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The present paper is concern with the compressor capacity control strategies which minimized energy consumption. New control methods are based on the steady state and dynamic mathematical models of refrigeration systems. The pulse width modulation control capacity mode was analyzed and cascade of capacity control for one and a group of compressors are suggested. A new capacity control method using mathematical model and electronic control system of the screw compressor was proposed for freezers which results in energy savings of the refrigeration plant.

INTRODUCTION

In most refrigeration systems the load varies significantly during operation. In view of controlability, wear of equipment and peak power consumption continuous adaption to loads is often essential. Better information on system dynamics would certainly improve the understanding of compressor capacity control strategy and reduce design errors.

MATHEMATICAL MODEL

The single stage refrigeration system with direct cooling consists of screw compressor, water condencer, evaporator, heat exchanger and cooling hold.

The set of equations can be written in matrix form as

$$\frac{\partial \mathbf{x}(\tau)}{\partial \tau} = \mathbf{A}\mathbf{x}(\tau) + \mathbf{B}\mathbf{u}(\tau)$$

$$\mathbf{x}^T(\tau) = \left[P_e,\ \delta T, P_c, T_a\right]$$

$$\mathbf{u}^T(\tau) = \left[m_p, T_{pi}, \dot{m}_a, h_1, h_2, T_w, \dot{m}_w\right]$$

CONTROL STRATEGY

The control accuracy can be increased if the evaporating temperature is changed continuously according to the air hold temperature or heat load deviation (Fig.1). According to this method the set value suction pressure is corrected by air temperature in the cooling hold. It enables us to improve the energy efficiency due to evaporating temperature raising under part load.

It enables us to raise the reliability of the control system by means of reducing the number of controller drive switches together with reducing the control valve wear. As a result of synthesis of pulse width capacity control system the optimal mode of modulation

$$\tau_n^u = \frac{\mathrm{mod}\left[\mathbf{P}_{s.n}^T \mathbf{H}^T \mathbf{QH}\mathbf{b}'(0)\right]}{U\left[\left(\mathbf{b}'(0)\right)^T \mathbf{H}^T \mathbf{QH}\mathbf{b}'(0) + c\right]}$$

and switching functions

$$S_n = \mathbf{P}_{s.n}^T \mathbf{H}^T \mathbf{QHb}\left(\tau_n^u\right),$$

are obtained meeting the optimisation criterion

$$J = \sum_{n=0}^{\infty} \Delta V_n + f\left(\tau_n^u\right) u_n^2$$

The transient behaviour analysis will prove the reducing actuator time positioning from 400s to 40s. The time response will reduce from 760s to 120s , the controller drive switchings will reduce from 261 to 6 and the suction pressure derivative will be under
55 Pa/s.

The less energy consumption for freezing is being resulted because of the optimal evaporating temperature definition. The energy consumption during freezing time versus evaporating temperature T_e has optimum (minimum).

The control capacity method (Fig.1) is based on measurement of a freezer air temperature, evaporator temperature and compressor power (or condenser temperature).The control action is based on the difference between the instantaneous value of controlled suction pressure and its desired value. The set value suction pressure is corrected by energy consumption.

Using the mathematical model, the program calculates regularly the optimum evaporating temperature (pressure suction) in the freezer and sets this value using continuous compressor control.

The static optimisation is realized due to solving heat balance equations
of the refrigerating hold

$$\begin{cases} \tau_f = \tau_f(T_a) \\ T_a = T_a(\tau_f, T_a) \end{cases}$$

and condenser

$$\begin{cases} T_c = T_c(T_w, T_c) \\ T_w = T_w(T_c, T_w) \end{cases}$$

Using the T_e, T_c, τ_f we can determine compressor power $Ne = Ne(T_e, T_c)$ and compressor energy consumption $W = Ne\tau_f$.

The control system is looking for the evaporating temperature in accordance with the minimum power consumption.

We investigated the energy efficiency under parallel compressors supplying one cold utilizer as well. As a result the maintain of equal capacities is more efficient than in serial capacities. The method and automatic capacity control system of parallel compressors with equal and any desired capacity ratio are developed (Fig.2). The suction pressure and electrical power difference and sum are considered as a controlling outputs. The switching over from the limit power mode to the mode of maintaining suction pressure is realized at a signal impling the limit value of suction pressure. At the same time the difference and sum of used compressor capacities are determined and by resulting difference equal (or any desired ratio) value of compressor capacities are being maintained; a sum of capacities is being compared with the given one which is equal to the limit capacity of one of the compressors. When the sum of capacities is lower than that of the given one, one of the compressors is being switched off.

CONCLUSIONS

The evaporating temperature raise under part load, the capacity control by optimal evaporating temperature at freezing and parallel compressor operating with equal capacities will improve energy efficience: Pulse width mode in capacity control will increase reliability and control accuracy.

These control methods are indirect to contrast with the previous control systems which could not in fact hold the minimum energy consumption under environmental changes. Implementation of new control system would improve refrigeration system energy efficiency.

NOMENCLATURE

$\mathbf{A}, \mathbf{B}, \mathbf{H}, \mathbf{Q}$	matrixes
h	actuator position
m	mass
$\dot{m}$	mass flow rate
N	power
n	step discretization
P	pressure
T	temperature
δT	superheat temperature
V	Lyapunov function
W	power consumption
$\mathbf{x}, \mathbf{u}, \mathbf{b}, \mathbf{P}$	column matrixes
τ	time, pulse duration

SUBSCRITS

a	air
c	condenser
e	evaporator
f	freezing
i	inlet
p	product
u	control
s	suction
w	water

REFERENCES

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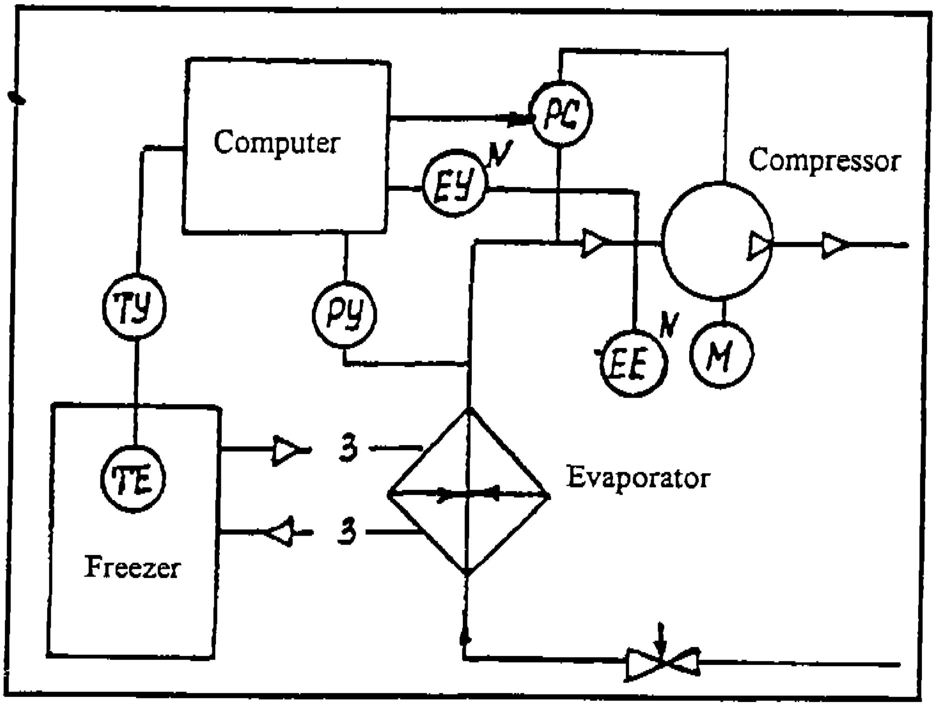

Figure 1. Compressor capacity control

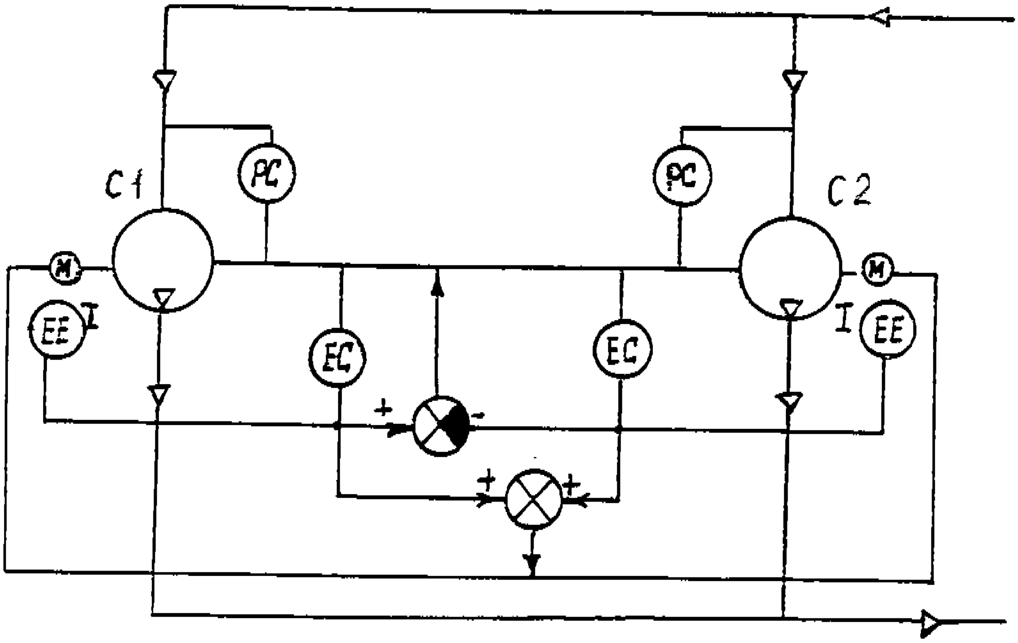

Figure 2. Parallel compressor capacity control