PERFORMANCE ANALYSIS OF 110 TR SCREW CHILLER PLANT

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Abstract- Screw chiller plants are important constituents of any medium or large scale manufacturing industry. Hence evaluating its performance at certain intervals is vital for its proper functioning. The case study involves the performance analysis of a 110 TR screw chiller plant at Tata Motors Limited, Sanand, Gujarat. The screw chiller plant under study is installed for the Engine Assembly shop. To evaluate the performance of the plant various parameters are recorded for different components of planti. E- compressor, chiller, condenser and the cooling tower for a period of 14 days. By applying required governing equations, the performance parameters viz. refrigeration effect, power consumed by compressor, coefficient of performance(COP) and energy efficiency ratio(EER) have been computed. The results have been compared with design values supplied by manufacturer and also suitable recommendations have been made to improve the performance of the plant.

Keywords- Chiller, COP, Refrigeration Effect, Condenser, Screw Compressor

I. INTRODUCTION

All air-conditioning systems require a means for generating the cooling effect that offsets the building heat gain due to external loads(wind, sun, outdoor temperature) and internal loads(heat and moisture from people, lights and equipment). In smaller buildings and residential applications, this is usually accomplished with an air-based system that ducts cold air from the point of generation (usually on the roof) to each space in the building that requires cooling. Larger buildings and multiple building campuses usually use a chiller plant to provide cooling. In such systems, chilled water is centrally generated and then piped throughout the building to air handling units serving individual tenant spaces, single floors or several floors. Ductwork then runs from each handler to the zones that are served. Though more costly to install and more complicated to operate, a chiller plant offers a number of benefits over simple packaged cooling units, including greater energy efficiency, better controllability, and longer life. Additionally, a chiller-based system can be much more efficient in terms of space utilization within the building because components need not be located within the same space. Chiller plants are usually used to cool large buildings because their components require much less space within the building than other air systems. One reason is less space is needed because size of pipes that convey chilled water throughout the building is much smaller than the size of air ducts that delivers cold air to provide the same cooling effect. Water is a more space-efficient heat transfer medium than air, and therefore works well in space-constrained applications such as high-rise buildings. One pound of water can store about four times as much thermal energy as the same mass of air, and because water is much denser than air, a pound of water has a much smaller volume than the pound of air. This difference in heat transfer capacity is exemplified by the fact that cooling ducts aretypically sized to provide 400 cubic feet per minute (cfm) of supply air per ton of cooling required, whereas a chilled water system requires only 1.6 to 3.0 gallons per minute (gpm) per ton (or about 0.13 to 0.33 cfm of fluid) with typical value in the range of 2.4 gpm/ton. Clearly, the chilled water pipes will be far smaller than the ducts to deliver the same rate of cooling. The benefit to the building owner is that less space will be required for mechanical systems within the building, which increases the amount of space that can be leased or put to other good use.

II. PLANT DETAILS

The plant under study is installed at Tata Motors Limited, Sanand in Gujarat state. This industry manufactures Tata Nano cars in abundance, and consisted of various assembly shops. The Engine Assembly Shop uses two 110 TR screw chiller plants to cool the laboratories and the rooms in the shop. The screw chiller plant supplies cool air to four rooms in the Engine Assembly Shopnamely Engine Assembly Room, Metrology Room, Tool Room and Tool Regrinding Room.It is named screw chiller plant because the compressor used is screw-type. The line diagram of the plant is shown in Fig. 1.

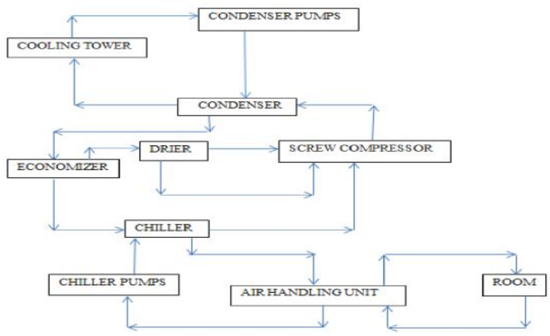

Fig. 1. The line diagram of 110 ton screw chiller plant

The plant consisted of a total of five AHU's, two screw chiller plants of 110 TR capacity each, three chiller pumps, three condenser pumps, and two cooling towers. Each screw chiller plant consisted of a screw compressor, an economizer, a condenser, a drier and a chiller. Four rooms within the Engine Assembly shop are supplied with cool air by the chiller plant.

The plant line diagram can easily be understood by dividing it into three different cycles – air, water and the refrigerant. The refrigerant used in the plant is R-22. The plant works on standard, saturated, single stage vapour compression cycle. The refrigerant in the form of saturated vapour gets compressed is entropically in the screw compressor. The superheated vapour then enters the condenser, where it rejects heat to the cold water supplied from the condenser pumps. In the process, the refrigerant vapour gets converted to liquid. This liquid refrigerant then enters the economizer, whose function is same as that of an expansion valve, and expands refrigerantisenthalpically into low pressure liquid. Some of the liquid leaks from the economizer, which is then allowed to go to the drier for dehydration, after which it enters the screw compressor again. Some of the vapour is directly injected into the screw compressor. The liquid then enters the chiller, where it extracts heat from the incoming hot water from the chiller pumps is obarically, and gets converted into vapour. This vapour re-enters the compressor again to continue the cycle.

The water cycle consists of two parts. The heat is absorbed from the refrigerant in the condenser by the water which is then passed to the cooling tower. The temperature of water is reduced in the cooling tower and pumped back to condenser by the condenser pumps. The cold water coming from the chiller enters the air handling units, where they cool air coming in from the rooms. The hot water from air handling unitsis pumped back into the chiller again and recirculated.

The air cycle involves the cooling of air by water in the AHU's which is then supplied to the four rooms. The warm air returning from these rooms is cooled again in AHU's and the cycle continues.

After careful study of various components and whole processes of the plant, parameters like pressure, temperature and relative humidity were measured at various locations of plant. Readings were taken at intervals of 2 hours daily for 14 days excluding Sunday. The parameters measured are: suction and discharge pressure of compressor, the air temperatures and its relative humidity within the four rooms, and the inlet and outlet temperatures of water in the chiller and the condenser.

III. PERFORMANCE EVALUATION

A. Assumptions

The following assumptions were made during the analysis of plant efficiency:

1)Steady flow of the refrigerant in the chiller plant.

2) Negligible potential and kinetic energy changes across each component.

3) No heat transfer in connecting pipe lines.

B. Governing Equations

For calculating the performances of various units like chiller, condenser and cooling tower the following governing equations were used :

$$\Delta Tco = \Delta Tct = T22 - T21 \quad (1)$$
$$\Delta T2 = T2 - T22 \quad (2)$$
$$\varepsilon co = (T22 - T21)/(T2 - T21) \quad (3)$$
$$\Delta Tch = T11 - T12 \quad (4)$$
$$\Delta T1 = T12 - T1 \quad (5)$$
$$\varepsilon ch = (T11 - T12)/(T11 - T1) \quad (6)$$
$$\Delta T3 = T21 - T0 \quad (7)$$
$$\eta ct = \{(T22 - T21) * 100\}/(T22 - T0) \quad (8)$$
$$Qco = mco * \Delta Tco * 1000 \quad (9)$$
$$Qch = mch * \Delta Tch * 1000 \quad (10)$$
$$RE = Qch/3024 \quad (11)$$
$$P = 1.732 * V * I * \cos\varphi \quad (12)$$
$$COP = Qch/(P * 860) \quad (13)$$
$$\eta = (P * 100)/RE \quad (14)$$
$$EER = (12 * 100)/\eta \quad (15)$$

C. Measurement of data

To evaluate performance of plant, the readings taken on a day when the whole plant was operating including engine assembly shop were taken into consideration. Therefore readings were taken on a day when all AHU's, cooling towers, chiller and condensers were under working condition. The following values were obtained of different parameters.

TABLE I
VALUES OF PARAMETERS WITH THEIR UNITS

Parameter	Value
V	415.00 V
I	116.00 A
P_{41}	0.44 MPa
P_{42}	1.31 MPa
T_0	27.50 °C
T_1	-3.50 °C
T_2	33.50 °C
T_{11}	12.50 °C
T_{12}	8.00 °C
T_{21}	30.00 °C
T_{22}	33.00 °C
m_{co}	101.97 m^3/hr
m_{ch}	66.31 m^3/hr

IV. RESULTS AND DISCUSSION

The results of various performance parameters obtained based on measurements are compared with the design data provided by the plant manufacturers, when the plant was installed at the Engine Assembly shop. The comparison gives good indication of the performance of the plant, and it also shows the areas where improvement is needed in order to reach higher efficiencies.

Table II
Comparison of actual and design values

Parameter	Design Value	Actual Value	Difference
Refrigeration Effect	110 TR	98.68 TR	-11.32 TR
COP	5.17	5.20	+0.03
Cooling Tower Range	4.2 oC	3 oC	-1.2 oC
Chiller Range	5.0 oC	4.5 oC	-1.5 oC
Condenser Range	5.0 oC	3.0 oC	-2.0 oC

From the comparison in the Table II, It is observed that the chiller, condenser and the cooling tower are functioning poorly. So, the task was to find out the reasons for this poor performance and suggest steps that could improve the performance of the individual units and hence the whole plant. After discussion with supervisor and experienced people at the plant, reason for poor performance was found.

The reason for less cooling tower range and condenser range was the high flow rate of water entering the cooling tower from the pumps. The solution to this problem is that the flow rate of water circulating in the condenser and cooling tower circuit has to be reduced according to heat balance equation. The reason for less chiller range was also due to the same reason as that of condenser. Hence, the solution for increasing the chiller range was to reduce the flow rate of water into the chiller pumps. Now, as the chiller range was low, the refrigeration effect produced was low as well. So, the reduction of flow rate of water to chiller pumps would increase the refrigeration effect and consequently the COP of plant.

Since any EER above 15 is considered good for screw chiller plants, the EER is better than expected. The effectiveness of chiller will increase once the range of chiller increases. The effectiveness of condenser and the efficiency of cooling tower is well within the desired levels.

CONCLUSION

The case study provides a valuable insight on the primary factors affecting the functioning of the screw chiller plants in general. Apart from load, the chiller and condenser water temperatures and the flow rate of water circulating in the chiller and condenser are main factors which affect the efficiency of the plant. These factors, if regulated and monitored at regular intervals, could highly improve the functioning of the plant. It means that industry could achieve higher COP by proper monitoring of various parameters at regular intervals.

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Nomenclature

V Voltage input to compressor
I Compressor motor current
φ Power Factor
P41 Suction pressure of vapourentering compressor
P42 Discharge pressure of vapourleaving compressor
To Ambient Air Wet Bulb temperature
T1 Chiller saturation temperature
T2 Condenser saturation temperature
T11 Chiller water inlet temperature
T12 Chiller water outlet temperature
T21 Condenser water inlet temperature
T22 Condenser water outlet temperature
ΔTco Condenser temperature range
ΔTch Chiller temperature range
ΔTct Cooling Tower temperature range
ΔT1 Chiller approach
ΔT2 Condenser approach
ΔT3 Cooling Tower approach
mco Condenser mass flow rate of water
mch Chiller mass flow rate of water
Qco Heat rejected to the condenser water
Qch Heat removal from chiller water
εco Effectiveness of condenser
εch Effectiveness of chiller
RE Refrigeration Effect
P Power consumed by compressor
COP Coefficient of Performance
η Full Load Efficiency
EER Energy Efficiency Ratio
ηct Cooling Tower efficiency

Subscripts

0 Ambient Air
1 Chiller
2 Condenser
3 Cooling Tower
4 Compressor
11 Chiller inlet
12 Chiller outlet
21 Condenser inlet
22 Condenser outlet
41 Compressor suction
42 Compressor discharge
co Condenser
ch Chiller
ct Cooling tower

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