THE ANALYSIS OF TRANSITION CONDITIONS FROM SELF-REGULATION TO AUTOMATIC CONTROL IN REFRIGERATION MACHINE

Emil JUGUREANU*, Marius ATANASIU*

*GH. ASACHI TECHNICAL UNIVERSITY, Iasi, Romania.

1. INTRODUCTION

At steady state operation of a refrigeration system, there must be a constant correspondence between powers of evaporator (V), compressor (C) and condenser (Cd) Fig. 1.

\[ Q_V = (Q_{\text{cp}})_V = (Q_{\text{cp}})_{\text{cd}} \]  
\[ (Q_{\text{cp}})_V = (Q_{\text{cp}})_{\text{cd}} \]  
\[ K_S S_R (T_C - T_R) = K_S S_0 (T_R - T_S) \]  
\[ \lambda \frac{V_h}{V_i} q_o \cdot \frac{n}{60} = m q_o \]  
\[ \lambda \frac{V_h}{V_i} q_c \cdot \frac{n}{60} = K_S S_C (T_C - T_R) = m q_C \]

Heat flux (eq. a and b) passing from the cold room (R), fig. 1 to the evaporator (V) vaporizes a liquid volume m, resulting a vapor volume V, which is taken from compressor (eq. c) and passes into the condensate (eq. d). Compressor power consumption is \( P = m l \) and depending on its size, will aspirer, compress and deliver a vapor volume \( V_{\text{compressor}} = \frac{\pi d^2}{4} S \), volume \( (V_{\text{compressor}}) \) which should correspond to the volume \( V \) that it was talked above.

At a stable operation of the installation, there must be a constant correlation between the amount of liquid that go into the evaporator and the amount...
of vapor that goes to the compressor. A decrease in the amount of liquid entering the evaporator leads to:
- a decrease of the refrigerating power;
- a overheating of the aspirated vapor into compressor.

An increase of the amount of liquid that enters the evaporator leads to:
- operation in wet regime, unfavorable for the compressor;
- the evaporator is filled with liquid that goes to the compressor also;
- variation of the ratio between liquid and vapor influence the heat exchange coefficients;

To permanently keep the equality between the relations described above, it is necessary, that at a stable working regime the operating point have to be at the intersection of the characteristic curves of installation components: evaporator, compressor, condenser, the expansion valve, see Fig. 2 ± 4.

2. STABILITY OF A WORKING REGIME IN THE EVAPORATOR AREA

Knowing the characteristic curves of the evaporator \((Q_0)_V\) and of the compressor \((Q_0)_{cp}\), given in Fig. 2, in a steady state of operation, may correspond to states 1, 2 or 3. For example, in a steady state of operation, represented by state 1 Fig. 2, characterized by temperatures \(T_0\) (temperature of the vapor drawn into the compressor), \(T_{R1}\) (cold room temperature), \(T_{C1}\) (vapor temperature delivered by compressor), corresponding to the flowing thermal fluxes:

\[
Q_0 = (Q_0)_V = (Q_0)_{cp} \quad (5)
\]

The regime can be destabilized by the variation of the cold room temperature \(T_R\), or by the temperature of the vapor delivered by compressor \(T_C\).

Two cases, A and B are distinguished, as follows.

Case A: increasing of the ambient temperature it is accompanied by a variation of the temperature in the cold room from \(T_{R1}\) to \(T_{R2}\) respectively the transition from state 1 to state 1', Figure 2. As the difference \(T_R - T_0\) increases results a higher \((Q')_V\), i.e. a increase of the evaporator power.

\[
\text{where } (Q'_0)_V > (Q_0)_{cp}, \text{ corresponding to } T_{C1}
\]

So the compressor cannot handle the power of the evaporator.

Solution: The vapor temperature is increase from \(T_0\) to \(T_{02}\), reaching at the operating state from point 2.

In this way the evaporator power \((Q')_V\) decreases, reaching at \(Q_{02}\), while in the same time the product \(\frac{1}{V_1} q_0\) is increasing resulting an increase of refrigeration power of the compressor from \(Q_{01}\) to \(Q_{02}\).
\[ Q_{02} = (Q_0)_{v} = (Q_0)_{cp} \] (6)

Case B: increasing the condensing temperature from \( T_{C1} \) to \( T_{C2} \), respective the transition from state 1 to state 1”, Fig. 2.

It comes to an unstable operation because the evaporator continues to produce vapors at the power \( Q_{01} \) (corresponding to state 1) and the compressor works at a lower cooling capacity \( Q_{o}^{*} \) (corresponding to state 1”)

Solution: It is increase the evaporation temperature from \( T_{01} \) to \( T_{03} \) (corresponding to point 3), where we obtain a stable regime in which:

\[ Q_{03} = (Q_0)_{v} = (Q_0)_{cp} \] (7)

3. STABILITY OF A WORKING REGIME IN THE CONDENSER AREA

We take state 1, fig. 3 a stable regime for which:

\[ Q_{C1} = (Q_C)_{cd} = (Q_C)_{cp} \] (8)

Similar to the previous case if the evaporating temperature increases from \( T_{01} \) to \( T_{02} \), the new equilibrium will be given by point 2, where:

\[ Q_{C2} = (Q_C)_{cd} = (Q_C)_{cp} \] (9)

where \( Q_{C2} > Q_{C1} \)

4. WORKING REGIME STABILITY IN THE CONDENSER AREA

To maintain a stable working regime, a great importance has the flow section of the expansion valve, \( V_L \), fig. 1, whose size must adapt continuously to the refrigerant flow rate \( m \) [kg / s].

At a given operating regime by the F point, Figure 4, section of the expansion valve must be between \( S_{L1} \) and \( S_{L2} \), through which it pass a refrigerant flow rate \( m \) [kg / s], that ensures the power:

\[ Q_0 = G \cdot q_0 = (Q_0)_{v} = (Q_0)_{cp} \] (10)

Since increasing of the condensation temperature \( T_C \) leads to a decrease of \( Q_0 \) (as discussed above), it is shown that:

\[ Q_0 = m \cdot q_0 = (Q_0)_{v} \] (11)

Fig. 3. Evaporator characteristic curves

Fig. 4. Expansion valve characteristic curves
The liquid flow \( m \) that pass through the expansion valve section must be increased.

This is achieved through by the adjustment (manual or automatic) of the cross-section area in the expansion valve.

**Conclusions:**

a) all components of the refrigeration system evaporator (V), compressor (cp), Condenser (Cd) and expansion valve (VL) have their characteristic curves.

b) by manual or automatic adjustment the refrigeration system must be brought to a stable regime of operation

c) a stable operating regime is given by the points of intersection in the characteristic curves from the refrigeration components.

5. STATIC CHARACTERISTIC OF THE REFRIGERATORS AND POSSIBILITIES OF SELF REGULATION.

Static characteristic of the installation is built in order to:

a) to always know \( T_R \), the cold room temperature, fig. 5, and cooling capacity \( Q_0 \) [W] of the refrigeration system that works according to the ambient temperature \( T_{am} \).

b) to observe if at the ambient temperature variations \( T_{am1} \rightarrow T_{am2} \), fig. 5 b, the device can self-regulate, which means that the installation can fit in a stable regime, where:

\[
Q_R = (Q_0)_V = (Q_0)_{cp} \quad (12)
\]

Fig. 5-a. \( Q_0 = f(T_0, T_R) \) la \( T_c = ct. \) \quad (13)

In a condensing temperature \( T_{C1} \), it is considered three operational states \( F_1, F_2, F_3 \), corresponding to cold room temperature \( T_{R1}, T_{R2}, T_{R3} \), which correspond to thermal load \( Q_{01}, Q_{02}, Q_{03} \) and that (at stable regime) we have:

\[
Q_R = (Q_0)_V = (Q_0)_{cp} \quad (14)
\]

Fig. 5-b. The characteristic curves are given \( Q_R = f(T_{am}, T_R) \) for the same values of temperature \( T_{R1}, T_{R2}, T_{R3} \). Points \( F'_1, F'_2, F'_3 \), represent steady state equilibrium where:

\[
Q_R = (Q_0)_V = (Q_0)_{cp} \quad (15)
\]

The characteristic curve \( Q_0 = f(T_{am}) \) is obtained by joining points \( F'1, F'2, F'3 \). This curve allows the determination of the heat flux that enters in the cold space \( R \), for different ambient temperatures, \( T_{am} \).

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**Fig. 5 Static characteristic of a refrigeration machine and the possibility of self regulation.**
Fig. 5-c. The static characteristic of the installation is given $Q_S = f(T_R)$ that is made for temperatures $T_{R1}, T_{R2}, T_{R3}$, and thermal fluxes $Q_{R1}, Q_{R2}, Q_{R3}$.

Workflow: at a certain ambient temperature $T_{am}$, fig. 5 b, we can determine the parameters, $T_{R1}, T_{01}$ si $Q_{01} = Q_{R1} = Q_{S1}$.

6. CONCLUSION

A. In the terms of a stable work regime to a specific ambient temperature $T_{am}$ it is known the temperature from the cold space $T_R$, the refrigerant temperature $T_0$ and heat load of the evaporator.

B. The refrigeration system has the ability in certain limits to self-regulate. So, for example, fig. 5-b, for the temperature variations $T_{am} = T_{am1}$ the refrigeration machine enter in a steady state regime without any intervention from outside. The steady state regime goes by the equation:

$$Q_R = (Q_0)_{V} = (Q_0)_c$$  \[16\]

with the corresponding variation of the others parameters $T_0$ and $T_R$.

C. Manual and automatic adjustment applies where:

- Self-regulation does not work;
- It is required to keep the temperatures $T_0$ and $T_R$ as constant as possible at all environmental temperature variations $T_{am}$.

REFERENCES


