FESIBILITY STUDY OF ELECTRONIC EXPANSION VALVE FOR TRANSPORT REFRIGERATION SYSTEM

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Abstract: Now a day's refrigeration became an essential part of the food chain. It is being used in all stages, from food processing, to distribution, retail and final consumption in home. This report presents a preliminary investigation on the development of electronic expansion valve technology for Transport Refrigeration Systems. Road transport refrigeration equipment is required to operate reliably in much harsher environments than stationary refrigeration equipment. At all the ambient conditions and different cargo box temperatures it is very difficult to maintain required capacity and constant set point temperature which are the basic requirements for the food industries to maintain product quality till the delivery.

The expansion valve currently used for the most of the TRS is Thermostatic Expansion Valve. Though it is less expensive compared to EEV, it has its own limitations to meet various requirements of TRS. To have solution for this problem incorporate a very well-organized expansion valve which can regulate the appropriate mass according to the capacity need along with temperature and super heat control. Though the cost of EEV is high, versatile characteristics of EEV which can able to satisfy or improve the performance of refrigeration cycle.

This paper provides the benefits that can be added through the EEV for transport refrigeration cycle to overcome limitations of TXV.

Key words: Transport Refrigeration System, EEV, TXV, super heat, mass flow distribution, quick response, controller, stepper motor.

1. INTRODUCTION

1.1Transport Refrigeration System:

Fig 1: Layout of Transport Refrigeration System

Road transport refrigeration equipment is required to carry not only the edible food items but the harvests, medicine, ice creams etc. the above mentioned products has to be maintained at different box temperature for its safety requirements. And there can be need to transport different goods within a single trailer by maintaining product dwelling temperature. The range of temperature that can be maintained can be from -25ºC to +25ºC in a single trailer unit. For this purpose the whole trailer box is divided into the two to three compartments to accommodate various kinds of goods at a time. This type of trailer units are called multi temperature units and another type is single temperature units where only one set point is maintained.

For both single and multi temperature units the cycle used is vapor compression refrigeration cycle which contains four major parts such as compressor, air cooled condenser, Expansion Valve, Evaporator. For multi temp units we have two to three evaporators and expansion valves based on the zones divided. As we have single condenser and receiver tank care need to be taken to supply proper amount of refrigerant to each evaporator by maintaining different temperatures simultaneously.

Generally Transport refrigeration systems need to be operated reliably in much harsher environments than stationary refrigeration equipment. Because of rapidly increasing use of transport refrigerated units to transport wider range of goods, home delivery and greater quality expectations, is placing considerable pressures on the transport refrigeration industry to meet temperature control requirements during the storage and transport of perishable foods. Due to the wide range of operating conditions and constraints imposed by available load, transport refrigeration equipment could not able to meet the expected capacity requirements. To meet varying load conditions and temperature requirements for different kinds of products it is necessary to supply the required amount of refrigerant which completely depends on the metering device called expansion valve.

1.2 Thermostatic Expansion Valve:

Fig 1.1: Thermostatic expansion valve

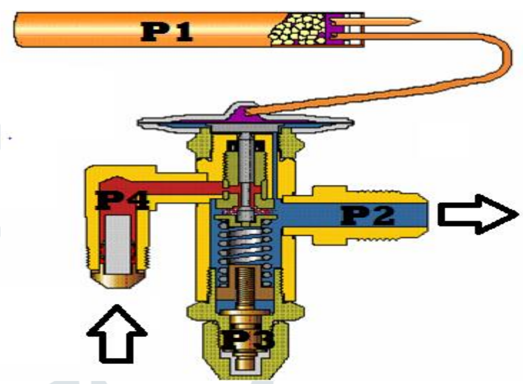

Fig 1.2: Cross sectional view of Thermostatic valve

Typically the expansion valve currently used for the transport trailer units is thermostatic expansion valve (TXV) which relies on a bulb filled with a special mix of refrigerant to mechanically regulate the amount of superheat (ESHT) in the system.

Architecture analysis of TXV:

Thermostatic Expansion Valve is a mechanically regulated valve. Sensing bulb is connected to the TXV by a length of capillary tubing which transmits bulb pressure to the top of the valve's diaphragm. The sensing bulb, capillary tubing and diaphragm assembly is referred to as the thermostatic element. The diaphragm is the actuating member of the valve. Its motion is transmitted to the pin and pin carrier assembly by means of one or two pushrods, allowing the pin to move in and out of the valve port. The superheat spring is located under the pin carrier, and a spring guide sets it in place. On externally adjustable valves, an external valve adjustment permits the spring pressure to be altered.

Working principle of Thermostatic Expansion Valve:

There are three fundamental pressures acting on the valve's diaphragm which affects its operation: sensing bulb pressure P1, equalizer pressure P2 and equivalent spring pressureP3. The sensing bulb pressure is a function of the temperature of the thermostatic charge, i.e. the substance within the bulb. This pressure acts on the top of the valve diaphragm causing the valve to move to a more open position. The equalizer and spring pressures act together underneath the diaphragm causing the valve to move to a more closed position. During normal valve operation, the sensing bulb pressure must equal the equalizer pressure plus the spring pressure, i.e. P1 = P2+P3.

1.3 Electronic Expansion Valve:

Fig 1.3.1: Electronic Expansion Valve

Fig 1.3.1: Cross sectional view of EEV

Electronic Expansion Valves are an evolution of the thermostatic expansion valves. Recently, several refrigeration component manufactures have introduced electronic expansion valves in an attempt to overcome the limitations of the thermal expansion valves for vapor compression refrigeration systems. It has a controller that centralizes the control of all components of the refrigerant circuit and optimizes the operation of the entire system

Due to variable performance characteristics of electronic expansion valve like

1. maintenance of low and constant superheat value irrespective of load conditions,
2. Quick and accurate response to load change,
3. Better refrigerant flow distribution,
4. Multi refrigerant fluid adaptability and
5. Hold up for blend glide issues which can contribute for improved system performance.
   So there is an interest in determining the effects with EEV for transport trailer units, if any, on refrigeration system performance characteristics, e.g. rate of pull down, fuel consumption, and cooling capacity.

Working Principle of Electronic Expansion Valve:

Basically two kinds of electronic expansion valves are there based on their operating principle to control the valve position by using stepper motor or pulse width modulation principle.

1.3.1 Stepper motor EEV:

EEVs control the flow of refrigerant which enters the evaporator. A stepper motor rotates in discrete steps using magnetic fields to move in fixed increments. Depending on the step size of the motor and the step pattern of the controller, stepper motors can achieve extremely accurate positioning. They do this in response to signals sent to them by an electronic controller. A small motor is used to open and close the valve port. The motor is called a step or stepper motor. Step motors do not rotate continuously. They are controlled by an electronic controller and rotate a fraction of a revolution for each signal sent to them by the electronic controller. Step motors can run at certain number of steps per second and can return to their exact position very quickly. The controller remembers the number of step signals sent by the controller. This makes it possible for the controller to return the valve to any previous position at any time. This gives the valve very accurate control of refrigerant that flows through it. Stepper motor EEV are designed for 2500 steps or more, so extraordinary resolution and control of flow is possible.

1.3.2 Pulse width modulated expansion valve:

Pulse width modulated expansion valves use a simple solenoid valve circuit to control the refrigerant flow. These valves can open or close completely for a set period of time upon receiving a signal from the controller. As an example, a PWM expansion valve remains open for the first three seconds, and then shuts down for the next three seconds to achieve 50% flow within six seconds. Such valves are used in multi-circuit evaporators due to their ability to adapt to changing loads, moving from a fully closed to a fully open position, and vice versa, in a span of a few milliseconds. A major drawback of PWM valves is power consumption. Such a valve pulses only when changes are required, it uses up solenoid holding power for the entire open portion of the cycle. They may also create excessive pulsation during start-up if used in low-tonnage systems.

2. ANALYSIS OF ELECTRONIC EXPANSION VALVE FUNCTIONALITIES TO OVERCOME LIMITATIONS OF THERMOSTATIC EXPANSION VALVE:

Though the capacity requirements are satisfied with functioning of TXV with in low cost as compared to the EEV still some limitations are present for better performance of whole system. Areas where we can have beneficial performance of EEV over the TXV are discussed below.

Advantages of TXV:

1. Low investment cost
2. High reliability
3. Low maintenance cost
4. Simple adjustment
5. Self adjusting flow control over limited range

Limitations of TXV for Transport Refrigeration System:

1. **Super heat:**

Maintaining Low super heat value:

It is well known fact that an increase in super heat causes drastic decrease in the capacity. In case of TXV we have two kinds of super heats i.e. static super heat and dynamic super heat. Static superheat is set by the spring and dynamic one is the obtained value at evaporator outlet. Total superheat is indicated by dynamic + static superheat. This static superheat is set by adjusting the spring for highest capacity at low box condition. So at high box temperature there is no control on the super heat. And as the box temperature increases super heat value also increases. Tassou and Al-Nizari [2] found that an increase in superheat setting from 14 °F to 25 °F produces a 16% reduction in capacity.
But with EEV which can work based on the control logic in the controller it is possible to set low superheat value for all the box conditions. So we can have the superheat value in between 5 to 8°C which contribute for the improvement in capacity. If the superheat value set above or below 8°C, the optimized system performance cannot be achieved [2].

Fewer oscillations in superheat:

Due to loading and unloading and frequent change in ambient temperatures more oscillations can be seen in superheat with the TXV which indicates the hunting or starving of evaporator.

But EEV has ability of extraordinary resolution for refrigerant distribution and quick response very less oscillation is observed in superheat. So by procuring EEV for transport refrigeration system we can able to maintain constant and low superheat value within the range of ±2°C [8].

Other limitations with TXV to have low super heat value:

Mounting of evaporator impacts the suction pipe line length: In practical situations there is a chance to alter the number of evaporators based on the capacity requirement and location of evaporators for better air flow distribution and to avoid the top freeze problem which can directly impacts the suction line length. As the suction line varies there is possibility of increase in superheat.

Limited installation flexibility (bulb location and mounting): Care needs to be taken while strapping bulb at the outlet of evaporator. If bulb is not able to maintain complete contact with the surface of evaporator, the exact value of the super heat cannot be measured. And to measure exact value of super heat bulb needs to be placed at exact location. So limited accuracy in measuring overheating.

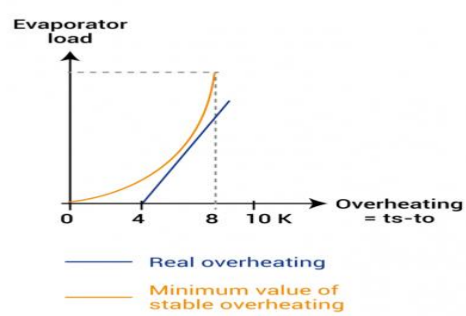

Fig 2.1: comparison of real overheating and stable over heating measurement with TXV

2. **Temperature control:** First and foremost parameter that every customer wants to maintain to keep the goods in desired condition especially for pharmaceuticals. Normally to maintain the set point temperature it is required to control the mass flow distribution to evaporator. In case of TXV to maintain the set point hot gas needs to be supplied for modulation of capacity and for regulation of suction pressure.
   EEV has flexibility to open required number of steps for appropriate amount of mass. The resolution of an EEV is governed by the stroke and number of steps in that stroke. So without supplying the hot gas also EEV can able to maintain tight temperature control within the range of ±0.3ºC which cannot be achieved by TXV [11].
3. **Pull down time:** Pull down time defined as time required reach set point temperature from ambient temperature. Normally TXV can able to reach the set points early when compared to the EEV. Why because at pull down period load or capacity required is high. At this point, TXV can open widely to supply full amount of refrigerant where as EEV cannot be opened 100%.
   At start up condition EEV has less opening which indicates there is always certain amount of refrigerant flow to the evaporator so that it cannot see high super heat for sending more refrigerant [2]. It takes nearly 800 sec for starving of refrigerant wit high super heat. To get solution for this problem providing proper algorithm to have high valve gain at pull down period and low valve gain at steady state condition.
4. **Coefficient of Performance:** COP is defined as ratio of cooling capacity to power consumption. If we have high SH value compressor power increases to compress high specific volume refrigerant and cooling capacity decreases as super heat increases because of inefficient usage of evaporator coil.
   So with the TXV super heat is not maintained consistently which can be eliminated by EEV to increase COP.
5. **Flooding:** Typically the superheat value is set to lower value to attain maximum capacity. But if the SH is low there is chance that liquid refrigerant can enter the compressor which causes damage to compressor reliability. To avoid flooding if the SH is set at high; Higher superheat value indicates that low refrigerant mass flow rate to evaporator which directly relates to the refrigerating effect. In the same manner low superheat value indicates possibility of liquid refrigerant flow to compressor [1]. So it is necessary to have optimum superheat valve to satisfy those two requirements. This can be possible with EEV by having lower super heat value where we can have optimized system performance by precise regulation of mass flow rate.
6. **Multi fluid adaptability & Handling of glide issues:** TXV is set for static super heat regarding one particular refrigerant. If we want to change the change the refrigerant type, spring force should be adjusted and the bulb charge may also be changed.
   As EEV has been operated by controller in which we can dump algorithm related to functionality requirements. So if we want shift for new refrigerant with low GDP and high efficient functionalities just change the refrigerant parameters in the controller option where we already have the logic employed for mentioned refrigerant types.
   Recently the refrigerants used are Azeotropes which are mixtures of other refrigerants. As each refrigerant has different boiling point it difficult to measure the exact super heat value at evaporator outlet. But EEV has ability to handle this kind of glide issues.
7. **Top Freezing (product dehydration):** In trailer normally evaporator is located front top of the container. Though the system reaches steady state and set point is maintained, the discharge air leaving from the evaporator is at very low temperature. This is air normally thrown at the top of the container. The products nearer to the discharge air get dehydrated due to the over cooling effect. This phenomenon is called top freeze. This can be controlled by EEV by increasing the discharge air temperature when it top freezing is observed [1].
8. **Capacity modulation:** Capacity modulation can be done by increasing or decreasing the superheat value through which the opening and closing of valve is regulated.
9. **High Pressure cutout:** Whenever it is observed that high Compressor discharge pressure or temperature system will automatically shut down. This can be regulated by actuating the compressor un loaders by decreasing the mass flow rate through EEV [1].
10. **Nuisance shutdowns:** Nuisance shutdowns caused by high compressor discharge temperature or pressure can be avoided by monitoring the engine coolant temperature there by decrease the superheat so that refrigerant mass flow rate decreased and engine load decreases [1].
11. **Engine coolant temperature:** With the control of superheat the load to engine can be minimized so that coolant temperature does not exceed the limit.
12. **Response:** To measure super heat value at the outlet of evaporator pressure and temperature sensors are mounted. We can have immersion type or probe to measure the superheat. Instead of bulb, through sensors signals reach quickly to controller which again sends signal to rotate the stepper motor to open appropriate amount of steps. For this reason EEV has very quick response [14] like less than 4 msesc.
13. **Energy savings:** As the ambient temperature reduces there is a flexibility of reducing condenser pressure so that compressor power reduces. But with the TXV it is not possible as the selection of TXV is done based on fixed capacity range, TXV cannot open more widely to supply the mass flow at lower condensation pressure. To meet the pressure drop requirement TXV needs to be worked more to supply more liquid refrigerant.
    When EEV is incorporated to Air conditioning unit [4] and super market cabinets [9], at lower ambient temperature between 0 to 20ºC EEV is able to regulate the mass of refrigerant to meet the desired pressure drop by increasing the steps for opening. There by the savings in energy are 17% for air conditioning unit and 36% for super market cabinets.

3. CONCLUSION:

The application of Electronic Expansion Valve to container refrigeration system will provide above discussed benefits when compared to the Thermostatic Expansion Valve. As the EEV is controlled by electronic controller and sensors it is easy to meet the requirements of Transport Refrigeration System. By controlling the superheat value it is possible to maintain system in optimized condition. Quick response with high resolution, constant superheat controlling with less oscillation are possible with EEV.

But the cost of the EEV is nearly four times greater than the TXV. But EEV requires less maintenance cost and high reliability. By having the more capacity and less power consumption the investment cost can be compensated.

4. RECOMMENDATION:

Electronic Expansion valve can able to close completely when there is no requirement of refrigerant flow to the evaporator. So it is recommended that solenoid valve which is placed before the expansion valve can be eliminated to compensate the cost of EEV.

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