Hunting Phenomena Of Automotive Air Conditioning Systems With Variable Displacement Compressor

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R15-3

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ABSTRACT

Automotive air conditioning (AAC) system with a variable displacement compressor (VDC) sometimes tends to experience hunting problems, where the system undergoes oscillation. The purpose of this paper is to study the hunting phenomena in this system and to find out the factors to cause the system stability by experimental investigation. In this paper, the test bench and testing method are described and four kinds of hunting phenomena summarized from our experiments are introduced in detail, i.e., hunting of the evaporator and thermal expansion valve (TEV) control loop, hunting in the AAC system with a VDC and fixed-area throttling device, hunting in the AAC system with a AAC and TEV, and hunting of ungoverned AAC system. Some analyses are made on this four hunting phenomena. These conclusions will give a further understanding for hunting phenomena of the automotive air conditioning system with a variable displacement compressor.

INTRODUCTION

The compressor capacity in an automotive air conditioning system with a constant displacement compressor is controlled by cycling off and on thereby creating an engine disturbance, which is becoming more noticeable as vehicles and engines become smaller. The infinitely variable displacement wobble plate compressor (here-after called “the variable displacement compressor” or VDC) was developed to address this problem. This type of compressor changes the angle of the wobble plate, and the piston stroke length, and the displacement consequently according to an increase or decrease of the pressure differential between the wobble-plate case and the suction chamber of the cylinder head to exactly match the vehicle air conditioning demand. The system has the advantages such as smooth continuous compressor operation, more comfortable environment inside the car, no frost formation in the evaporator and improved fuel economy compared to a system that cycles the compressor off and on to control capacity (Skinner, T.J 1985 and Takai, K 1989).

However in the automotive air conditioning system with a variable displacement compressor, there is the hunting phenomenon sometimes, i.e., all parameters such as the refrigerant mass flow rate, refrigerant pressures and temperatures at different points, and the supply air temperature oscillate with constant amplitude and constant period. The instability can lead lower safety, lower life span and higher energy consumption and restrains its broad application. Inoue, A. et al (1988) had made an experimental investigation on evaluation of VDC with TEV in an AAC system, the interrelationship of refrigerant flow rate adjustment of VDC and TEV and the influence of VDC and TEV on system hunting were analyzed. Tian, C.Q et al (2000, 2001) had analyzed the factors that influence system stability by the experimental investigation into an AAC system with a VDC and TEV. But above researches just dealt with the AAC system with a VDC and TEV and many problems remain unresolved.

The paper tries to study the hunting phenomena in the AAC system with a VDC this system and to find out the causes to raise the system stability by experimental investigation.

TEST SYSTEM

The test bench, shown in Figure 1, was built inside two environmental chambers. The compressor, the condenser and the receiver were placed in the outdoor environmental chamber, the evaporator and the throttling device in indoor one. Both chambers can keep constant temperature and humidity needed in our experiments. The whole system includes main experimental body, the control system and the measure system.

The main body in the test system contains the compressor, the condenser, the receiver, the evaporator and the throttling device. The compressor used here is a 5 cylinder; wobble plate type, infinitely variable displacement compressor, whose displacement range is from 10 to 156 cc (cubic centimeter per revolution). The condenser is parallel type, the evaporator core is tube-fin type, the evaporator fan is driven by a four-speed motor. There are two throttling devices installed in parallel in this test system, the one throttling device is the thermal expansion valve and the other is the electronic expansion valve (pulse motor controlled) that is manually controlled and can be regarded as a fixed area throttling device when not be adjusted. So the test system can be used to observe the hunting phenomena of the AAC systems with a VDC and TEV or with a VDC and fixed area throttling device like orifice tube.

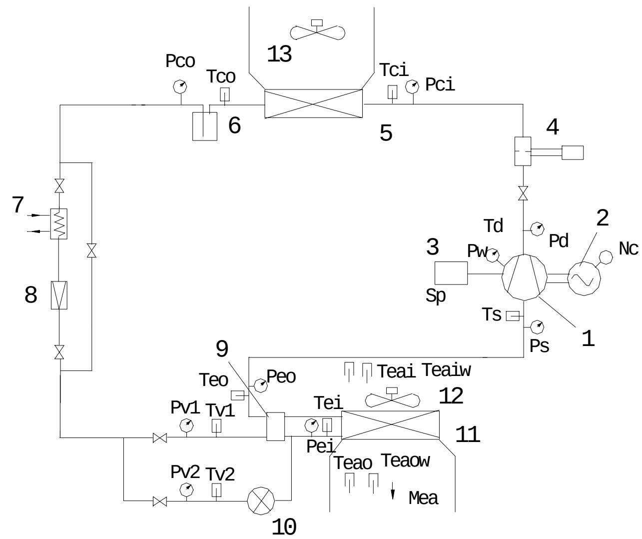

Figure 1: Schematic of test system

1 compressor 2 variable frequency motor 3-stroke measure device 4-throttle flow-meter
5 condenser 6 receiver 7 subcooler 8 mass flow-meter 9 thermal expansion valve
10 electronic expansion valve 11 evaporator 12 evaporator fan 13 condenser fan

The parameters controlled in this test system are the compressor rotary speed, the compressor discharge pressure, the cooling load and the opening of electronic expansion valve. The compressor is driven by a variable frequency motor with the compressor speed changed by adjusting the power frequency. The condenser fan is also driven by a variable frequency motor so the compressor discharge pressure can be controlled by modifying the air velocity through the condenser by adjusting the fan motor power frequency. The cooling load is adjusted by the air dry-bulb and wet-bulb temperature at the evaporator inlet (controlled by the indoor environmental chamber) or by the air velocity through the evaporator (control by the four speed fan). The opening of electronic expansion valve is controlled by manually adjusting the pulse number input of the valve.

The parameters measured in this test system include the compressor rotary speed Nc, the piston stroke length Sp, the refrigerant mass flow rate Mr, the refrigerant temperature Ts, Td, Tci, Tco, Tv1, Tv2, Tei, Teo, the refrigerant pressure Ps, Pw, Pd, Pci, Pco, Pv1, Pv2, Pei, Peo, the air flow rate through the evaporator Mea, and the air dry-bulb and wet-bulb temperature of the evaporator inlet and outlet Teai, Teao, Teaiw, Teaow (see also Figure 1). The compressor speed is measured with an electric eddy current sensor. The piston stroke length is measured with the inductance type displacement transducer. The refrigerant mass flow rate is measured with the throttle flow meter and mass flow meter. The refrigerant temperatures are measured with the copper-constantan thermocouples, whose accuracy is $\pm 0.2^{\circ}C$. The refrigerant pressure is measured with voltage-output type pressure sensors, whose accuracy is $\pm$ 0.1%. The air dry-bulb and wet-bulb temperatures are measured with the platinum resistance temperature sensors, which have been calibrated and can keep the accuracy within $0.1^{\circ}C$. These sensors above all produce electric voltage or current, which are sent to a digital Data Acquisition/Switch Unit and a computer to record the test data.

The test data are recorded every 1 second by the data acquisition unit.

HUNTING PHENOMENA

At our test bench, the experiments had been made both with the AAC system with a VDC and TEV and the AAC system with a VDC and electronic expansion valve under the conditions both with and without refrigerant leakage. The sudden changes of the compressor rotary speed, the compressor discharge pressure, the cooling load and the opening of electronic expansion valve were made to disturb the system and to observe its dynamic characteristics. Four kinds of hunting phenomena had been summarized from our experiments, i.e., hunting of the evaporator and TEV control loop, hunting in the AAC system with a VDC and fixed-area throttling device, hunting in the AAC system with a VDC and TEV, and hunting of ungoverned AAC system.

Hunting of evaporator and TEV control loop

Open the valve before the thermal expansion valve and close the valve before the electronic expansion valve to form the test system as the AAC system with a VDC and TEV, and charge the refrigerant just enough. The hunting occurs when changing the power frequency of the condenser fan motor to increase the condenser blast volume and decrease the discharge pressure (shown in Figure 2). The compressor rotary speed keeps constant. It can be seen from Figure 2 that except the piston stroke length Sp, all the parameters including the discharge pressure Pd, the wobble plate case pressure Pw, the suction pressure Ps, refrigerant flow rate Mr, the refrigerant superheat at the evaporator outlet Sh, and subcooling degree at the TEV inlet Scv oscillate with constant amplitude and constant period (here the hunting period is 60 seconds). The piston stroke length keeps constant, which means that the variable displacement compressor works as the constant displacement compressor. Sh oscillates from 1 $^{\circ}$C to 13°C, which means the opening of TEV is adjusted periodically and the hunting is controlled by the evaporator and TEV control loop.

The experimental result shows that sudden decrease of the discharge pressure can cause system hunting easily. When the discharge pressure decreases abruptly we can observe from transparent TEV inlet pipe that the liquid refrigerant here changes to two-phase suddenly, which causes the refrigerant flow rate through TEV to go down and the superheat at the evaporator outlet increases acutely. This sudden increase of superheat at the evaporator outlet can make the opening of TEV and refrigerant flow rate increase, which then makes Sh decrease again. In addition there is the time lag of TEV's operation to Sh change, the system hunting will occur. The liquid state and two-phase state appear alternately along with the system hunting (it is can be verified from Figure 2 that the subcooling temperature at TEV inlet oscillates and its lowest value is near 0°C).

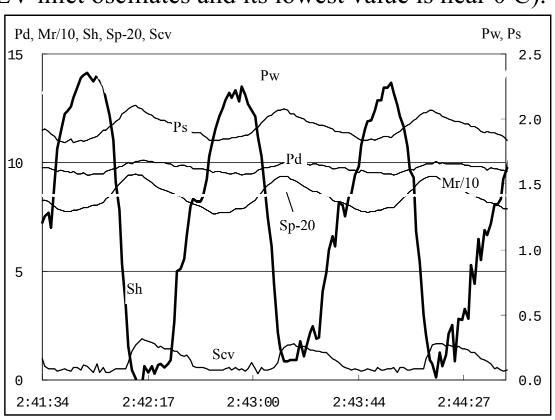

Figure 2: Hunting of evaporator and TEV control loop

Hunting in AAC system with a VDC and fixed-area throttling device

Using the electronic expansion valve as the throttling device, the test system is formed as the AAC system with a VDC and fixed-area throttling device. The system is with refrigerant leakage and the compressor rotary speed keeps 2000rpm. Figure 3 shows that all the parameters including Sp, Pd, Pw, Ps, Mr, Sh, Scv oscillate with constant amplitude and constant period of 120 seconds. The piston stroke length oscillates from 13mm to 23.5mm, which shows that VDC adjusts its piston stroke length and its displacement along with the system hunting. Due to the refrigerant leakage, there is not enough refrigerant in the system and the liquid state and two-phase state appear alternately along with the system hunting. The subcooling temperature at TEV inlet Scv oscillates and its lowest value is near $0^{\circ}C$ (Figure 3).

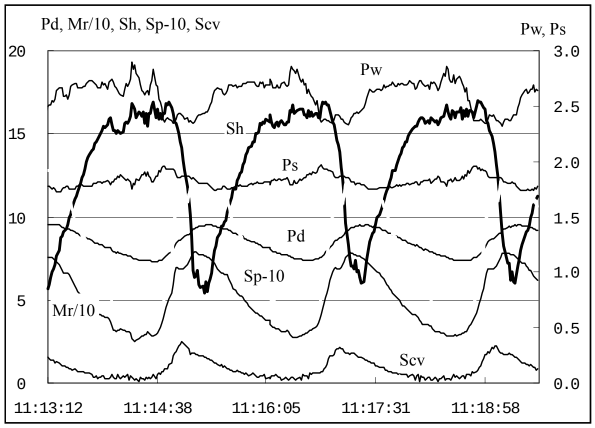

Figure 3: Hunting in AAC system with a VDC and fixed-area throttling device

Hunting in the AAC system with a VDC and TEV

Using the thermal expansion valve as the throttling device, the test system is formed as the AAC system with a VDC and TEV. There are two devices to control refrigerant flow rate separately, i.e., the variable displacement compressor and the thermal expansion valve. The variable displacement compressor changes the wobble plate angle and the displacement consequently according to an increase or decrease of the pressure differential between the wobble plate case and the suction chamber ΔPws; and the thermal expansion valve regulates proportionally the refrigerant flow rate with the refrigerant superheat at the evaporator outlet Sh as the control signal. Figure 4 shows one of the hunting phenomena in the AAC system with a VDC and TEV. The oscillation period is 65 seconds. Sh oscillates from $5^{\circ}C$ to $8^{\circ}C$, which means the TEV opening oscillates. Ps and Pw oscillate inversely and the pressure differential between the wobble plate case and the suction chamber ΔPws changes from 0.47 bar to 0.85 bar. Our experiment shows that the piston stroke length can be reduced when ΔPws is larger than or equal to 0.8 bar and the piston stroke length can be increased when ΔPws is less than or equal to 0.5 bar, so the piston stroke length oscillates too. Both the piston stroke length of the variable displacement compressor and the opening of the thermal expansion valve oscillate and adjust the refrigerant flow rate together. The parameter coupling and inharmonious control are the main cause to raise system hunting here.

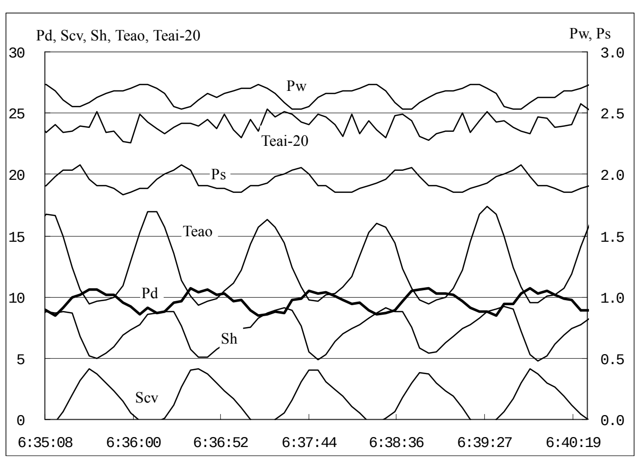

Figure 4: Hunting in AAC system with a VDC and TEV

Hunting of ungoverned AAC system

When the piston stroke length keeps constant (same as a constant displacement compressor) and the throttling device is a fixed-area throttling device, neither the displacement adjustment of the compressor nor the evaporator and TEV control loop exists in the AAC system, which is defined as the ungoverned AAC system in this paper.

Figure 5 shows the hunting of the AAC system with a VDC and fixed-area throttling device when increasing the opening of the electronic expansion valve, and here the system is without refrigerant leakage and has a proper refrigerant charge. The compressor rotary speed keeps 2200rpm. It can be seen from Figure 5 that except Sp, all the parameters including Pd, Pw, Ps, Mr, Sh, and the refrigerant temperature at the evaporator outlet Teo oscillate with constant amplitude and constant period of 30 seconds. The piston stroke length is at the maximum displacement point all the time. The opening of the electronic expansion valve is increased suddenly and the refrigerant flow rate will increase. As the cooling load keeps constant, the refrigerant supply to the evaporator is too large to evaporate, some refrigerant droplets leave the evaporator suddenly. These refrigerant droplets evaporate inside the suction pipe and the compressor inlet to make the suction specific volume decrease and Ps increase, the refrigerant mass flow rate of the compressor increases at the constant rotary speed and constant (maximum) piston stroke length, which in turn increases the refrigerant flowing into the evaporator and make the suction specific volume decrease and Ps increase more. So there is a positive feedback in the ungoverned AAC system, a refrigerant oversupply to the evaporator will cause the system hunting, and the two phase and superheat state appear alternately at the evaporator outlet along with the system hunting (Figure 3 shows that Sh oscillates and its lowest value is around $0^{\circ}C$). In the practical AAC system with an orifice tube there is a gas-liquid separator installed between the evaporator and the compressor, which not only can accumulate and evaporate the liquid refrigerant and to ensure the compressor safe operation, but also can diminish or eliminate the system hunting caused by refrigerant oversupply to the evaporator.

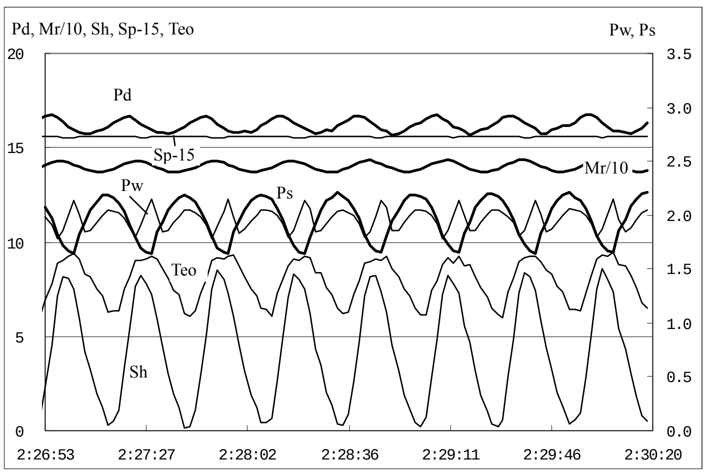

Figure 5: Hunting of ungoverned AAC system (1)

Figure 6 shows the system hunting of the AAC system with a VDC and TEV. As the cooling load is 8.5 kW and greatly over the normal cooling load (5 kW), the piston stroke length keeps maximum and Sh is high enough to keep the TEV opening maximum. So the AAC system with a VDC and TEV becomes an ungoverned AAC system here. The oscillation period is 70 seconds and is longer than the hunting in the Figure 5. The liquid state and two-phase state appear at the TEV inlet alternately along with the system hunting due to the over cooling load. Pd, Pw and Ps change in-phase, which is different from other hunting phenomena discussed above.

From Figure 5 and Figure 6, we can learn that there is the hunting phenomenon even in the ungoverned AAC system, whose period is related to system composition and working condition.

CONCLUSIONS

From the experimental investigation on the hunting of the AAC system with a VDC, four kinds of hunting phenomena, i.e., hunting of the evaporator and TEV control loop, hunting in the AAC system with a VDC and fixed-area throttling device, hunting in the AAC system with a AAC and TEV, and hunting of ungoverned AAC system are summarized. Why the hunting phenomena occur and how the hunting phenomena run are analyzed. These conclusions will give a further understanding for hunting phenomena of the automotive air conditioning system with a variable displacement compressor.

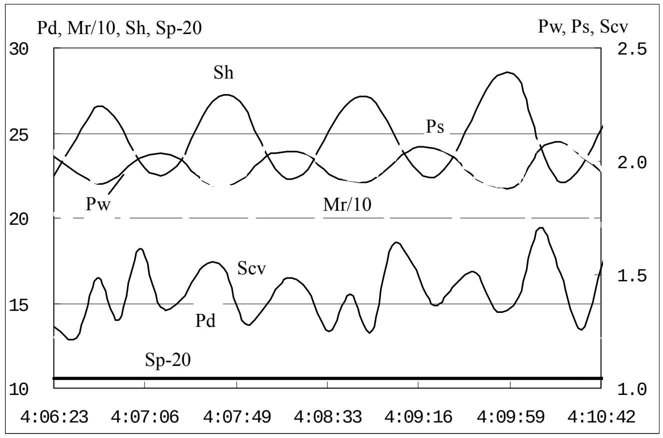

Figure 6: Hunting of ungoverned AAC system (2)

ACKNOWLEDGEMENTS

We would like to acknowledge the support of National Natural Science Foundation of China.

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