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PERFORMANCE OF A MEDIUM SIZE, CONSTANT SUPERHEATING PC-CONTROLLED EXPANSION VALVE FOR CHILLERS

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ABSTRACT

A electronic expansion valve, developed by authors was tested in a chiller test bench and its performance compared with a similar thermostatic expansion valve. A PC operated PID control was used, using constant superheating as control strategy. The experimental results obtained suggest that the use of electronic valves can increase the COP in chillers due mainly to the increase of cooling capacity, was also observed good stability when chiller was submitted to changes in operational conditions.

INTRODUCTION

In 1988, Brazil consumed 7,6 % of the total electric energy demand [1] for commercial and residential air conditioning and refrigeration. Taking into account that Brazil is in a world scale one of the countries that makes less intensive use of refrigeration systems, it means that a thoughtful analysis of best use and control of these systems is always required. One topic recently explored for control and optimal operation of refrigeration systems is the performance of expansion valves.

Most of the research works deals with modelling of expansion valves, using orifice similarity models [2], [3], [4], [5]; in 1971, Najork [6] and in 1982 Broersen [7] studied thermostatic valves dynamic behaviour, in 1986, Van der Meer and Touber [8] published an accurate study about mass flow rate control problems; later in 1987 Van der Meer [9] analyzed control problems related to mass flow rate in vapour compression chilling systems (VCCS); recent works [10], [11] have also studied control of expansion valves towards a better operation of VCCS; the authors of this work observed that new ways of controlling expansion valves are an open door in nowadays research. This paper deals with the experimental analysis of a medium size, constant superheating, PC controlled expansion valve working in a VCCS system, comparing its operation with that of a conventional thermostatic expansion valve (TEV).

ELECTRONIC EXPANSION VALVE PROTOTYPE DEVELOPED (EEVP)

Figure [1] shows the scheme of the electronic expansion valve prototype developed and built by the authors, it is driven by a screw coupled to a step motor.

The orifice diameter used is 2 mm, the pointer is a 30° conic shape, the step motor is characterized by 200 steps/round, and the screw used has a step of 0.8 mm/round; from totally close position to completely open, the valve is able to give 4.66 rounds.

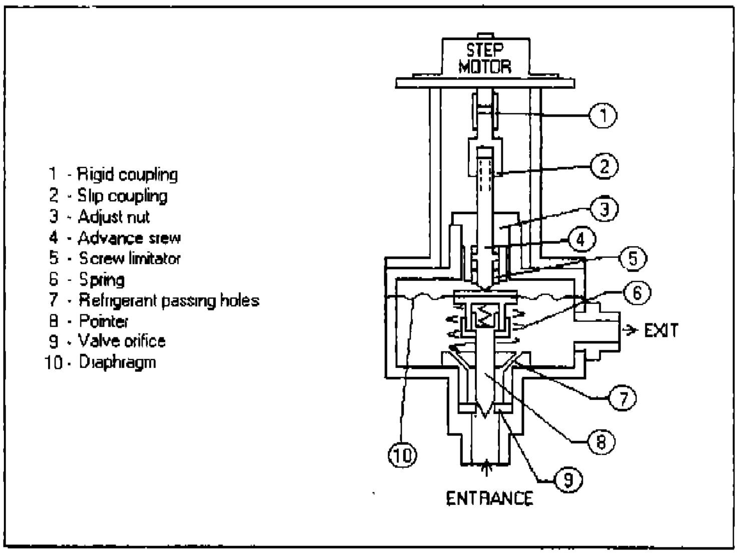

Figure 1 : Electronic expansion valve prototype (EEVP)

TESTING BENCH USED

The testing bench used for EEVP is shown in Figure 2. It allows the determination of energy balances for each component, using last generation sensors (piezo electric pressure transducers, piezoresistive pressure transducers, shaft encoders, LVDT type rotameter, thermocouples, torque meter, watt meter). The testing bench uses a data acquisition card installed in a PC-XT micro computer, with specific softwares developed for data treatment.

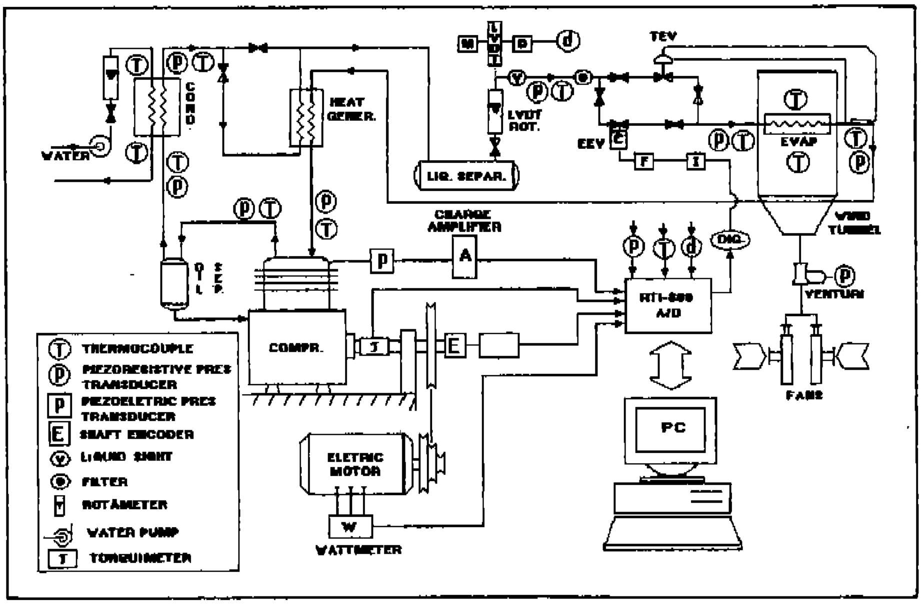

Figure 2. : Testing bench used

TESTING METHODOLOGY OF "EEVP"

30 steady state experiments were conducted with each of the valves in order to compare thermal parameters of VCCS testing bench. Several tests were also realised to determine EEVP control parameters, time constant and sensibility during steady state and transient operations. The methodology always keeps constant total mass of refrigerant inside the VCCS (8 kg) and compressor rotation (660 r/min); each test was realised keeping evaporation (T_{ev}) and condensation (T_{cd}) temperatures constant, by adjusting water flow rate in condenser (210 - 680 kg/h) and air flow rate in evaporator (310 - 716 kg/h). The superheating degree (ΔT_{sup}) desired was estimated 6K for both valves operating at 275K and 308K evaporation and condensation temperatures respectively.

In order to control the EEVP, the superheating was estimated directly by measuring evaporator inside pressure and exit temperature. The superheating measured was conveniently treated by a control routine to cause opening or closing movements of EEVP pointer. The EEVP was always totally close or in a safe position that was previously determined to give superheating above 6K at the beginning of each experiment and specific routines allowed its operation manually or automatically in order to keep ΔT_{sup} close to 6K. In order to realise a good energy balance in the compressor, a shaft encoder and a piezoelectric pressure transducer were used to obtain indicative diagrams. After each test, routines developed for this work, allowed the calculations of thermodynamic properties of refrigerant (R12), in each point indicated in figure 2, also refrigeration capacity ($\dot{Q}_R$), indicative work, refrigerant mass flow rate ($\dot{M}_R$), compressor power consumption ($\dot{W}_{el}$), water flow rate, air flow rate and thermal parameters like real coefficient of performance (COP_r) and Carnot equivalent coefficient of performance (COP_c) defined by equation (1).

$$COP_c = \frac{T_{ev}}{(T_{cd} - T_{ev})} \tag{1}$$

CONTROL SYSTEM OF "EEVP"

The control system used was the direct digital control (DDC), with a retrofeed proportional, integral and derivative (P I D) action system, as shown in equation (2).

$$m(t) = K_1\, e(t) + K_2 \int e(t)\, dt + K_3 \frac{d}{d_t}[e(t)] \tag{2}$$

The parameters K_1, K_2, e K_3, were determined by the methodology proposed by Ziegler-Nichols [12], for an open loop control; for that it is necessary to use a step entrance (in our case it was suddenly closed or opened the EEVP) to obtain a VCCS answer, because of hysteresis it was necessary to obtain parameters for valve opening , different from parameters for valve closing. These six parameters were obtained for only one arbitrarily chosen operational condition.

EXPERIMENTAL RESULTS

Figure 3 shows superheating history of VCCS, controlled by a thermostatic expansion valve (TEV); time constant is more than 140 sec and operation before this time was very unstable.

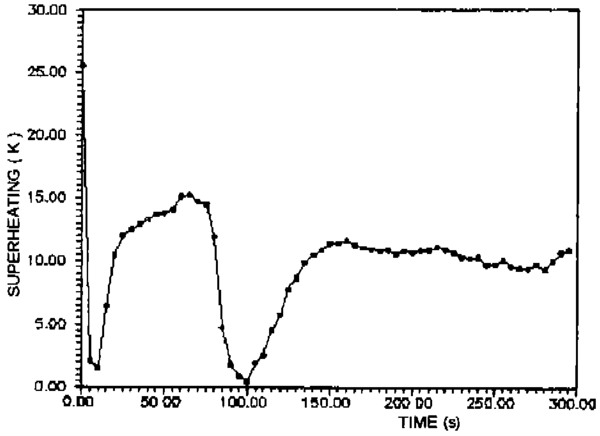

Figure 3 : History of superheating for specified T_{ev} and T_{cd}, using TEV

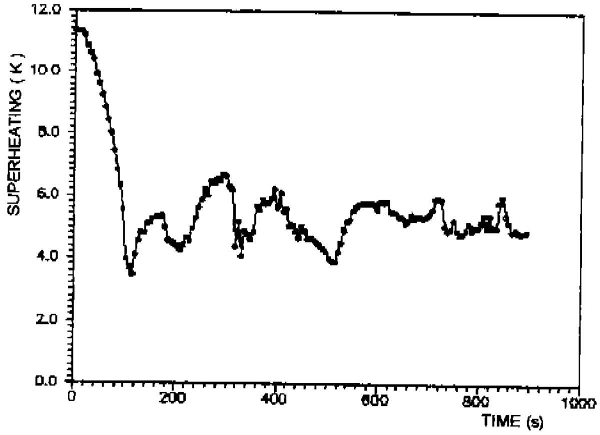

Figure 4 : History of superheating for specified T_{ev} and T_{cd}, using EEVP

Figure 4 shows superheating history when we use electronic expansion valve controlled by DDC system.

A settling time less than 100 sec is observed, assuming that superheating oscillations of ±1.5K give a good stability to VCCS systems. Figure 5 shows the superheating obtained with thermostatic expansion valve for $274K \leq T_{ev} \leq 281K$; $305K \leq T_{cd} \leq 317K$. Figure 6 shows the superheating obtained using an electronic expansion valve for the same range of T_{ev} and T_{cd}., used for the TEV.

In figures 5 and 6, we can observe that EEVP keeps superheating in the range 6K ± 1.5K whereas for TEV, superheating varies from 0K to 18K causing instabilities when superheating is close to 0K.

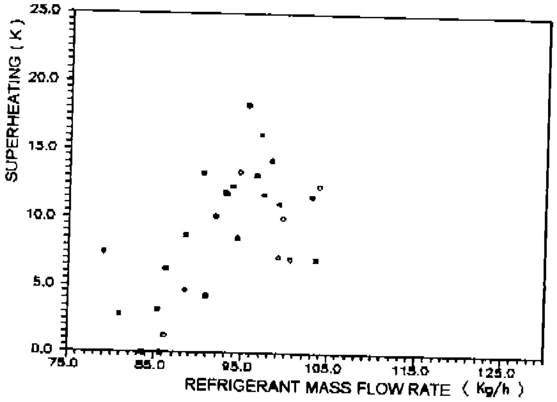

Figure 5 : Superheating for different T_{ev} and T_{cd}, using TEV

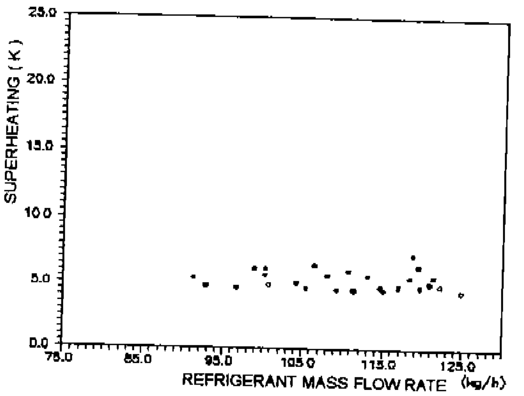

Figure 6 : Superheating for different T_{ev} and T_{cd}, using EEVP

Figure 7 shows real COP for both valves as a function of refrigerant mass flow rate ($\dot{M}_R$); we can observe that when $80 \leq \dot{M}_R \leq 100$ kg/h and $312K \leq T_{cd} \leq 315K$ thermostatic valve (TEV) gives higher COP but when bigger $\dot{M}_R$ are required ($\dot{M}_R > 100$ kg/h) the EEVP seems to be more efficient (bigger COP) than thermostatic valve, it was to be mentioned here that TEV used doesn't allowed $\dot{M}_R$ bigger than 105 kg/h for a orifice diameter of 2 mm.

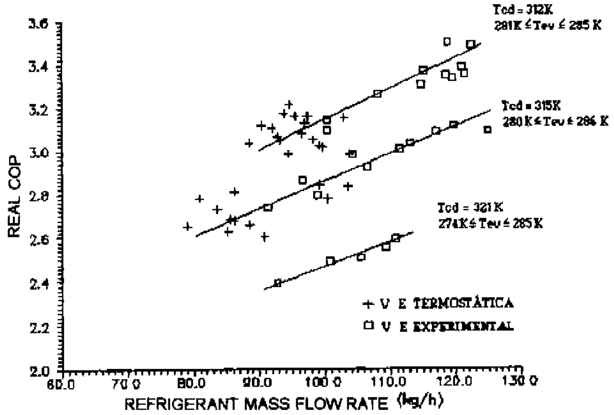

Figure 7 Real COP as a function of refrigerant mass flow rate for both valves

CLOSING REMARKS

From results shown above, we can observe that thermostatic valves increase superheating when higher refrigeration capacitys are required (see figure 5); we also observed that for TEV using, $T_{ev} \geq 276K$ and $T_{cd} \geq 316K$ operation of the VCCS is more stable and superheating tends to be 6K.

We can then conclude that, due to limitations of $\dot{M}_R$ imposed by TEV, refrigeration systems controlled by these valves have less sensibility to refrigeration capacitys bigger than the nominal allowed by this valves.

Electronic valves can keep superheating almost constant when controlled by DDC control system; the $\dot{M}_R$ can vary more than when using TEV, causing bigger COP^s when VCCS operate at $T_{cd} \geq 312K$.

We can also observe in figure 7 that for refrigeration capacity bigger than 3.6 kW and not very low evaporation temperatures $T_{ev} \geq 273K$, electronic valves with constant superheating seems to be in our case more appropriated than thermostatic valves.

SUGGESTIONS

For future works, we suggest the use of a pointer with parabolic shape to allow a linear variation of flow passage area; this will be better for controlling this valve. It is also necessary to obtain control parameters for different operating conditions in order to have a better idea of these parameters. Also we observed that a refrigeration system monitored by a PC-computer allows a better adjustment of T_{ev} and T_{cd} ; if we want wider ranges for T_{ev} and T_{cd} , it is recommended to install an intermediary heat exchanger between evaporator and condenser.

REFERENCES

[1] - CEMIG, 1988, *Seminário sobre Aquecimento Solar como Alternativa de Conservação de Energia*,Belo Horizonte.

[2] - ABRANOVICH, F.E., 1983, "Throttling Area in Needle and Poppet Valves," *Machine Design*, Vol. 55,pp. 291-292.

[3] - DAVIES, A., DANIEL S,T.C., 1973, "Single and Two Phase Flow of Dichlorofluormethane (R12) through Sharp Edged Orifices," ASHRAE trans., Vol 79, pp. 109,123.

[4] - LI LI, Z.C., HAN B., BAOQI, H., ZHANG, Y.Y., 1986, "An Experimental Investigation on Expansion Devices in Refrigeration System," *Science et Thechnique du Froid*, Refrigeration and Technology, Purdue Univ. (USA), pp. 81-87.

[5] - KRAKOW, K.I., LINS, S., 1988, "Refrigerant Flow through Orifices," ASHRAE Trans. Vol. 94, pp.484,489.

[6] - NAJORK, H., 1971, "Investigation of Dynamical Behaviour of Evaporators with Thermostatic Expansion Valve," III Cong. Int. Froid Vol 2 , Washington, pp. 759-769.

[7] - BROERSEN, M.P.T., 1982, "Control with a Thermostatic Expansion Valve. Int. J. Refrig.," Vol. 5, pp. 209-212.

[8] - VAN DER MEER, J.S.,TOUBER, S., 1986, "Influence of the Expansion Valve on the Evaporator Performance," *Science et Technique du Froid*, Refrigeration and Technology, Purdue Univ. (USA), pp. 71-79.

[9] - VAN DER MEER, J.S., 1987, "Simulation of a Refrigerant Evaporator," PhD thesis, Delft Univ., 152p.

[10] - YASUDA, H., YSHIBANE, K., 1987, "Refrigerant Flow Control by an Electrical Driven Expansion Valve in Refrigeration Systems," XVII Cong. Int. du Froid, Vienne, Paris IIR, pp. 654-659.

[11] - GUIGUEMDE, R., 1990, "Modelisation de la Détente Diphasique d'un Fluide pour Application aux Detendeurs de Pompe a Chaleur," These de Doctorat, INSA de Lion, 177p.

[12] - ZIEGLER,J.G, NICHOLS,N.B., "Optimum Settings for Automatic Controllers," ASME Trans., vol. 64, p. 759-768, 1742.

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