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Development and Experimental Researches on a Multi-Connected Air-Conditioning System

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ABSTRACT

A multi-connected air-conditioning system having one outdoor unit and four indoor units, with 5 HP constant speed scroll compressor paralleled with 4 HP frequency inverter scroll compressor, was developed. Many experiments were taken under different working conditions and different system parameters. The performances and the operating characteristics were obtained. The oil-back ability was validated and the necessary oil-back/oil equilibrium operation modes were improved. The influences of the connection pipeline on the performances and the operating parameters were also analyzed. The different charge amount of refrigerant and its influence were tested and analyzed. In the end, according to the state standard of multi-connected air-condition (heat pump) unit, the IPLV of this system with double compressors was calculated based on the part load performances.

1. INTRODUCTION

In recent years, multi-connected air-conditioning systems are getting into more and more applications in China and take a quick rising market share. A multi-connected air-conditioning system is an on-the-spot assembled product to some extent. Manufacturers usually do not produce final products but just their parts such as outdoor units, indoor units, controller, etc. According to the requests of a certain application, the numbers and the types of these parts are then selected and determined. At last, the chosen parts are connected and formed a final and formal product for this certain case. This special characteristic of such kind of product brings great convenience to users, builders and manufacturers, and has many advantages, for example, flexibilities of structures and operations suitable for different applications, independent control and operation mode to each in-door unit, different temperature control for different areas or rooms, diversity of the indoor units in types, and high efficient as manufacturers declared.

China government has issued a national product standard for multi-connected air-conditioning unit in 2002. According to the regulations of this standard, the performance of a multi-connected air-conditioning unit should be tested under such a situation: one outdoor unit and minimum number of indoor units as requested by this outdoor unit, 5m connection pipeline before and after the refrigerant distributor, all indoor units should operate simultaneously. It means that the standard orders a "standard" combination for a multi-connected air-conditioning system to evaluate its performance.

It is obvious that the holistic performances and the operation characteristics of a multi-connected air-conditioning system greatly vary with the number, the capacities, and the types of indoor units, and the connection pipeline (the length, the height difference, the diameter, and the flow line of connection tubes), etc. The standard products could not testify the actual performances and operation characteristics in real application case. The actual performance and operation characteristics in one real application could not testify those in other applications because there are almost not any two same applications. Manufacturers usually measure and declare good performances of their products, but the measurements are taken on a "standard" product. It is obvious that each real application will be different from others and furthermore different from the "standard" case. There are many factors which may cause the

“differences” above. These factors will also influence the performance and the operating characteristics of a real multi-connected air-conditioning system.

In order to understand the actual performances and the operation characteristics, a multi-connected air-conditioning system based on real application was developed and assembled on-the-spot. Its performances and operation characteristics were tested and analyzed under different working conditions.

2. DEVELOPMENT OF THE SAMPLE SYSTEM

Compressor is the main energy-consumption part and any efficiency improvement of compressor will directly result in the energy-saving of the air-conditioning system. Zhang Zhi-li, Wu Xi-ping (2002) compared the applications of different type compressors in air-conditioning systems and concluded that, compared with a reciprocating compressor of same refrigeration capacity, the usage of a scroll compressor was estimated 10%-15% of energy saving. Furthermore, more than one compressor parallel connected is a good and common way in such a system due to its advantages of low cost and the improvement of adjustment characteristics. Two scroll compressors were used in the sample multi-connected air conditioning system.

A great challenge for multi-connected air-conditioning system is the capacity adjustment. Different from a common room air-conditioner, the capacity of a multi-connected air conditioning system varies not only with the outdoor temperature but also with the number of indoor units in operation. Therefore, the part-load performance is very important for this kind of product. Shao Shuang-quan (2004) concluded that the simple ON/OFF adjustment mode would cause an energy loss up to 10%-15%. Thus one of the two compressors of the sample system was a variable speed scroll compressor of 4 HP input power. Another one is constant speed scroll compressor of 5 HP

Compared with capillary tube, electronic-magnetic expansion valve can not only meet the requirements of part load operation but also cause energy saving due to its perfect adjusting characteristics. Shao Shuang-quan *et al.* (2001) found out that, for the part load operations, the refrigerating capacity and the EER of an air-conditioner with electrical expansion valves is at least 20% higher and 10% higher in average than that with capillary tubes. The advantage of energy saving is hence obvious. Therefore, four individual electronic expansion valves were used in each indoor unit of the sample system and controlled independently.

3. EXPERIMENT SYSTEM

A sample multi-connected air-conditioning system with R22 as refrigerant was designed and assembled in the lab. Its outdoor unit contained two compressors connected in parallel and shared the same condenser. Every compressor was equipped with an oil separator and an oil filter. The other auxiliary parts included the high pressure storage tank, single-way valves, and the electronic expansion valves. It contained three indoor units of 3 HP and one indoor unit of 1 HP. All the indoor units used electronic expansion valves as throttling devices.

Table 1 and Table 2 show the characteristic parameters of two scroll compressors.

Table 1: Constant speed scroll compressor

MODEL	503DH-80C2Y	REFRIGERANT	R-22
MOTOR	4.4 kW	WEIGHT	37Kg
CAPACITY	14.9 kW	POWER INPUT	4.4 kW
EER	3.4 W/W	RUNNING CURRENT	7.9 A
ELECTRIC SOURCE	380~400 V, 50 Hz	SOUND LEVEL	≤60 dB(A)
OIL HARGE	1.8 L	VIBRATION	≤15 m/s ²

Table 2: Variable speed scroll compressor

MODEL	401DHV-64D2Y	REFRIGERANT	R-22
MOTOR	5.56 kW	WEIGHT	36Kg
CAPACITY	18 kW (at 75Hz)	POWER INPUT	5.6 kW (at 75Hz)
EER	3.2 W/W (at 75Hz)	RUNNING CURRENT	10.5 A
ELECTRIC SOURCE	380~415 V, 50 Hz	SOUND LEVEL	≤66 dB(A)
OIL CHARGE	1.8 L	VIBRATION	≤15 m/s ²

The structural drawing of the experimental system is shown in Figure 1 as below:

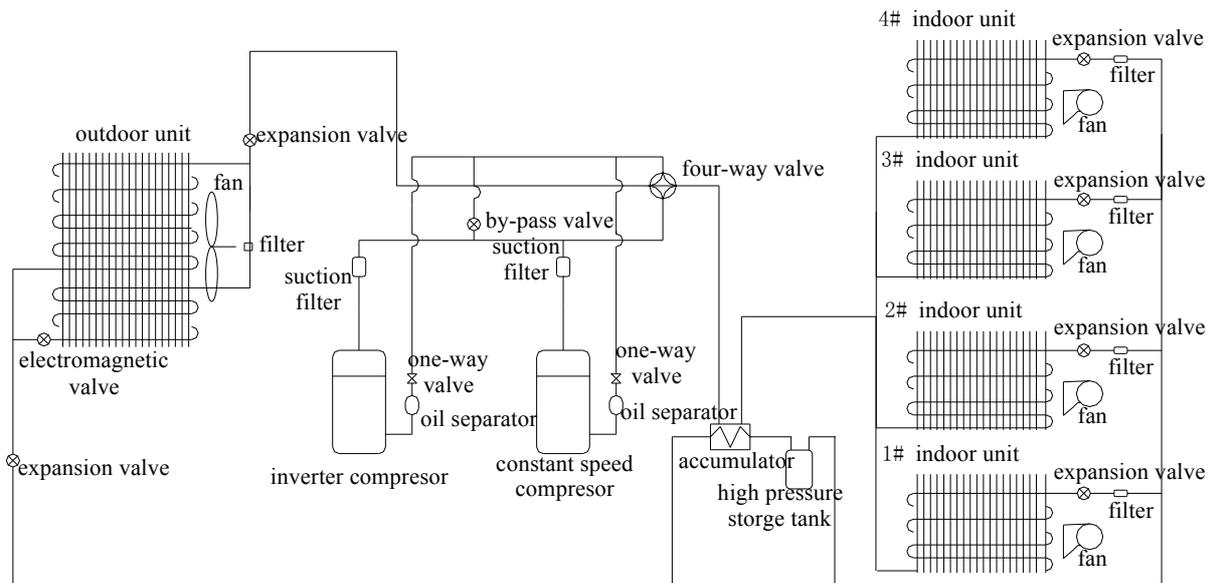


Figure 1: The sketch map of the sample multi-connected air-conditioning system

Some one-way valves were used to prevent the refrigerant back flow to the compressor while it stops. For the purpose of heating operation, a four-way valve was used. There were also other components such as filters, liquid-gas separators etc. some of them are not included in Figure 1.

4. ANALYSIS OF PERFORMANCES AND OPERATING CHARACTERISTICS

Many operating parameters were tested in different working conditions and different loads, such as the air parameters (the dry and the wet bulb temperatures, velocities) inlet and outlet of the outdoor unit and each indoor unit, the electrical parameters, the amount of condensed water, the temperatures and the pressures of refrigerant at each special point. The performances of the system can be calculated with these tested parameters.

All tests were controlled at 33 and 36 °C of outdoor temperatures and 24 °C of indoor temperature.

4.1 Influences of Connection Line Length

It is no doubt that the length of connection pipeline which connects the outdoor unit and the indoor units will cause the pressure loss along the pipe line. The test results clearly showed this loss of up to 9%. This loss will further influence the performance of the system. Figure 2 and figure 3 show the variety of capacity with the connection pipeline length.

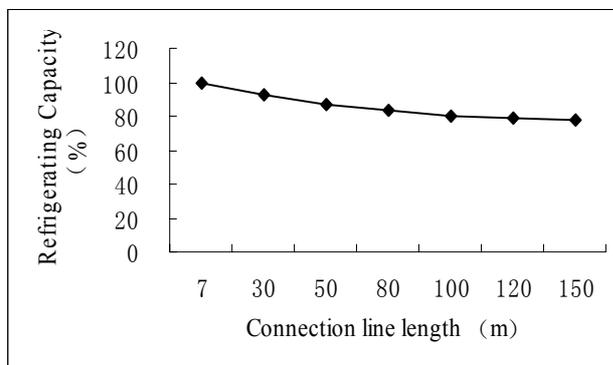


Figure 2: The variety of refrigerating capacity with the connection line length

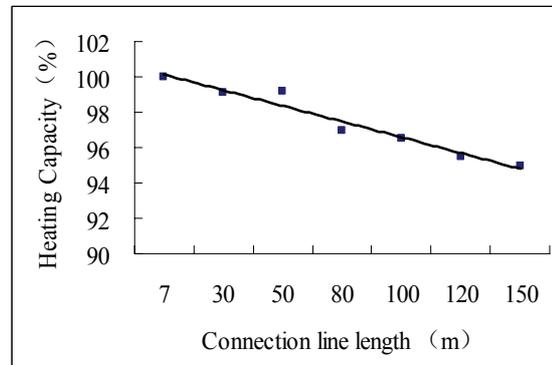


Figure 3: The variety of heating capacity with the connection line length

From these figures, we know that both refrigerating and heating capacity drop with the increase of pipeline length. When the length increased from 5m to 150m (the longest length that manufacturers declared), the refrigerating capacity quickly decreased from 100% to 78%; and the heating capacity decreased from 100% to 95%. The additional electric heating function remedied the capacity loss during heating operation and makes the situation much better than that during refrigerating operation. But the performance in heating operation was worse because of the greater influence of pressure loss on lower evaporation pressure.

4.2 Oil Backflow

The complicity and the diversity of a multi-connected air-conditioning system bring the problem of oil backflow. This problem might cause the shortage of compressor oil and further influence the reliability of the system. A view window was equipped to each compressor to observe the change of oil levels while compressors run. The results showed that there were two problems for oil backflow, the oil detained in the system and the oil unbalance between the two compressors. In order to solve these problems, an oil backflow operation mode and an oil balance operation mode were added into the control functions.

Figure 4 shows the oil level variety of the constant speed compressor with time. Figure 5 shows the oil level variety of the inverter compressor with its frequency (after 10 minute operation).

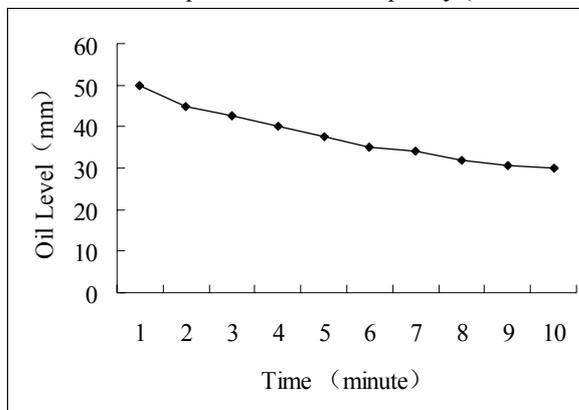


Figure 4: The variety of oil level with time

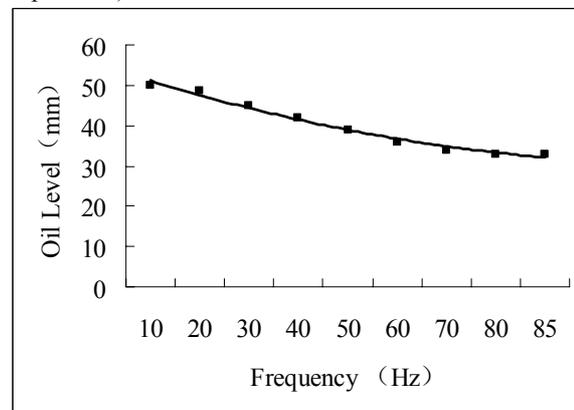


Figure 5: The variety of oil level with frequency

It is known from these figures that the oil level of the constant speed compressor dropped with the operation time and gradually stayed at a stable position. The oil level of the inverter compressor dropped with its frequency and then gradually stayed at a stable position, too. At lower frequency, oil level drop of the inverter compressor was obviously less than that of the constant speed compressor. But anyway, the improvement in control functions obtained good and obvious effect.

4.3 Refrigerant Charge Amount

As the expansion valves are usually equipped in each indoor unit, the length of connection pipeline also influences the optimal refrigerant charge amount and further influences the performance of the system. Long pipeline length usually means more refrigerant charge amount. It is obvious that refrigerant supplement is needed for a real system whose length of connection pipeline is usually longer than that of a "standard" product in most cases. But due to the diversity of multi-connected air-conditioning systems, it is very different to develop a universal regulation for all applications. The on-the-spot debugging is necessary to obtain the optimal refrigerant charge amount and further to obtain the optimal performance.

Figure 6 shows the EERs at different load ratios and different refrigerant charge amounts. It is clear that the EERs at normal refrigerant charge amounts (optimal ones) were better than those when refrigerant charge amount was short. The higher the load was, the greater the difference was.

The refrigerant charge amount also influences the operation characteristics of the system. Figure 7 shows the discharge pressures and the suction pressures at different load ratios and different refrigerant charge amounts. It is also clear that the less refrigerant charge amounts caused lower discharge pressures and suction pressures. The higher the load was, the greater the difference was.

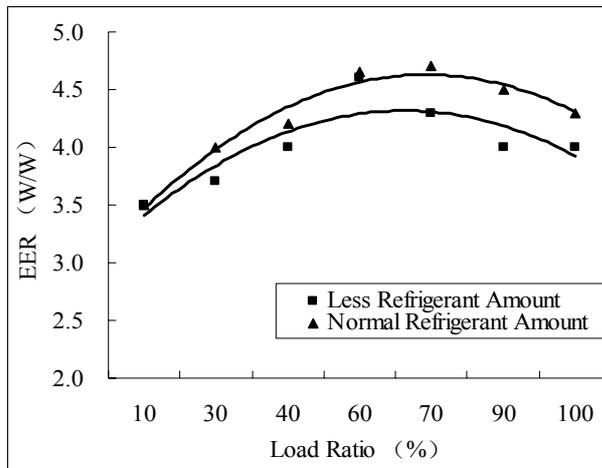


Figure 6: EER at different refrigerant amounts

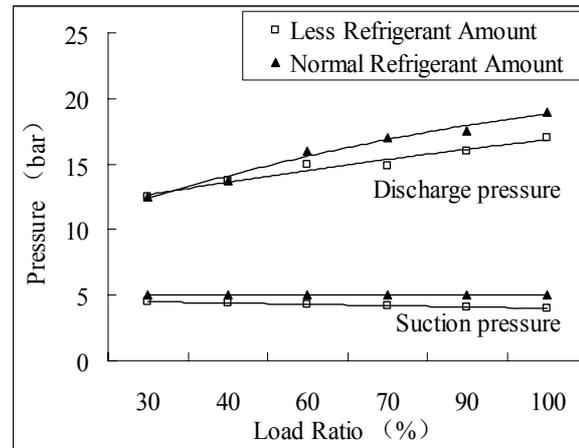


Figure 7: Pressure at different refrigerant amounts

4.4 Influence of Outdoor Temperature and Load Ratio

Figure 8 shows the refrigeration capacities of the system at different load ratios and different outdoor temperatures while the indoor temperatures were controlled at 24°C. There are two factors which influence the load ratio, the number of indoor units in operation and the outdoor temperatures. More indoor units in operation and higher outdoor temperatures mean greater loads. So it is clear in the figure that the refrigeration capacities increased with the load ratio getting up, and that the refrigeration capacities at 36°C of the outdoor temperature were more than those at 33°C. The higher the loads were, the greater the differences were.

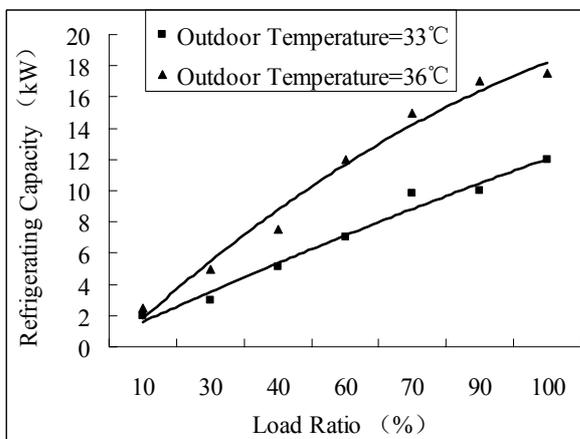


Figure 8: Refrigeration capacity at different outdoor temperatures

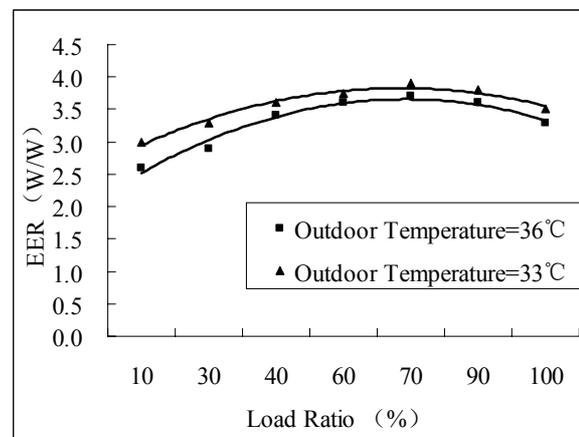


Figure 9: EER at different outdoor temperatures

Figure 9 shows the EERs of the system at different load ratios and different outdoor temperatures while the indoor temperatures were controlled at 24°C. From this figure, the EERs at both outdoor temperatures increased with the increase of the load at first and then dropped down slightly. The peak points happened at about 70% load. The EER at the minimum load is lower than that at the full load. The reason for this is that, through the heat transfer loss is relative small at lower loads, the energy consumption of the controller takes a relative greater proportion in total input power and counteracts the benefit of heat transfer loss reduction. It was found that the power consumption of the controller might account to approximately 15% of total input energy.

5. CALCULATION OF INTEGRATED PART LOAD VALUE

IPLV (Integrated Part Load Value) is the evaluation value to estimate the performances of multi-connected air conditioning systems. It takes the part load performances into account and can be calculated as:

$$PLF = A0 + (A1 \times Q) + (A2 \times Q^2) + (A3 \times Q^3) + (A4 \times Q^4) + (A5 \times Q^5) + (A6 \times Q^6) \quad (1)$$

Where,

PLF -- part load factor

Q -- load ratio at the rated condition

$A0 \sim A6$ -- constants

Then, IPLV is:

$$IPLV(C) = (PLF_1 - PLF_2) \times (EER_1 + EER_2) + (PLF_2 - PLF_3) \times (EER_2 + EER_3) + (PLF_3 - PLF_4) \times (EER_3 + EER_4) + (PLF_4) \times (EER_4) \quad (2)$$

Where, PLF_1 , PLF_2 , PLF_3 and PLF_4 are part load factors of 100%, 75%, 50%, 25% and 25% load at the tested working conditions. EER_1 , EER_2 , EER_3 and EER_4 are energy efficiency ratios of 100%, 75%, 50%, 25% and 25% load at the tested working conditions.

When the outdoor temperature was 36°C and the indoor temperature was 24°C, the refrigerating IPLV of the sample multi-connected air conditioning system was calculated as:

$$IPLRV(\text{Refrigerating}) = 3.59$$

When the outdoor temperature was 33°C and the indoor temperature was 24°C, the heating IPLV of the sample multi-connected air conditioning system was calculated as:

$$IPLV(\text{Refrigerating}) = 3.72$$

The calculated results of IPLV show that the integrated energy efficiency of the sample multi-connected air-conditioning system was very high compared with common system. It is the advantage of such kind of product.

6. CONCLUSIONS

It can be concluded from mentioned above that

1. The difference between different application cases brings the great diversity of multi-connected air-conditioning systems. This diversity will cause the performance and the operation characteristic difference between different combinations and even between different applications of same combination.
2. The length of connection pipeline of a multi-connected air-conditioning system greatly influences its performance and operation characteristics, such as refrigerant charge amount, capacity, EER, suction pressure and discharge pressure, etc. Unfortunately, there is now not a universal regulation to deal with this issue.
3. Compressor oil has been verified a big problem which will influence the reliability of a multi-connected air-conditioning system. This problem contains two aspects, the oil detained in the system and the oil unbalance between the two compressors. Some improvements in control mode should be necessary.
4. In most cases, a multi-connected air-conditioning system has good performances. This benefit, combining with other advantages, will make it a good market potential.

Some further work including the comparison between "standard" product and real system is still under doing.

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