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Adjustable throat-area expansion valves used in automotive air conditioning systems: A mini review

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A B S T R A C T

Adjustable throat-area expansion valves (ATAEV) are functioned as area regulator control units. In literatures, there are many expansion valves normally used in automotive air-conditioning systems, as regulator and electrical type valves. Nevertheless, a review study for such issue has not been introduced, according to the best of author knowledge. The present paper presents a review study for expansion valves used in air conditioning of automobiles. Different types of expansion valves are discussed including the working principles and the limitation of their working conditions.

1 Introduction

Adjustable throat-area expansion valves (ATAEV) are essential part of automotive air conditioning system. Fig. 1 shows the components of automotive air conditioning system, while Fig. 2. Shows a schematic view of the adjustable throat-area expansion valve and it working principle. In fact, there are many area regulator control units, as expansion valves and capillary tubes. Expansion valves (EVs), as regulator and electrical type valves, are normally used for adjustable throat-area in air conditioning systems. The electronic expansion valves, driven by a stepper controlled by a pulse signal generator, have been widely applied in refrigeration systems. The stepper is normally afford definite adjustments to valve control, for example, opening diameter of 1.8 millimeter will reach a exactness up to 0.002 mm2 of throat space per one pulse signal. Due to precise and quick management for refrigerant flow, the refrigeration systems exploitation EEVs have far more benefits than those exploitation conventional enlargement devices in terms of refrigerant supply stability and superheat control reduction. The study by Aprea and Mastrullo [1] showed that EEV has a far better management for superheat underneath steady-state conditions. As a result, EEV will execute a lot of robust improved management strategy and contains a more steady operation [2]. Moreover, the EEV systems have far better stability as compared with the capillary tubes [3]. The robustness of EEVs may be attributed to specific flow metering or precise gap adjustment, while other expansion valves aren't similar to EEVs. The impact of the valve parameters was investigated by imposing a step increase of the suction line pressure and simulating the response of the evaporator superheat over time. This approach allowed comparison of the steady state and transient behavior of superheat with totally different valve styles. This study presents a review work of adjustable throat-area expansion valves (ATAEV) applied in automotive industries. This study is one of our sequences studies in automotive industries, see e.g., [4–34] and

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refrigeration/air containing systems, see e.g., [35,36].

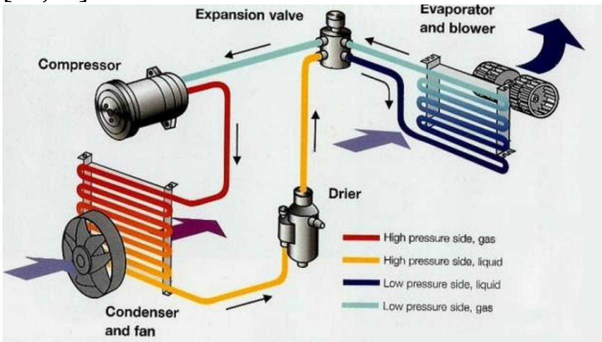

Figure 1. Details of automotive air conditioning system.

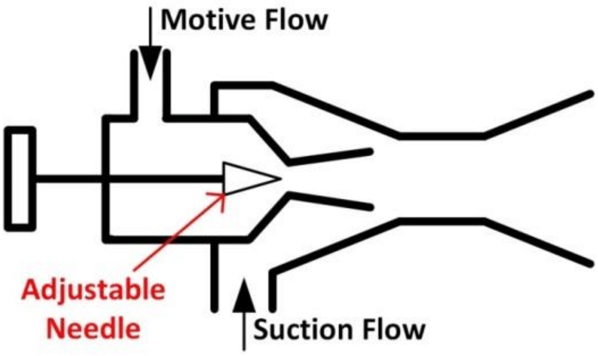

Figure 2. Schematic view of the adjustable throat-area expansion valve.

1. Literature overview

The expansion devices control the refrigerant mass flow and balance the system pressure in automotive refrigeration cycle. A capillary tube and a throttling expansion valve (TXV) are used as devices in many applications, as refrigeration, air-conditioner, and chiller systems. Despite the fact that the capillary tubes and short tube orifices have benefits of simplicity and low price, they're not applicable for a system that needs precise flow control with accurate flowrate. The working principle of the capillary tube is shown in Fig. 3, while Fig. 4 shows the schematic view of the capillary tube.

The TXV adopts a mechanical management technique, which supports constant superheat at the evaporator outlet. However, the time interval of the TXV is comparatively slow, and this slowness causes an unstable operative condition referred to as superheat looking [37]. Recently, multi-type heat pumps and inverter-type heat pumps have used electronic expansion valves (EEVs) rather than the standard growth devices [38,39]. The EEV, as shown in Figs. 5 and 6, affords a definite, fast, and stable flow management for a good vary of rate as a result of it uses a vigorous electronic management technique supported a complicated management algorithmic program. The EEV in multi–type heat pumps permits a lot of comfort management and energy conservation. Most of the previous studies on growth devices investigated constant-area growth devices, like capillary tubes and short tube orifices. Most capillary models changed the two-phase friction issue within the tube supported the measured knowledge [40–42]. Empirical correlations for the resistance pressure drop, mass rate, and delay of vaporization were additionally developed to predict the flow characteristics of refrigerants passing through capillary tubes [43–46]. Additionally, the prevailing empirical or semi-empirical models of flashing flow of refrigerants in brief tube passages were developed by modifying the orifice flow equation. Aaron and Domanski [47] developed an empirical correlation for R22 mass flowrate through short tube passages at subcooled water conditions by modifying the single-phase orifice equation. Choi et al. [48] developed a generalized correlation for R12, R22, R134a, R407C, R410A, and R502 flowing through short tube orifices by playing dimensional analysis. However, analysis on the mass flow characteristics of EEVs is extremely restricted. Shanwei et al. [49] measured the mass flow characteristics through EEVs for various tapered needle valves and passage inner diameters at an equivalent water and outlet conditions. They finished that there was no obvious relationship between mass rate and needle valve pure mathematics (taper angle) at an equivalent flow space. The mass rate remained constant with an equivalent flow space even though the needle valve pure mathematics was varied. It is worth to say that they didn't take into account the results of the passage length within the EEVs. Choi and Kim [50] compared the performance of a setup having EEV as a growth device thereupon and a capillary for numerous refrigerant charge conditions. In general, for a good vary of operative conditions, the EEV system showed abundant higher performance than the capillary system. As a result, the EEV has many benefits, as it could be wide applied in inverter-type setup and a multi-type setup systems. However, the experimental

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knowledge and mass flow models for EEVs are often restricted in literature. Comprehensive studies on the flow characteristics of refrigerant flow through EEVs required to properly choose and analyze the growth device in multi-type heat pumps. The objectives of the study to investigate research for the mass flow characteristics of R22 and R410A through EEVs and to develop an empirical correlation for the mass flow prediction through EEVs. The mass flow rates through EEVs were measured by varied the EEV step control, water and outlet pressures, and the subcooling. Empirical mass flow correlation was developed by incorporating a dimensionless correction constant in terms of EEV geometries and operative conditions. Kasayi [51] applied meticulous analysis and came up with that the flow constant of valve is relative to Reynolds range and flow direction. Atake and Akiyama [52] implies that the flow constant of slippery valve is normally set by Reynolds range, valve openings, and radial clearance. Davies and Davids [53] believed that flow constant is usually controlled by refrigerant in outlet condition rather than other parameters; additionally, the relation between actual mass rate and throttled refrigerant condition is linear inverse relation. In literature, the study on R407C and R410A isn't sufficiently lined in previous studies, despite the fact that these refrigerants are used or thought in new refrigeration systems [54–56].

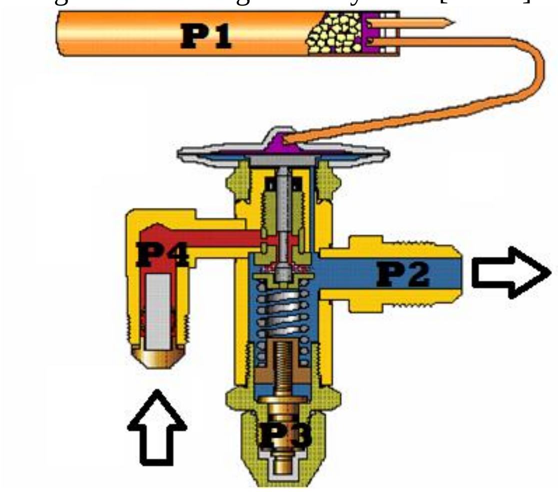

Figure 3. The working principle of the capillary tube.

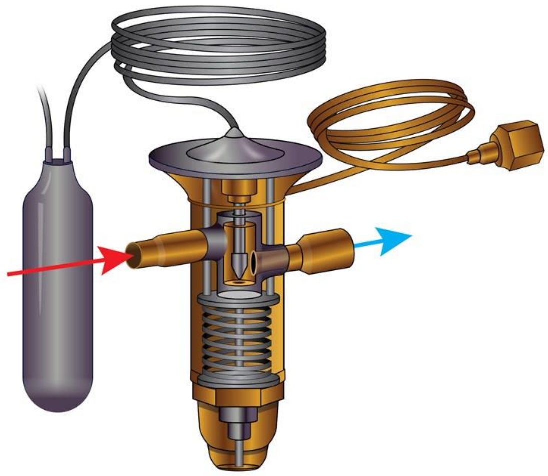

Figure 4. Schematic view of the capillary tube.

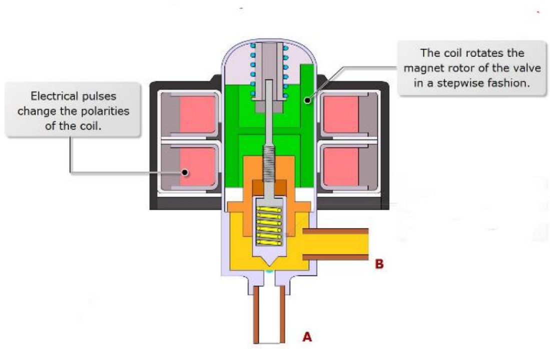

Figure 5. The working principle of electronic expansion valve.

Figure 6. Schematic view of the electronic expansion valve.

In some refrigeration applications, as in automotive, difficulties arise in modeling of EVs due to establishing stable operational

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conditions. The unstable issue is addressed by mathematical modelling tools for regulator growth valve and a two-phase concentric-tube. The model accustomed the dynamic response of the evaporator and EV to changes within the system operational conditions. The model applied equations for the conservation of mass, momentum, and energy to simulate the flow and heat transfer, while differential equations for the two-phase region and mean void fraction are applied for the dynamic behavior of the evaporator. The model additionally has the aptitude to look at the consequences of refrigerant and heat flux distribution. The regulator growth valve model takes into consideration the pressure forces on the diaphragm in addition to the pressure drop across the passageway and the refrigerant mass flowrate. The model additionally includes the consequences of the spring constant, bulb time constant, and offset temperature, as determined by the force applied at valve closing conditions. Superheat response was investigated by imposing suction line pressure oscillations that are varied over a variety of frequencies. Giant superheat fluctuations were found to exist during a given band, wherever the amount was found to get on the order of fifty to a hundred seconds; pressure oscillations during this vary ought to be avoided operating condition. Disturbances outside of this band didn't turn out important superheat responses. Factors influencing the magnitude of the superheat response depend upon the frequency of the perturbations: at high frequencies the valve doesn't answer superheat fluctuations (feedback), however is incredibly sensitive to the slope of the flow versus superheat curve as determined by valve geometry; on the other hand, at low frequencies, the valve behavior is dominated by the superheat feedback; and also the flow versus superheat curve is insignificant.

The mass flowrate model for EEVs within the literature [57–60] considered single correlation with variable flow space. The flow constant within the equation is quite complicated and that needs a dynamically adjustment by a motor and therefore the flow constant could be varied. In recent years, characteristics of the EEV are investigated through experimental and modeling tools. Early studies [61–63] developed a correlation for flow constant within the EEVs. The correlation have conducted some analysis within the theoretical modeling of mass flow characteristics in EEV. Accordingly, prediction of refrigerant mass flow in EEV at totally different conditions was presented. Buckingham theorem [64,65] developed correlations for the flow constant depends on plenty of parameters, like flow space, water condition (pressure, density, subcooling, viscosity, surface tension), outlet condition, and so on. However, the models don't characterize physical behavior of flowing through EXV and therefore the use of the correlations is restricted. Actually, their validations with experimental knowledge yielded results among a relative deviation of 100%. The studies, on the other hand, investigated mass flow characteristics of R22, R410A and R407c in EEV. The single-phase correlation is changed by introducing fluid enlargement; the mass flow constant is especially influenced by EEV range and subcooling. Therefore, a simplified model for mass flow constant was developed by incorporating couple of parameters: EEV range and subcooling.

2. Conclusions

There are many area regulator control units as electrical expansion valves normally used in air-conditioning systems for automobiles. Electronic expansion valves (EEVs) are ones of widely used in refrigeration systems because of the flexibility of its mass flow regulating mechanisms and a robust adaptability to a wide range of operating conditions. The current work provides a review study for adjustable throat-area expansion valves used in refrigeration/air conditioning systems for automotive. Yet, similar review study has not been introduced in literature, according to the best of author knowledge.

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