MONITORING QAC LAB PERFORMANCE DATA

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Our customers occasionally purchase Certified or even Witnessed Performance Tests to assure themselves that Carrier is providing the superior product that was promised. On occasion, Carrier will also independently perform such tests for similar reasons.

The data is valuable to Carrier not only because it represents a way to promote customer satisfaction, but it also allows Carrier to directly monitor and immediately arrest adverse changes in production quality.

This note describes how the data is treated and used in advancing Carrier's objectives for monitoring product quality.

ARI Tolerances

Measurement of any physical property, even the simplest, has a level of uncertainty that depends upon the instruments used and the environment under which the measurement is performed. The Air-Conditioning & Refrigeration Institute (ARI) recognizes this fact in providing guidelines in ARI Standard 550/590-98. (See Appendix C, for example.)

Essentially, the tests performed by Carrier must show that the chiller's power consumption conforms to promises made to our customer for various, but specific, operating conditions chosen by the customer to represent how the customer intends to use the chiller. (Alternately, ARI Standard 550/590-98 specifies certain test points that are considered typical of water chiller applications.)

Specifically, power is measured (and generally quoted as IkW/Ton or IkW/kW) while maintaining required conditions of evaporator and condenser water flow rates (gpm or lps), evaporator leaving chilled water temperature (F or C), condenser inlet water temperature (F or C) and capacity (Tons or kW).

Such data may be gathered at only the customer's "design" point or at several points of the customer's choosing that may lead to confirmation of the chiller's off-design performance potential.
The tolerances for each of the control parameters are given in the table below.

Control Parameter	Required setting accuracy
Evap., cond. water flow rates	± 5%
Leaving chilled water temperature	± 0.5F [± 0.3C)
Condenser entering water temp.	± 0.5F [± 0.3C)
Full load capacity	± 5%
Capacity at part load	± 2% of full load
Input voltage	± 10%
Input frequency	± 1%

The resultant chiller relative power consumption (e.g., IkW/Ton) must be within the following tolerance of the value "sold" to the customer:

$$\text{Tolerance for measured IkW/Ton, \%} = 10.5 - (0.07 \times \%FL) + [1500/(dT_{FL} \times \%FL)]$$ [1]

Where %FL is the percent of full load capacity at which the point is being evaluated, and where dT_{FL} is the difference between entering and leaving evaporator water temperature at full load. Thus, the formula recognizes that measurement uncertainty increases at part load.

One will recognize that because the tolerances naturally allow conditions to be either high or low with respect to nominal, the effect on the unit's performance will be biased according to the actual stable settings achieved during the test. It is Carrier's objective to eliminate this arbitrary "bias" when viewing how the unit actually performed versus the unit's expected performance. (Usually, this makes one to two percent difference; not large, but not negligible either.)

Using the Measurements

The need for tolerances on both control and measured parameters is obvious for any real-world physical process because some phenomena are always outside the test operator's control. In addition, the test piece itself (i.e., the chiller, in this case) can be expected to have some performance variability attributed to manufacturing (i.e., machining and assembly) tolerances.

It is Carrier's objective to minimize these uncertainties. Carrier can do this in the following manner:

(a) Assume that the performance test measurements are absolutely correct.
(b) Evaluate the unit with the same "tool" from which the original performance was estimated for our customer.
(c) Assume that any deviation between measured and predicted performance is due to uncertainty in the manufacturing process.

A water chiller is selected to provide evaporator discharge water at a given temperature. The unit is required to do this for a certain design cooling capacity. It is constrained by the water conditions into which heat may be rejected. The customer provides the means to move water through each of the circuits;

[1] The factor of 1500 in this equation becomes 833.3 when water temperatures are measured in SI units (i.e., degrees Celsius):

i.e., the evaporator circuit that uses the chilled water and the condenser circuit that removes the process heat.

Hence, the following are the design variables:

(a) Capacity (Tons or kW)
(b) Evaporator leaving water temperature (F or C)
(c) Evaporator water flow rate (gpm or l/s)
(d) Condenser inlet water temperature (F or C)
(e) Condenser water flow rate (gpm or l/s)

Since these parameters were required for the original design and since they are the principal control variables for the performance test, then their measured values can be used to determine how the unit should *theoretically* perform at conditions near, but not exactly matching, the original design point.

In fact, this process can be used to evaluate measured conditions at any operating point, including part load, extending all the way to shut-off.

This procedure can be viewed as a *numerical simulation* of the *physical test* performed in the lab.

Interpreting the Results

Any difference between the measured value of IkW/Ton (or IkW/kW) and the results of the numerical simulation essentially defines the manufacturing capability to repeatedly achieve the chiller's published ratings, *assuming that the real effect of measurement uncertainty in the lab test is negligible* and, of course, that the ratings are correct.

It is quite satisfactory to assume that direct measurement uncertainty has little influence on the overall uncertainty of the measured value for IkW/Ton. This simply means that the conditions are measured accurately even if the operator was incapable of precisely setting specified conditions during the lab test.

However, it is still difficult to use the results of any one test to determine much about the dynamics of an ongoing process. For this, one generally uses trend charts and, perhaps, the mathematics of statistics to answer such important questions as

- What is the scatter of performance measurements? That is, how consistent is the unit's performance?
- How does performance trend with respect to time? That is, is the process improving or deteriorating?

An example of a trend chart is shown in Fig. 1. The chart is a hypothetical example, showing the difference between the measured performance of a chiller and its rated performance, plotted for all chillers as a function of the test date of each chiller. The example could indicate (a) that the chillers are being made more consistently as time passes, but (b) perhaps there is

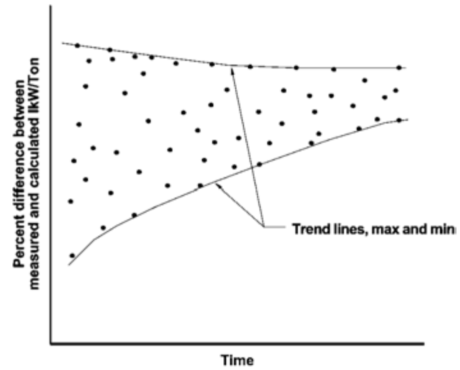

Figure 1. An example of a trend chart

something being done to promote the consistency that may also be degrading the chillers' general performance. For example, suppose an assembly can be made more consistently if some clearance is enlarged, but enlarging the clearance leads to the increase of a parasitic loss. This would not be a good choice with regard to performance; and if it makes sense with respect to fabrication cost, the chillers' performance must be de-rated.

Statistics is an extremely useful tool. It can be used, for example, to determine if one particular feature of the chiller is the major contributor to an observed problem. However, statistics requires large numbers of measurements to establish reasonable confidence for conclusions drawn from physical observations. With the varied nature of our customers' requirements, it is rare that more than a few units will ever have exactly the same material content.

For example, a little more than about 10% of the 19XR chillers sold by Carrier have been tested in our QAC Lab for their "full load" performance. (Far fewer have been tested for part load performance.) Only one compressor code has as many as 35 "full load" tests. Only as many as six of these are the same model; i.e., contain the same evaporator, condenser, compressor and motor codes. (One other group among the 35 contains four other units that are "similar.") These do not represent statistically significant numbers.

Statistics provides a useful means to analyze chiller performance measurements only if further assumptions are made that increase the number of units that can be considered "similar."

To reach numbers of statistical significance, one might assume that any difference between measured and predicted performance is directly attributed to compressor aerodynamic performance. All inefficiencies then are ignored for other potential loss sources; e.g., heat transfer, motor and mechanical performance.

This is reasonable where heat transfer is concerned because measurements at the time of test can isolate such problems for immediate corrective action. The difference between refrigerant saturation temperature within each vessel and the temperature of the water leaving the vessel is compared to expectations to discern heat transfer inefficiency. Corrective action may be as simple as verifying the charge level or removing air inadvertently left in the chiller.

Separating abnormal motor or mechanical losses is considerably more difficult. These remain as potential compressor performance issues.

Conclusion:

Chiller performance differences are put into “bins” on the basis of the compressor designation code. Analysis may then show, for example, if there are specific compressor codes that require re-rating.

This procedure has worked well for Carrier and its customers to date.

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