

FEDCO

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SEMINAR # 69
FUNDAMENTALS OF CENTRIFUGAL CHILLERS

CENTRIFUGAL CHILLER BASICS

Fred Betz, PE, FASHRAE, Life Member
TC 8.2 CENTRIFUGAL MACHINES

Centrifugal Chillers

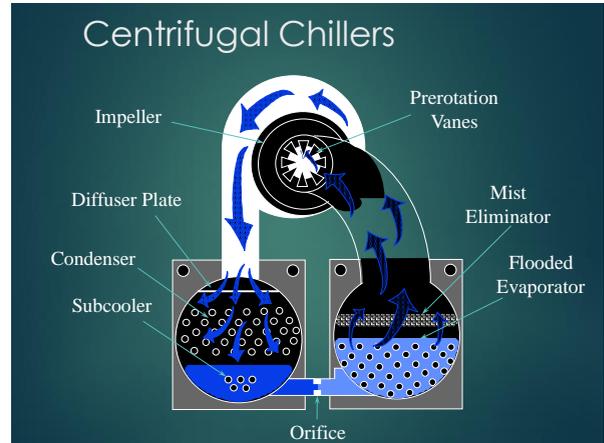
- ▶ Centrifugal Compressor
 - ▶ Creates pressure from centrifugal force
 - ▶ Creates a refrigerant velocity that is converted to pressure
 - ▶ No seal between inlet and outlet side

LEARNING OBJECTIVES

- 1 Convey the basic operation of a Centrifugal Chiller.
- 2 Explain the differences between a Centrifugal Chiller and a positive displacement chiller.
- 3 Describe the typical options that are available when specifying centrifugal chillers, what the option provides and what the advantage of the option is
- 4 Define centrifugal chiller efficiencies and explain the requirements of ASHRAE 90.1 relative to centrifugal chillers.

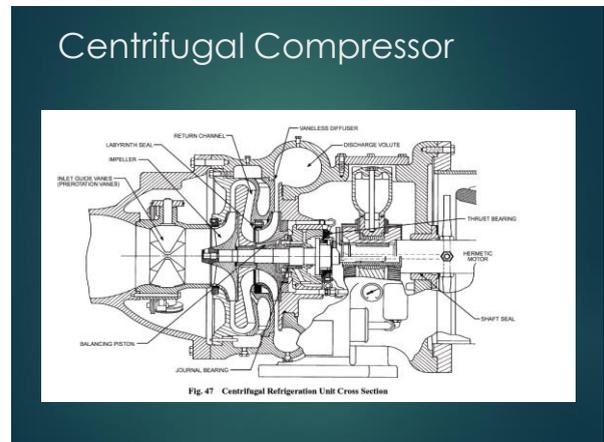
Describe the typical applications when a centrifugal chiller is used rather than other types. ASHRAE is a Registered Provider with The American Institute of Architects Continuing Education Systems. Credit earned on completion of this program will be reported to ASHRAE Records for AIA members. Certificates of Completion for non-AIA members are available on request.

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AGENDA

1. CENTRIFUGAL CHILLER BASIC OPERATION
2. CHILLER CAPACITIES
3. ENERGY USAGE
4. CENTRIFUGAL CHILLER APPLICATIONS



Centrifugal Chillers

- ▶ Generally More efficient than Positive Displacement (PD) Machines
- ▶ Less available "lift" than PD
- ▶ Lower Refrigerant Pressure than PD
- ▶ Therefore
 - ▶ Not usually in low temp application
 - ▶ Although can be used for ice storage systems
 - ▶ Less appropriate for air cooled package
- ▶ Longer Equipment Life
 - ▶ Less metal to metal contact

Capacities

- ▶ Packages available up to 5000 Tons
- ▶ Field assembled up to 10,000 tons



Chiller Capacities

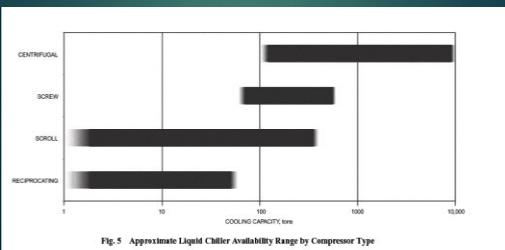


Capacities

- ▶ Some small compressors for 60 – 100 tons
 - ▶ Typically used in modular type applications
- ▶ Multiple Compressor Packages
 - ▶ Multiple small compressors
 - ▶ Dual large compressors – for back-up reliability
- ▶ Better part load efficiency
 - ▶ Operates like two series chillers

Capacities

- ▶ Historically 200 tons and above



Multiple Compressors



Dual Compressors



Oil or Oil Free ?

- ▶ Oil Free
 - ▶ Not necessarily better efficiency
 - ▶ Can be higher maintenance
 - ▶ Higher first cost
- ▶ With Oil
 - ▶ Oil has the ability to help analyze compressor condition

Drives

- ▶ Hermetic / Semi-Hermetic
 - ▶ Refrigerant cooled motor
 - ▶ Motor heat reduces capacity
- ▶ Open with Electric Motor
 - ▶ Motor heat into equipment room
- ▶ Engine / Turbine / etc
- ▶ Variable Speed

Energy Usage



Bearings – Oil or Oil Free ?

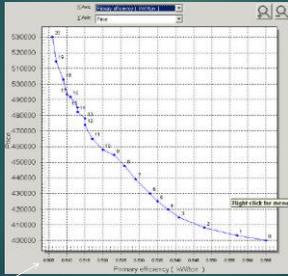
- ▶ Major Manufacturers offer both
- ▶ Two basic types of oil free bearings
 - ▶ Magnetic and Ceramic
- ▶ Both have advantages and disadvantages

Energy Usage

- ▶ Energy usage – expressed in kW / ton
- ▶ Typical is 0.50 to 0.57 kW/ton at rated conditions
 - ▶ 90.1-2013 allows .560 for centrifugal and .61 for PD at 300-600 tons
 - ▶ Sliding scale for other sizes.
- ▶ Most manufacturers have wide range of efficiency options
 - ▶ Numerous compressor sizes
 - ▶ Wide range of condenser and evaporator sizes
 - ▶ Cost varies widely also

Chiller Selections

1000 ton chiller selections from one manufacturer



0.505 kW/ton

0.565 kW/ton

Chiller Specification

- ▶ Specify minimum performance
- ▶ Request additional prices for better efficiency
- ▶ Remember the "tolerances"
 - ▶ If specified capacity is absolutely required
 - ▶ You must specify your allowable tolerance (zero?)
 - ▶ Or specify a 5% higher capacity to meet min after tolerance

Energy Usage

- ▶ IPLV and NPLV ratings – AHRI 550 / 590
- ▶ Weighted ratings based on annual ton-hours
 - ▶ 1% at full load - with 85 °F condenser water
 - ▶ 42% at ¾ loaded – with 75 °F condenser water
 - ▶ 45% at ½ loaded – with 65 °F condenser water
 - ▶ 12% at ¼ loaded – with 65 °F condenser water
- ▶ Usable for a single machine HVAC installation
 - ▶ in the proper climate
- ▶ Not as usable for a multiple chiller plant

Capacity Control

- ▶ Unloading – Part Load
 - ▶ Unloading by changing inlet vane position
 - ▶ Used on all Centrifugal machines
 - ▶ Unloading by changing compressor speed
 - ▶ Using VFD
 - ▶ Controls lift
 - ▶ Greatly improved efficiency at low condenser water temperature and reduced load
 - ▶ Speed only reduced when lift is less than specified
 - ▶ Must run full speed when cond and chw are at design temps

ARI 550/590 Tolerance

2011 Standard

Note sizeable tolerances

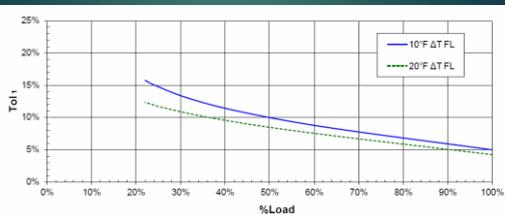
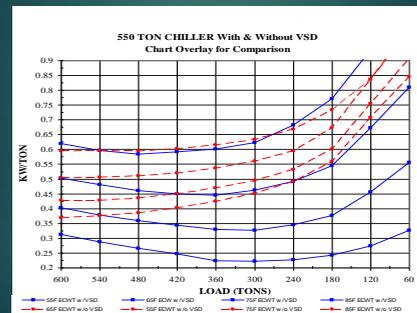


Figure 3. Allowable Tolerance (Tol) Curves for Full and Part Load Points

Variable Speed Drive



Energy Analysis

- ▶ Energy Analysis
 - ▶ BIN Method
 - ▶ Uses 5 degree temperature "BINs" for detailed analysis – number of hours in each "BIN"
 - ▶ Must determine load and condenser water temp for each BIN
 - ▶ Must get data from chiller Manufacturer for kW/ton at each load and corresponding cond water temp
 - ▶ Need more than IPLV data
 - ▶ Most accurate method for Life Cycle Cost analysis

Refrigerants for Centrifugals

- ▶ Refrigerants
 - ▶ Centrifugals use low / medium press. refrigerants
 - ▶ R 123, R 134a currently used in centrifugals – that is changing
 - ▶ R123 operates at below atmospheric pressure
 - ▶ Cond press = 15.8 psia Evap press = 2.3 psia
 - ▶ A leak will leak air into machine – must be purged
 - ▶ R134a operates at medium pressure
 - ▶ Cond press = 111.2 psia Evap press = 23.6 psia
 - ▶ Vessels must be PV rated
 - ▶ A leak will allow refrigerant to escape

BIN Method Energy Evaluation

Table 1. Sample Energy Modeling Spreadsheet

PLANT INFORMATION (U.S. UNITS)										
Quantity of Chillers	3	#	400	TR	1011	TR				
Quantity of Chilled Water (GPM)	3	#	35	SGP	25.4	TR				
Chilled Water Temp	44.0	TR			44.0	TR				
Chilled Water Range	1.0	TR			1.0	TR				

ANNUAL ELECTRIC CONSUMPTION OF CHILLER PLANT																	
REFRIG LOAD	PROFILE			ELECTRIC CENTRIFUGAL CHILLER					COOLING TOWER/FAN/MOTOR					TOTAL			
	LOAD TONS	LOAD kW PER YR	HOURS	FCWT	FCWP	COND. LOAD	COND. COP	COND. kW	COND. kWh/yr	COND. ON	COND. kWh/yr	COND. kWh/yr	COND. kWh/yr		COND. kWh/yr		
25	450	1371	430	52	14.5	1	15.2%	0.501	3.1	158.3	46.30	1	20	14.4	31.2%	4.20	1485
40	700	2070	630	52	13.0	1	16.2%	0.511	3.0	149.4	175.01	1	20	14.4	31.2%	4.20	1314.07
45	780	2280	680	48	11.5	1	18.0%	0.540	2.6	116.0	116.01	1	20	14.4	31.2%	4.20	1060.01
50	850	2475	740	45	10.4	1	19.0%	0.560	2.5	103.1	103.10	1	20	14.4	31.2%	4.20	870.00
55	900	2610	810	40	9.4	1	20.0%	0.570	2.4	93.0	93.00	1	20	14.4	31.2%	4.20	740.00
60	950	2700	880	35	8.6	1	20.5%	0.575	2.3	85.0	85.00	1	20	14.4	31.2%	4.20	630.00
65	1000	2760	950	30	8.0	1	21.0%	0.580	2.2	78.0	78.00	1	20	14.4	31.2%	4.20	530.00
70	1050	2800	1020	25	7.6	1	21.5%	0.585	2.1	72.0	72.00	1	20	14.4	31.2%	4.20	440.00
75	1100	2820	1090	20	7.3	1	22.0%	0.590	2.0	67.0	67.00	1	20	14.4	31.2%	4.20	360.00
80	1150	2830	1160	15	7.1	1	22.5%	0.595	1.9	63.0	63.00	1	20	14.4	31.2%	4.20	290.00
85	1200	2830	1230	10	7.0	1	23.0%	0.600	1.8	60.0	60.00	1	20	14.4	31.2%	4.20	230.00
90	1250	2820	1300	5	7.0	1	23.5%	0.605	1.7	58.0	58.00	1	20	14.4	31.2%	4.20	180.00
95	1300	2800	1370	0	7.0	1	24.0%	0.610	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	140.00
100	1350	2770	1440	0	7.0	1	24.5%	0.615	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	110.00
105	1400	2730	1510	0	7.0	1	25.0%	0.620	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	90.00
110	1450	2680	1580	0	7.0	1	25.5%	0.625	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	75.00
115	1500	2620	1650	0	7.0	1	26.0%	0.630	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	60.00
120	1550	2550	1720	0	7.0	1	26.5%	0.635	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	50.00
125	1600	2480	1790	0	7.0	1	27.0%	0.640	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	40.00
130	1650	2400	1860	0	7.0	1	27.5%	0.645	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	30.00
135	1700	2320	1930	0	7.0	1	28.0%	0.650	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	25.00
140	1750	2240	2000	0	7.0	1	28.5%	0.655	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	20.00
145	1800	2160	2070	0	7.0	1	29.0%	0.660	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	15.00
150	1850	2080	2140	0	7.0	1	29.5%	0.665	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	10.00
155	1900	2000	2210	0	7.0	1	30.0%	0.670	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	5.00
160	1950	1920	2280	0	7.0	1	30.5%	0.675	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
165	2000	1840	2350	0	7.0	1	31.0%	0.680	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
170	2050	1760	2420	0	7.0	1	31.5%	0.685	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
175	2100	1680	2490	0	7.0	1	32.0%	0.690	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
180	2150	1600	2560	0	7.0	1	32.5%	0.695	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
185	2200	1520	2630	0	7.0	1	33.0%	0.700	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
190	2250	1440	2700	0	7.0	1	33.5%	0.705	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
195	2300	1360	2770	0	7.0	1	34.0%	0.710	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
200	2350	1280	2840	0	7.0	1	34.5%	0.715	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
205	2400	1200	2910	0	7.0	1	35.0%	0.720	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
210	2450	1120	2980	0	7.0	1	35.5%	0.725	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
215	2500	1040	3050	0	7.0	1	36.0%	0.730	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
220	2550	960	3120	0	7.0	1	36.5%	0.735	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
225	2600	880	3190	0	7.0	1	37.0%	0.740	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
230	2650	800	3260	0	7.0	1	37.5%	0.745	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
235	2700	720	3330	0	7.0	1	38.0%	0.750	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
240	2750	640	3400	0	7.0	1	38.5%	0.755	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
245	2800	560	3470	0	7.0	1	39.0%	0.760	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
250	2850	480	3540	0	7.0	1	39.5%	0.765	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
255	2900	400	3610	0	7.0	1	40.0%	0.770	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
260	2950	320	3680	0	7.0	1	40.5%	0.775	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
265	3000	240	3750	0	7.0	1	41.0%	0.780	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
270	3050	160	3820	0	7.0	1	41.5%	0.785	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
275	3100	80	3890	0	7.0	1	42.0%	0.790	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
280	3150	0	3960	0	7.0	1	42.5%	0.795	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
285	3200	0	4030	0	7.0	1	43.0%	0.800	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
290	3250	0	4100	0	7.0	1	43.5%	0.805	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
295	3300	0	4170	0	7.0	1	44.0%	0.810	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
300	3350	0	4240	0	7.0	1	44.5%	0.815	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
305	3400	0	4310	0	7.0	1	45.0%	0.820	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
310	3450	0	4380	0	7.0	1	45.5%	0.825	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
315	3500	0	4450	0	7.0	1	46.0%	0.830	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
320	3550	0	4520	0	7.0	1	46.5%	0.835	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
325	3600	0	4590	0	7.0	1	47.0%	0.840	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
330	3650	0	4660	0	7.0	1	47.5%	0.845	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
335	3700	0	4730	0	7.0	1	48.0%	0.850	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
340	3750	0	4800	0	7.0	1	48.5%	0.855	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
345	3800	0	4870	0	7.0	1	49.0%	0.860	1.7	57.0	57.00	1	20	14.4	31.2%	4.20	0.00
350	3850	0	4940	0	7.0	1	49.5%	0.865	1.7	57.0							

Centrifugal Chiller Applications



Centrifugals - Disadvantages

- ▶ Higher cost
- ▶ Must deal with Surge
- ▶ Typically not for air cooled applications
- ▶ Typically not for low temperature applications
- ▶ Typically not for heat pump applications

Applications

- ▶ Building Air Conditioning
- ▶ Heat Recovery – for low hot water temp
- ▶ Heat Pump
- ▶ Process – large load, medium temp
- ▶ Single / Multiple Chiller Systems

QUESTIONS ?

Fred Betz

Centrifugals - Advantages

- ▶ Energy Efficiency better than Positive Displacement Machine
- ▶ Higher Capacities
- ▶ Longer Life
- ▶ Very low sound levels available