УДК 621.43

Eugeniy Trushliakov[1]
Andrii Radchenko
Serhiy Forduy[1]
Marcin Kruzel[3]
Victor Khaldobin
Anatolii Zubarev
Artem Hrych

Enhancing the Operation Efficiency of Air conditioning system for Integrated power plant on the base of its monitoring

[1]Admiral Makarov National University of Shipbuilding, Heroes of Ukraine Avenue, 9, Mykolayiv, Ukraine
[2]PepsiCo, Inc., Kyiv, Ukraine
[3]Technical University of Koshalin, Poland

Abstact

The operation of the ambient air conditioning systems (ACS) is characterized by considerable fluctuations of the heat load in response to the current climatic conditions. This needs the analyses of the efficiency of application of compressors with frequency converters for refrigeration capacity regulation in actual climatic conditions. A new method and approach to analyzing the efficiency of ACS cooling capacity adjusting by using the compressor with changing the rotational speed of the motor as an example has been developed, according to which the overall range of changeable heat loads is divided in two zones: the zone of ambient air processing with considerable fluctuations of the current heat load, that requires effective refrigeration capacity regulation by compressor with frequency converters (from 100% rated refrigeration capacity down to about 50 %) and not adjustable zone of reduced refrigeration capacity below 50 % rated refrigeration capacity of compressor. The magnitudes of threshold refrigeration capacity between both zones are chosen according to the rational value of installed (design) refrigeration capacity on the ACS, required for cooling the ambient air to a target temperature that ensures the maximum annual refrigeration capacity production in actual current climatic conditions. The proposed method and approach to the analysis of the efficiency of the refrigeration capacity regulation of the ACS compressor by distributing the overall range of changes in current heat loads allows to increase the efficiency of utilizing the installed refrigeration capacity in current climatic conditions.

Keywords: Ambient Air Processing, Stable Heat Load, Changeable Heat Load, Threshold Refrigeration Capacity, Refrigeration Capacity Distribution

Introduction

The operation of the ambient air conditioning systems (ACS) is characterized by significant fluctuations of the heat load in accordance with the current ambient air temperature t_{amb} and relative humidity φ_{amb} [1, 2]. At the same time, the operation of closed type air conditioning systems (processing of indoor air) is characterized by relatively insignificant fluctuations in the heat load on the air coolers (AC), corresponding to changes in the room air temperature in a rather narrow range (about 5 °C) compared to the cooling of the ambient air. For such closed type air conditioning systems, it is very effective to use compressors with frequency converters that provide refrigeration capacity regulation from nominal (rated) to 50% of nominal and even lower. In this case, due to a change in the rotational speed of the piston compressor electric motor, the suction pressure, respectively, and the boiling point of the refrigerant in the evaporator-air cooler are kept constant, which ensures efficient operation of the compressor at high coefficient of performance (COP) while reducing the heat load to 50% of the nominal. However, the cost of compressors with frequency converters is 3-5 times higher than those without it.

The aim of the study is to develop an approach to the analysis of the efficiency of regulating the refrigeration capacity of an ACS compressor with a frequency converter for actual climatic conditions.

Research Methodology

In general case, an overall heat load of any ACS comprises the unstable heat load zone, corresponding to ambient (outdoor) air processing with considerable heat load fluctuations in response to actual climatic conditions, and a comparatively stable heat load zone for subsequent air cooling (subcooling) to a target temperature.

In modern VRF systems the load modulation is performed by varying refrigerant feed to air coolers. The COP, and the specific (per unit of refrigerant mass flow) generated refrigeration capacity are stabilized due to a change in the rotational speed of the piston compressor while reducing the heat load to 50% of the nominal.

Authors developed a methodological approach to the analysis of the efficiency of regulation of the cooling capacity of ACS in actual climatic conditions, according to which the overall range of changes in current heat loads is divided into two zones: the zone of effective regulation of refrigeration capacity without energy loss and the zone of reduced not adjustable (unregulated) refrigeration capacity.

For convenience of calculation for other refrigeration capacities of ACS the heat loads are represented in relative (specific) values per unit air mass flow (G_a = 1 kg/s)– as specific heat load, or refrigeration capacity of a refrigerating machine (RM), $q_0 = Q_0/G_a$, *kJ/kg*, where Q_0 is the total heat load (refrigeration capacity) for air flow G_a.

The rational value $q_{0.rat}$ of specific refrigeration capacity q_0 (related to the unit of air flow G_a = 1 kg/s) on the AC, required for cooling the ambient air to a target temperature 10ºC ensures the maximum specific annual refrigeration capacity production $\sum(q_0{\cdot}\tau)$ taking into account the actual current climatic conditions [3].

The specific cooling capacity is calculated as: $q_0 = \xi{\cdot}c_{ma}{\cdot}(t_{amb} - t_{a2})$, kJ/kg, where: ξ – coefficient of water vapor condensation heat, calculated as ratio of the overall heat removed from the air being cooled, including the latent heat of water vapor condensed from the ambient air, to the sensible heat removed; t_{amb} – ambient air temperature; t_{a2} – air temperature at the air cooler outlet; c_a – humid air specific heat.

The specific annual refrigeration capacity production $\sum(q_0{\cdot}\tau) = \sum(\xi{\cdot}c_{ma}{\cdot}(t_{amb} - t_{a2}) \cdot \tau)$, where τ – time interval, *h*.

The rational specific cooling capacity $q_{0.rat}$ is divided in half $q_{0.rat}/2$ to determine the ranges of constant and variable (adjustable) loads.

The specific refrigeration capacity consumption in the zone of its frequency regulation $q_{0.10/2\text{reg}>0}$ (positive values in the zone of adjustable refrigeration capacity from 100 to 50% – above $q_{0.10rat}/2$) defined as $q_{0/2\text{reg}>0} = q_0 - q_{0.rat}/2 \geq 0$, as well as below the range of its frequency regulation $q_{0.10/2reg<0}$ (positive values in the unregulated range of refrigeration capacity below 50% – below $q_{0.10rat}/2$): $q_{0/2reg<0} = q_{0rat}/2 - q_0 \geq 0$. The values of the unused excess of the installed refrigeration capacity: $q_{0.10rat}/2 - q_{0.10/2reg>0}$ in the zone of its frequency regulation (above $q_{0.10rat}/2$), its excess: $q_{0.10rat}/2 - q_{0.10/2reg<0}$ outside the range of its regulation (below $q_{0.10rat}/2$), the total expenditures of increasing consumption $\Sigma(q_{0.10/2\text{reg}>0}{\cdot}\tau) = \Sigma[(q_{0.10} - q_{0.10rat}/2){\cdot}\tau] \geq 0$ and excess of refrigeration capacity $\Sigma[(q_{0.10rat}/2 - q_{0.10/2reg>0}){\cdot}\tau] = q_{0.10} - q_{0.10rat}/2 \geq 0$ in the zone of its regulation (above $q_{0.10rat}/2$) and consumption $\Sigma(q_{0.10/2reg<0}{\cdot}\tau) = \Sigma[(q_{0.10rat}/2 - q_{0.10}){\cdot}\tau] \geq 0$ and excess of installed refrigeration capacity $\Sigma[(q_{0.10rat}/2 - q_{0.10/2reg<0}){\cdot}\tau] = \Sigma[(q_{0.10} - q_{0.10rat}/2){\cdot}\tau] \geq 0$ below the range of its regulation (lower $q_{0.10rat}/2$).

Results

For the climatic conditions of the south of Ukraine, when air is cooled to a temperature of t_{a2} = 10 ºC, the maximum specific annual refrigeration capacity production $\sum(q_0{\cdot}\tau)$ takes place at specific (at G_a = 1 kg/s) refrigeration capacity $q_0 \approx 34$ *kJ/kg*, which is taken as rational $q_{0.rat}$ [3].

Current values of ambient temperature t_{amb}, specific heat loads at the ACS air cooler (AC) $q_{0.10}$, consumption of specific refrigeration capacity in the zone of its frequency regulation $q_{0.10/2\text{reg}>0} = q_{0.10} - q_{0.10rat}/2 \geq 0$ (positive values in the zone of adjustable refrigeration capacity from 100 to 50% – above $q_{0.10rat}/2$), as well as below the range of its frequency regulation $q_{0.10/2reg<0} = q_{0.10rat}/2 - q_{0.10} \geq 0$ (positive values in the unregulated range of refrigeration capacity below 50% – below $q_{0.10rat}/2$) when the ambient air is cooled to the temperature t_{a2} = 10 ºC for climatic conditions (Voznesensk, Nikolaev region, 2015) are shown. The calculations were performed for $q_{0.10rat}$ = 34 kJ/kg, the threshold value $q_{0.10rat}/2 \approx 17$ *kJ/kg*, corresponding to a 50% reduction in the nominal refrigeration capacity.

As it shows, the share of cold production at 50% frequency regulation of refrigeration capacity is: $\Sigma(q_{0.10/2reg>0}{\cdot}\tau)/(\Sigma(q_{0.10/2reg>0}{\cdot}\tau) + \Sigma(q_{0.10/2reg<0}{\cdot}\tau)) \approx 0{,}47$, i.e. about 47% of the total monthly amount of cold expended for cooling the air in the range of variation of the current heat load $q_{0.10}$ from 0 to $q_{0.10rat}$ = 34 *kJ/kg*.

However, with respect to the unused monthly excess of the installed cooling capacity over the expendable for cooling the air $\Sigma[(q_{0.10rat}/2 - q_{0.10/2reg>0})\cdot\tau] = q_{0.10} - q_{0.10rat}/2 \geq 0$ in the region of 50% of its frequency regulation, the share of refrigeration capacity monthly production is 2200/(2200+10500)≈0,17), i.e. about 17%, and almost half as much (2200/[2 (2200+10500)] ≈0,087) in the entire range of changes in the current heat load $q_{0.10}$ from 0 to $q_{0.10rat}$ = 34 *kJ/kg* for the July.

This indicates, firstly, the presence of significant reserves to increase the efficiency of ACS by using the excess of installed refrigeration capacity over that consumed for cooling air, in particular, by accumulating it for subsequent consumption, which provides a significant reduction in installed refrigeration capacity, and secondly, the possibility to use other methods of regulating refrigeration capacity in addition to changing the speed of the compressor motor, for example, by turning off the cylinders or the compressor itself in the case of several compressors etc.

If ACS operates in June or August, the efficiency of applying the refrigeration capacity control by changing the rotational speed of the compressor electric motor will be even lower, and taking into account 3-5 times higher cost of compressors with frequency converters, their application for ACS becomes problematic. When ambient air is being cooled from t_{amb} to the higher temperatures t_{a2} = 15, 17 and 20 ºC, as the cooling temperature t_{a2} rises a significant proportion of the unstable heat load is replaced from its adjustable range ($q_{0/2reg>0} = q_0 - q_{0.rat/2} \geq 0$), which falls on the $q_0 \geq q_{0.rat}/2$, into the range of unregulated heat load $q_0 \leq q_{0.rat}/2$.

As it shows, the share of refrigeration capacity monthly production at 50% frequency regulation of refrigeration capacity is: $\Sigma(q_{0.15/2reg>0}\cdot\tau)/(\Sigma(q_{0.15/2reg>0}\cdot\tau) + \Sigma(q_{0.15/2reg<0}\cdot\tau)) \approx 0.17$, i.e. about 17% of the total monthly amount of refrigeration capacity expended for cooling the air in the range of variation of the current heat load $q_{0.15}$ from 0 to $q_{0.15rat}$ = 25 kJ/kg.

The share of refrigeration capacity monthly production at 50% frequency regulation of refrigeration capacity is: $\Sigma(q_{0.17/2reg>0}\cdot\tau)/(\Sigma(q_{0.17/2reg>0}\cdot\tau) + \Sigma(q_{0.17/2reg<0}\cdot\tau)) \approx$ 0,093, i.e. about 9,3% of the total monthly amount of refrigeration capacity expended for cooling the air in the range of variation of the current heat load $q_{0.17}$ from 0 to $q_{0.17rat}$ = 22 kJ/kg.

Conclusions

A method and approach to the analyzing the efficiency of regulation of the refrigeration capacity of ACS in actual climatic conditions is proposed, according to which the entire range of changes in current heat loads is divided in two zones: the zone of ambient air processing with considerable fluctuations of the current heat load, that requires effective refrigeration capacity regulation by compressor with frequency converters (from 100% rated refrigeration capacity down to about 50 %) and not adjustable zone of reduced refrigeration capacity below 50 % rated refrigeration capacity of compressor. The magnitudes of threshold refrigeration capacity between both zones are chosen according to the rational value of installed refrigeration capacity on the ACS, required for cooling the ambient air to a target temperature that ensures the maximum annual refrigeration capacity production in actual climatic conditions.

It is shown that for the warmest summer month, the proportion of refrigeration capacity monthly consumed for cooling the ambient air to a set temperature with a 50% frequency control of refrigeration capacity is about 10% of its total amount that could be monthly produced at rated load. At higher temperatures of chilled air, as in cooler periods during the summer months, it is even smaller. This indicates a low efficiency of regulating the refrigeration capacity of ACS by changing the rotation speed of the reciprocating compressor electric motor and the need for other control methods.

The proposed method and approach to the analysis of the efficiency of the refrigeration capacity regulation of the ACS compressor by distributing the overall range of changes in current heat loads allows to increase the efficiency of utilizing the installed refrigeration capacity in current climatic conditions.

References

1. Marque, R.P., Hacon, D., Tessarollo, A., Parise, J.A.R.: Thermodynamic analysis of trigeneration systems taking into account refrigeration, heating and electricity load demands. Energy and Buildings 42, 2323–2330 (2010).
2. Ortiga, J., Carles, B.J., Alberto, C.: Operational optimization of a complex trigeneration system connected to a district heating and cooling network. Applied Thermal Engineering 50, 1536–1542 (2013).
3. Li, Y., Wu, J., Shiochi, S.: Modeling and energy simulation of the variable refrigerant flow air conditioning system with water-cooled condenser under cooling conditions. Energy Build. 41, 949–957 (2009).