Seminar 21

Uncertainties in Compressor Performance and Field Performance of Liquid-Chilling Systems

An overview of Compressor Performance Uncertainties

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Learning Objectives

Explain five (5) major compressor performance uncertainties

1. Measurement uncertainty;
2. Lab to lab testing reproducibility uncertainty;
3. Manufacturing uncertainty;
4. Performance prediction uncertainty; and
5. Tested vs rated condition uncertainty.

Provide recommendations for how to manage uncertainties in performance of compressors.

Acknowledgements

This presentation is based on a 2017 AHRI/ASERCOM White Paper entitled, *Tolerances and Uncertainties in Performance Data of Refrigerant Compressors.*

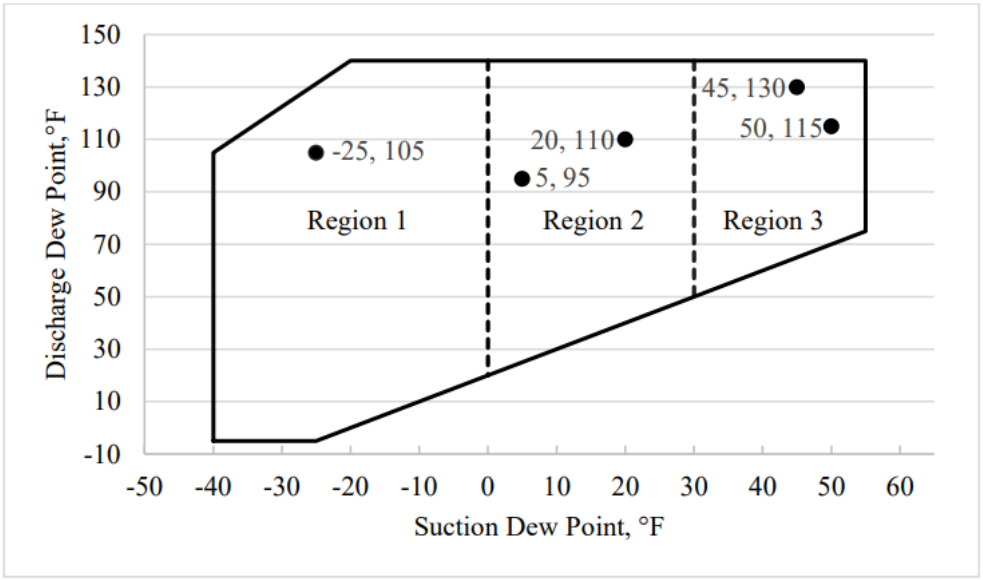
Slides were developed with support from the AHRI Compressor Section with particular support from Matt Cambio and Steve Holden.

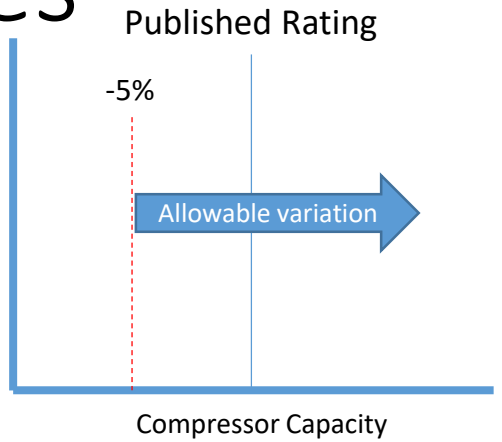
Agenda

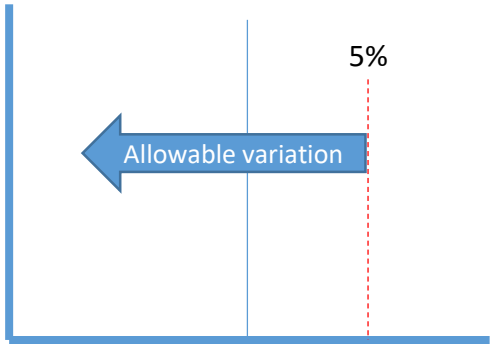
- Compressor Rating Tolerances
- Compressor Rating Uncertainties
- Five (5) Sources of Compressor Rating Uncertainty:
  1. Measurement System Uncertainty
  2. Lab-to-Lab Variation
  3. Manufacturing Variation
  4. Performance Prediction Error
  5. Tested vs. Rated Condition
- Uncertainty Management

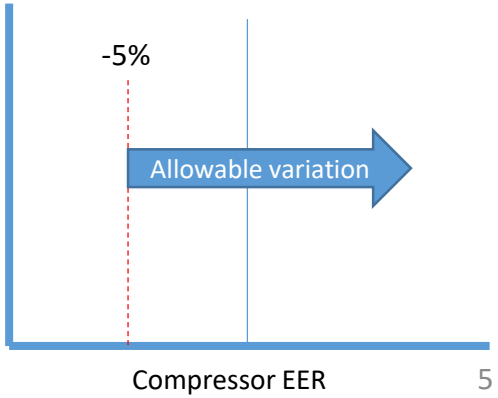
Compressor Rating Tolerances

- Published ratings refer to mean performance
  - AHRI 540
  - EN 12900
- Standards specify allowable tolerances on the rating data
  - 5% High Temp
  - 7.5% Medium Temp
  - 10% Low Temp



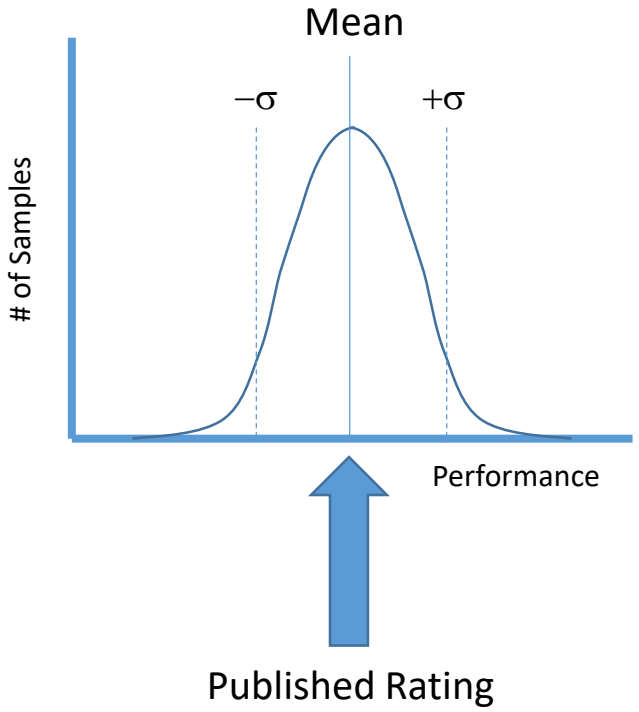






Compressor Performance Uncertainty

- Inherent in compressor performance is variation or uncertainty.
- Distribution of performance data is expressed by a mean and standard deviation (σ) and assumed to be a normal distribution.
- Compressor ratings published per the AHRI standards (540, 545, 570) require that the rating data represents the mean performance level of that compressor.



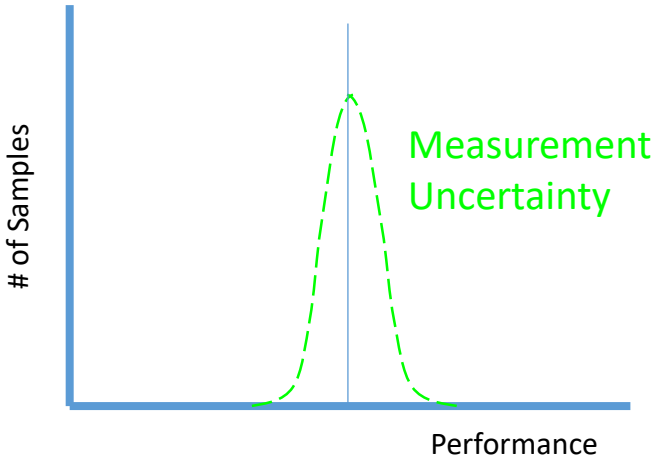
AHRI/ASERCOM White Paper

- Study co-sponsored by AHRI and ASERCOM looked into the sources of uncertainty in compressor performance.
- Identified 5 Sources of uncertainty:
  - Measurement System Uncertainty
  - Lab-to-Lab Variation
  - Manufacturing Variation
  - Performance Prediction Error
  - Tested vs. Rated Condition
- Total compressor uncertainty is determined based on the accumulating effects of sources of uncertainty.

Measurement System Uncertainty

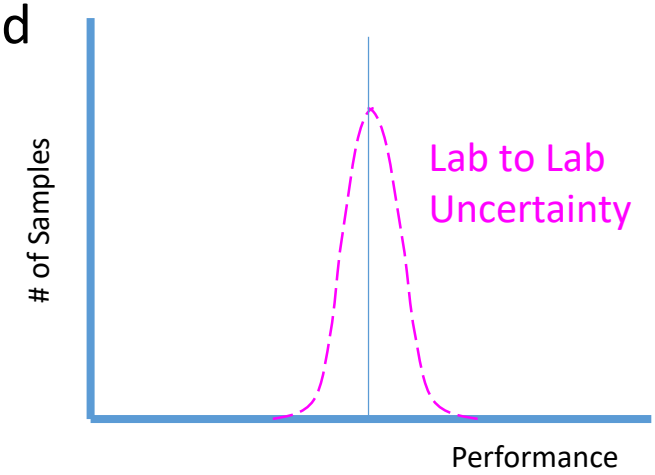
- Type of Measurement Uncertainty
  - Type A – Statistical variation. Repeatability of a single measurement.
  - Type B – Bias built into the measurement system (addressed in the next slide).
- Uncertainty allowed by

  ASHRAE 23 and EN 13771
  - Temperature ±0.3 K resp ±0.5 °F
  - Temperature differences ±1% of the difference
  - Pressure ±1% of value
  - Electrical power ±1% of value
- Standard allowable uncertainties equate to
  - ±1.5% on capacity at high temperatures
  - ± 2.1% on capacity at low temperatures
  - ± 1.3% on power
  - ± 2% on COP at high temperatures
  - ± 3% on COP at low temperatures



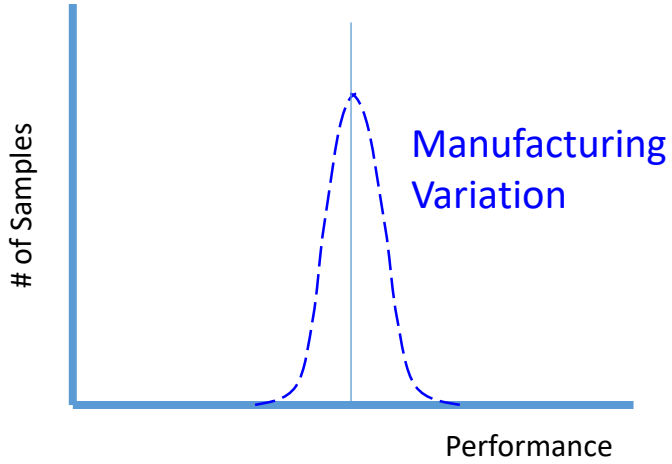
Lab-to-Lab Uncertainty

- Lab-to-Lab refers to the reproducibility of a measurement from one facility to another.
- The uncertainties (Type B) among laboratories are based on:
  - Calibration of measurement devices
  - Measurement methods, such as volume flow measurement or mass flow measurement on suction or discharge site
  - Quality of electrical power grid
  - Refrigerant properties or refrigerant properties database
- ASERCOM Study of seven European labs showed
  - R404A operation at low temperatures
    - Cooling capacity +/- 2.1%
    - Power consumption +/- 1.2%
    - COP/EER +/- 2.3%
  - R404A operation at medium temperatures
    - Cooling capacity +/- 1.5%
    - Power consumption +/- 1.5%
    - COP/EER +/- 1.8%



Manufacturing Variation

- Variation occurs in, but not limited to, these factors:
  - Dimensional variability in mechanical components
    - Internal gas leaks
      - Rotor & gate leakage in rotary compressors
      - Wrap leakage in scroll compressors
      - Rotor to rotor and rotor to bore leakage in screw compressors
      - Discharge and suction valve leakage
    - Varying effect of clearance volume in reciprocating compressors across the operating range
    - Bearing alignments
  - Electric motor efficiency
  - Mechanical losses in friction surfaces
- Typical product variability in cooling capacity is around ±1.5%.



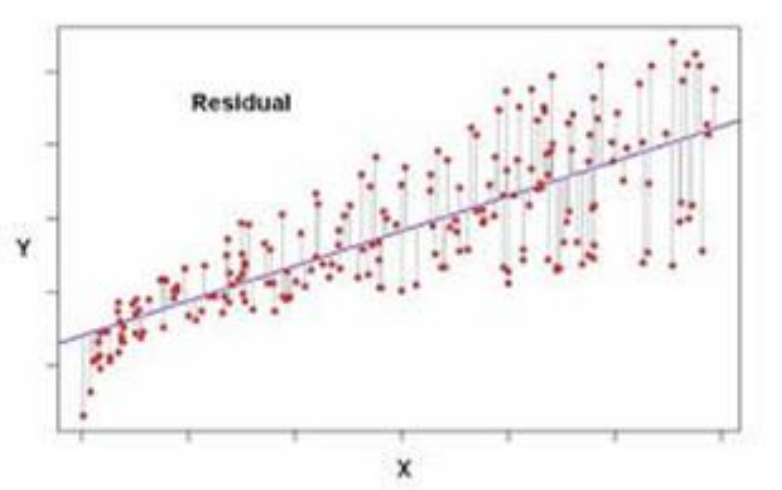
Performance Prediction Error

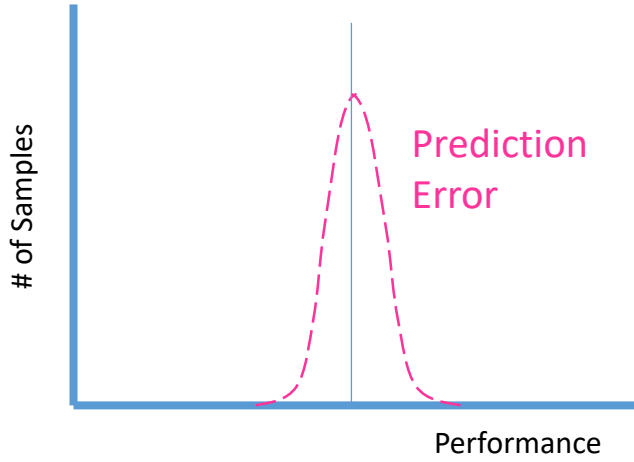
- AHRI performance standards require that compressor ratings use a 10-coefficent polynomial equation:

$$X = C1 + C2(T_s) + C3(T_d) + C4(T_s^2) + C5(T_s\,T_d) + C6(T_d^2) + C7(T_s^3) + C8(T_s^2\,T_d) + C9(T_s\,T_d^2) + C10(T_d^3)$$

  - C1 through C10 = Regression coefficients
  - T_d & T_s = Discharge & Suction dew point temperature, °F, °C
  - X = Performance metric (capacity, power, EER or mass flow rate)

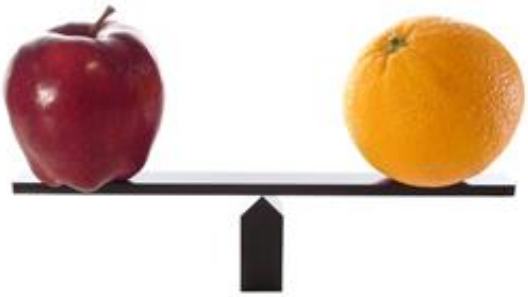
- Aute and Martin evaluated the regression uncertainty for this equation and showed average uncertainty as high as 4% and 5% for mass flow rate and power, respectively.

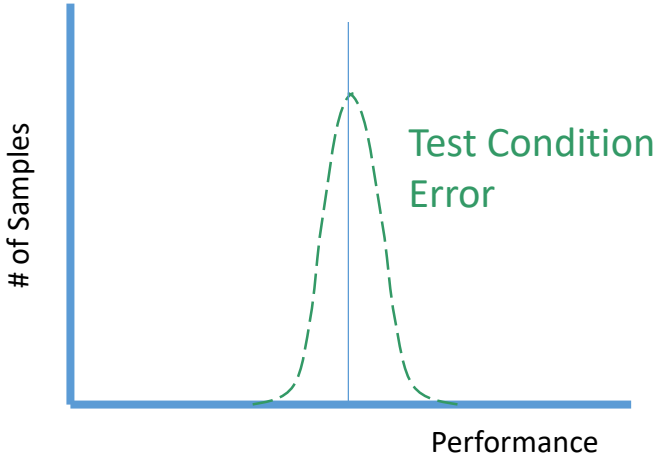




Tested vs. Rated Condition Error

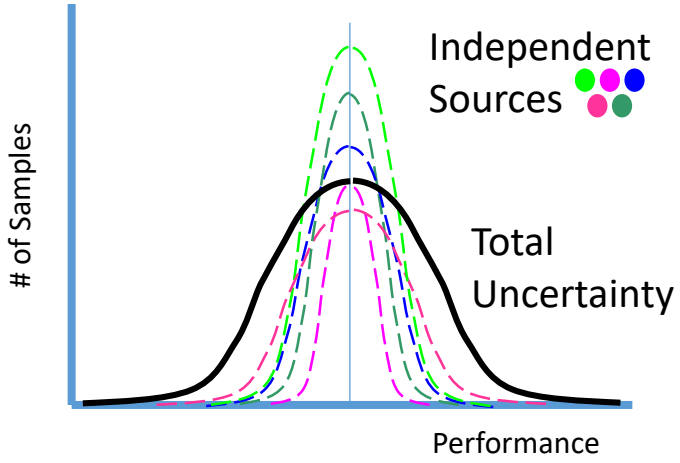
- Compressor testing standards allow for deviations in the input from basic/specified test conditions.
- Difference between actual test conditions and specified test conditions can create errors in mass flow/capacity and power of order 1.5% and 2% respectively.
- The actual test condition may be further away from the specified test condition if the system is not stable or in transient condition while the test parameters are being recorded.





Total Uncertainty

- Need to combine these independent sources of uncertainty
- Total uncertainty is calculated by summing squared deviations from the mean.
- Combining the independent uncertainties provides a total uncertainty in the published rating
  - ±5.0% on Capacity
  - ±4.9% on Power

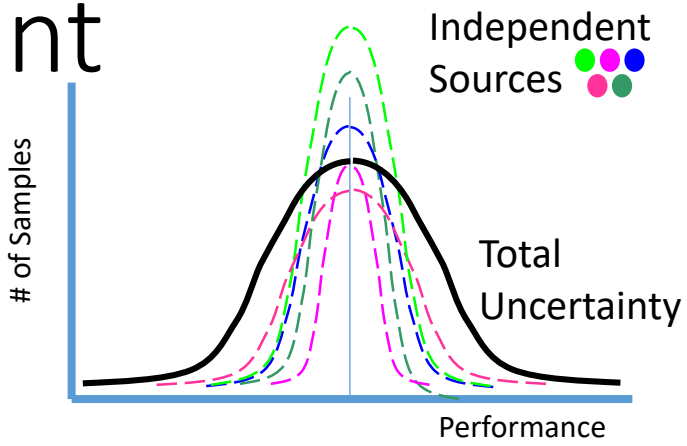


Source	High Temp Suction Conditions			
	Capacity		Power	
	Uncertainty	Variability	Uncertainty	Variability
Measurement	±1.5%	$(1.5\%)^2$	±1.3%	$(1.3\%)^2$
Lab-to-Lab	±1.5%	$(1.5\%)^2$	±1.5%	$(1.5\%)^2$
Manufacturing	±1.5%	$(1.5\%)^2$	*	*
Prediction	±4.0%	$(4.0\%)^2$	±4.0%	$(4.0\%)^2$
Test	±1.5%	$(1.5\%)^2$	±2.0%	$(2.0\%)^2$
Total Variability		0.0025		0.0024
Total Uncertainty	±5.0%	↵	±4.9%	↵

*Only capacity variation was studied. Power variation is also expected, but not shown here.

Uncertainty Management

- More accurate measurement systems
- Single lab data generation
- Decreased manufacturing tolerances
- Systematic validation testing
- Test at rated conditions



Source	High Temp Suction Conditions			
	Capacity		Power	
	Uncertainty	Variability	Uncertainty	Variability
Measurement	**±0.75%**	**$(0.75\%)^2$**	**±0.65%**	**$(0.65\%)^2$**
Lab-to-Lab	**-**	**-**	**-**	**-**
Manufacturing	**±1.0%**	**$(1.0\%)^2$**	*****	*****
Prediction	**±2.0%**	**$(2.0\%)^2$**	**±2.0%**	**$(2.0\%)^2$**
Test	**-**	**-**	**-**	**-**
Total Variability		**0.00056**		**0.00044**
Total Uncertainty	±2.4%		±2.1%	

*Only capacity variation was studied. Power variation is also expected, but not shown here.

Conclusions

- Compressor rating tolerances and uncertainties are different.
- There are five (5) sources of compressor rating uncertainty:
  1. Measurement System Uncertainty
  2. Lab-to-Lab Variation
  3. Manufacturing Variation
  4. Performance Prediction Error
  5. Tested vs. Rated Condition
- Compressor rating uncertainty can be managed but not removed.

Questions?

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