Orifice Plate Flowmeter

- Simple, Relatively Inexpensive
- Requires Long Runs of Piping and Possibly Flow Conditioners

21 Flow Conditioners
22 Other Differential Type Flow Meters
Venturi Flowmeter

- Advantages
- Pressure drop is lower than with an orifice
- Can handle dirty flows without degrading accuracy
- Disadvantages
- Susceptible to installation effects
- Difficult to manufacture
- Big and heavy in large sizes
- Range is not adjustable, as with an orifice meter
- V-Cone
- Also known as a reverse Venturi
- Compact and requires short installation lenghts

23 Other Types of Flow Meters
24 Practical Uncertainty Levels in Field Testing
25 Basic Themodynamics and Performance Calculations
26 Head, Work and Energy
27 Entropy
28 Gas Laws
29 Compressibility Factor
30 Equation of State – Some Models
31 Equation of State
32 Capacity vs Standard/Normal Flow
33 Centrifugal Compressor Operating Map
34 Summary of Compressor Operating Limits
    - Maximum Operating Speed
    - Minimum Operating Speed
    - Upper Flow Limit- Choke or Stonewall
    - Low Flow Limit
35 Pumping vs Compression
36 Isentropic Compression
37 Polytropic Compression
38 Efficiency Definitions
39 Power Required to Drive a Compressor
- Compressor power is determined from flow and changes in the thermodynamic properties of the gas
- Thermodynamic properties are calculated from
- Measured temperatures
- Measured pressures
- Gas composition determined from lab analysis
- Power Calculation

40 Simplification for Ideal Gas
41 Real Gas Effects
42 Non-Dimensional Parameters and Their Use
Fan law proportionality
Two factors which make "Fan Law" application invalid:
Machine Mach Number Effects
Reynolds Number Effects
43 Non-Dimensional Parameters
- Common Non-Dimensional Parameters Found on Compressor and Turbine Performance Maps
- Other "semi" Non-Dimensional parameter very useful in determining type of turbomachine for a given application

44 Test Overview
45 Planning for Field Performance Tests
- Pretest Agreements
  - Test Procedure and Acceptance Criteria
  - Instrumentation/P&ID
    - Data Reduction
    - Procedure for Test Uncertainties
    - Test Attendance and Roles
- How to accomplish necessary operating conditions
- Personnel Onsite Should Be Authorized to Accept or Reject Data

- Test Installation Easier If Introduced
  in Planning Stage

46 Field Measurements and Instrumentation

- Pressure, Temperature, Flow Rate, Gas Composition, Torque, Rotational Speed.
- Instrumentation should be calibrated prior to test. An end-to-end test of instruments with data acquisition system is recommended.
- Two approaches to measurement of temperature and pressure:
- Measurement in uniform flow field further from compressor with correction for losses in between.
- Measurement near compressor with a greater number of sensors to correct for non-uniformities.
- Flow measurement critical for accurate performance assessment. All flow meters should have adequate flow conditioning or upstream length according to standards
- Gas composition accuracy relies on proper sampling methods and accurate chromatograph analysis.
- For rotational speed, either magnetic speed pickups or key phasor probes on the compressor are acceptable.

47 Test Results
48 Repeatability
49 Test Uncertainty
50 Minimizing Measurement Uncertainty
51 Test Conditions Effect of Unsteady Conditions
52 Test Uncertainties: Theory
53 Compressor Efficiency Example
54 Useful Test Standards and References

- ASME PTC 10-1997, *Performance Test Code on Compressors and Exhausters*
- ASME PTC 19.5-2004, Flow Measurement
- ASME PTC19.1-2205, Test Uncertainty
- Coleman, H.W., Steele, W., G., Experimentation and Uncertainty Analysis for Engineers, 1998, John Wiley & Sons, New York
- Brun, K., and Nored, M., *Guideline for Field Testing of Gas Turbine and Centrifugal Compressor Performance*, Release 2.0, GMRC, 2006

55 ASME PTC-10 Test Requirements
56 ASME PTC-10 Recommended Configuration for Temperature and Pressure Measurement
57 ASME PTC-19.5 Recommended Configuration for Flow Measurement
58 Questions