Comparison Between Different Arrangements of Bypass Valves in Scroll Compressors

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COMPARISON BETWEEN DIFFERENT ARRANGEMENTS OF BYPASS VALVES IN SCROLL COMPRESSORS

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ABSTRACT

This paper has constructed a bypass valve or called mechanism in the scroll-type compressor (STC) and integrates it into the developed simulation package. The uncovered area and interval can be found at first, and then the effects to over-compression can be observed for variable operating conditions. By subtle design and adjustment, the suitable arrangement of bypass valves can be found that the uncovered interval can be maintained over the whole working cycle. Hence the consideration for different operating conditions can be discarded, even though the over-compression occurs at any instant during the working cycle, there are conductive passages that can bypass it. Besides, liquid slug, which causes fatal effect to the STC, can also be prevented by using the arrangement of bypass valves.

1. INTRODUCTION

The variable compression-ratio scroll-type compressor (STC) has been studied for recent years. Morimoto *et al.* (1994) had investigated the STC to obtain high Seasonal Energy Efficiency Ratio (SEER) with variable compression-ratio and speed considerations. The compression-ratio is defined as the ratio of the saturated condenser (high-end) pressure to the saturated evaporator (low-end) pressure (P_{dis}/P_s) and is decided by operating conditions(load conditions) of system. Due to intrinsic limitation of fixed volume ratio and separated compression chambers in the STC, two problems, under-compression and over-compression are produced when operating pressure ratio can not match the design compression-ratio and extra work is wasted in both problems (Schein and Radermacher, 2001). Under-compression can not be avoided except for designing specific suction-delay mechanism, or using check valve to reduce back-flow. For over-compression, bypass valves can be added to fixed scroll as a solution. Several patents had been provided to give varied numbers and locations of bypass valves to overcome the difficulty. However, rare literatures focus on it to investigate the details about bypass mechanism. This paper discusses several cases that have different arrangements of bypass valves by using a developed STC computer package.

2. BYPASS MODEL

Bypass mechanism, includes bypass hole and valve, is added to fixed scroll to conduct over-compressed refrigerant from compressing chambers and avoid backflow from discharge reservoir. Due to separated chambers with different pressure during the working cycle, the determination of the bypass hole's location is the main consideration. Profiles of a pair of scrolls in this paper are created by an involute with base circle. Two parameters, the involute angle of fixed scroll (ϕ_a), the distance (d) between the center of bypass hole and fixed scroll profile can be used to define the location of bypass hole. After that, using coordinate transformation and numerical technique to resolve the relation between bypass hole and the orbiting scroll.

After that, setting the reasonable diameter (D_m) of the bypass hole (must smaller than the thickness of scroll wrap to prevent leakage from adjacent chambers due to pressure difference), then the uncovered interval and area of the bypass hole during the working cycle can be found. In addition, a one dimension valve (Chen *et al.*, 2001), which neglects its dynamic behavior was used as bypass valve in this paper. Figure 1 depicts the related parameters.

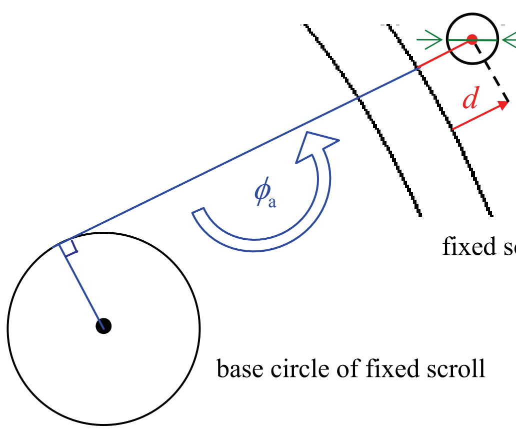

Figure 1: Parameters of bypass hole

3. SIMULATION PACKAGE

The simulation package includes compression and discharge processes, leakage between scroll wraps, dynamic balance from mechanical parts used in STC and power consumption estimations (Chang *et al.*, 2004). Some assumptions in this study are presented:

1. Chambers of the scroll pairs are symmetric
2. Homogeneous refrigerant in the chambers.
3. Gravitational, kinetic energy variations are neglected
4. Neglecting oil effects

Figure 2 shows the flow chart of the simulation process. Based on it, the bypass model can be treated as a kind of leakage flow and when pressure in compression chamber (P_{ch}) is bigger than the discharge pressure (P_{dis}), the bypass valve is opened to conduct refrigerant and after the pressure in it is balanced to P_{dis}, the valve will close. The model was integrated into the compression and discharge process to determine and observe the influence to STC.

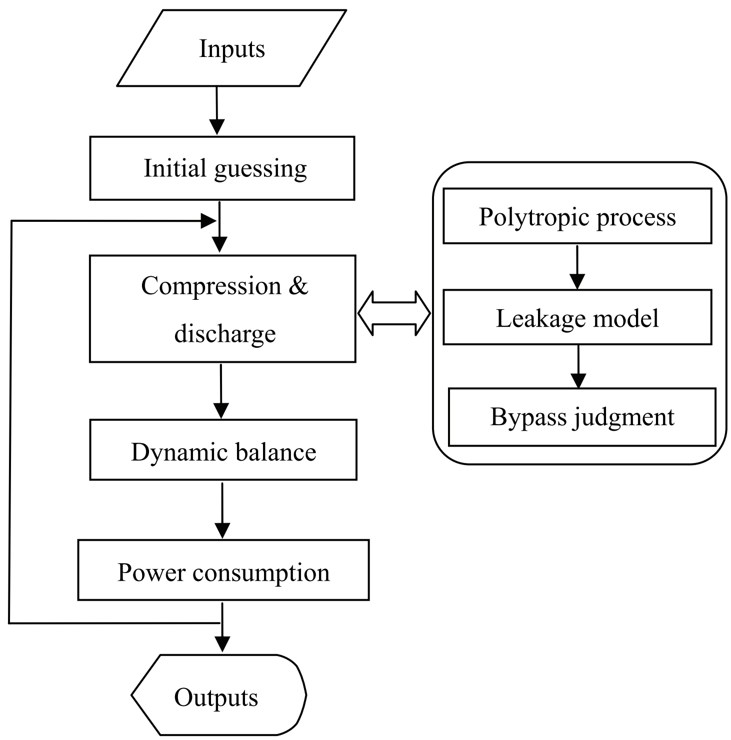

Figure 2: Flow chart of simulation package

4. SIMULATION RESULTS

By using the package described above, a STC with and without bypass valves has been simulated and analyzed. The geometric observation about uncovered area and interval during an orbiting cycle is the first theme, the bypass effects during compression process are investigated as follows.

4.1. Geometric observation

A low-side R-22 STC product with volume ratio 2.71 is analyzed initially and some major geometric parameters are given in Table 1. One pair of symmetric bypass holes are located in fixed scroll and the related parameters are shown in Table 2 and Figure 3 is the position of the bypass holes. The uncovered interval is a range that the bypass holes are not be covered by wrap of the orbiting scroll. Due to the symmetry of bypass holes, the uncovered areas of bypass holes have the similar trend during the orbiting cycle as Fig. 4 shows. However, the uncovered interval does not represent the acting interval because of possible disagreement with the bypass condition ($P_{ch} > P_{dis}$) during the compression process.

Table 1: Parameters of the STC

Parameters	Unit	Value
Base circle radius (r_b)	mm	2.06
Thickness of the scroll (t)	mm	2.71
Involute angle of the scroll (ϕ)	deg	1100
Height of the scroll (h)	mm	22

Table2: Parameters of bypass hole

Parameters	Unit	Value
Involute angle of bypass hole 1 (ϕ_1)	deg	340
Diameter of bypass hole 1 (D_{m1})	mm	0.75
Distance of bypass hole 1 (d_1)	mm	1.2
Involute angle of bypass hole 1'($\phi_{1'}$)	deg	520
Diameter of bypass hole 1' ($D_{m1'}$)	mm	0.75
Distance of bypass hole 1' ($d_{1'}$)	mm	1.2

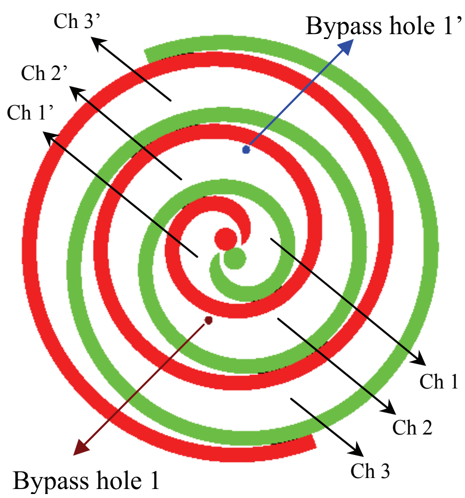

Figure 3: Position of bypass holes

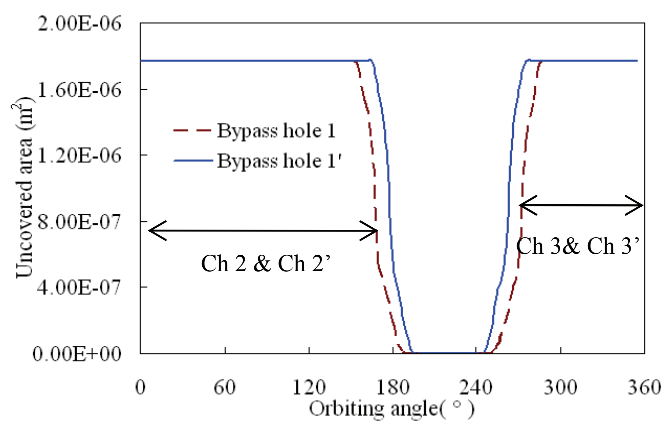

Figure 4: Uncovered interval of bypass holes

4.2. Uncovered interval & acting interval during working cycle

Figure 5 shows the working cycle about pressure v.s. crank angle of the STC with and without bypass mechanism at evaporating temperature T_{evp} = 4.4 ℃ and condensing temperature T_{con}= 37.8 ℃, the pressure ratio in this condition is 2.63(-). It can be seen that the acting interval (100°) is shorter than the uncovered interval (300°), the pair of bypass holes can suit this operating condition. The compression efficiency η_C can be improved by 5.2% and a few rise on volumetric efficiency η_V (2.2%). The results show that the extra work can be reduced to avoid over-compression but the effect is limited because of this testing condition with high compression ratio and speed.

Figure 6 shows the same arrangement in STC with the same speed but different operating condition, 2.23(-) in pressure ratio. The acting interval is extended (from 100° to 145°) and the position of bypass holes still match up the design requirement at this operating condition (< 300°), and η_C can be lifted by 9.1%. Generally speaking, the η_C can be advanced by 2% to 10% for different operating conditions. Therefore, bypass mechanism used in STC is necessary to lower compression-ratio conditions for higher efficiency consideration.

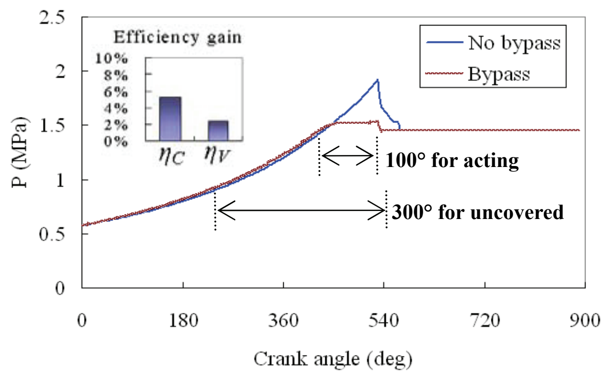

Figure 5: Working cycle

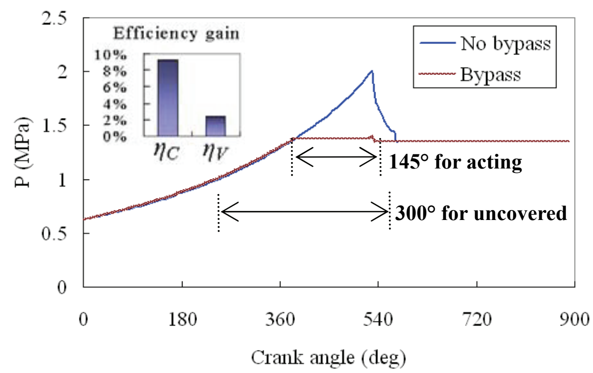

Figure 6: Working cycle at different condition

5. SIMULATION RESULTS BETWEEN DIFFERENT ARRANGEMENTS

From the discussion of previous section, it can be seen that one pair of bypass holes which are shown in Fig. 3, have shorter uncovered interval (300°) than the working cycle. After that, three cases with different arrangements of two pair of bypass holes have been investigated as below:

5.1. Case A:

The same STC but with 2 pairs of bypass holes is analyzed first. For the case A, the second pair of bypass holes are added (as shown in Fig. 7) but the first ones remained the same position as Figure 3. Table 3 depicts the parameters and the corresponding illustrations of uncovered interval of the three cases are shown in Fig. 10. It can been seen that the uncovered interval can be extended from 300° to 425°, however, the covered interval still exist at the beginning stage (0° ~ 130°) of the working cycle. Hence, two pairs of bypass holes can span the working interval but need more delicate arrangement to conform the design requirement.

5.2. Case B:

Different locations about the second pair of bypass holes are presented in Fig. 8 and the related parameters are shown in Table 4. From Fig. 10, the simulation results present that the uncovered interval is extended to the beginning stage (0° ~ 190° and 255° ~ 550°) but a covered interval, which is about 65°(190° ~ 255°), appears at the middle stage during the working cycle, can lead potential to arise over-compression. So the arrangement of these two pairs of bypass holes in case B is still unsatisfied.

5.3. Case C:

Another arrangement of bypass holes is shown in Case C and the parameters and diagram are shown in Table 5 & Figure 9. From Figure 10, it can be found that the uncovered interval, which is extended to 550°, can completely uncover bypass holes at every compression chamber throughout the whole working cycle. The results depict the arrangements of bypass holes in the STC with different operating conditions can bypass over-compressed refrigerant arbitrarily from any compression chambers.

Besides, liquid slug is another problem that must to be taken into consideration (Wang *et al*., 2007). The liquid refrigerant is sucked into compression chambers of the STC during the suction stage due to not enough superheat. In general, a tiny amount of liquid refrigerant in chambers can be accepted. However, when too much liquid refrigerant is sucked into chambers, which means abnormal rise of pressure in chambers will take place and cause STC fatal damage. In order to prevent this phenomenon, the STC must have passages to conduct the abrupt high-pressure refrigerant. Hence, bypass mechanism with suitable design can be the way to settle it. The arrangement in case C, except avoiding over-compression, the liquid slug can be prevented because of completely uncovered interval throughout the working cycle. In addition to case C, not only one solution, but other arrangements can also be designed to match up the requirement that bypass holes with completely uncovered interval.

Table 3: Parameters of bypass holes: Case A

Parameters	Unit	Value
Involute angle of bypass hole 1 (ϕ_1)	deg	340
Diameter of bypass hole 1 (D_{m1})	mm	0.75
Distance of bypass hole 1 (d_1)	mm	1.2
Involute angle of bypass hole 1'($\phi_{1'}$)	deg	520
Diameter of bypass hole 1' ($D_{m1'}$)	mm	0.75
Distance of bypass hole 1' ($d_{1'}$)	mm	1.2
Involute angle of bypass hole 2 (ϕ_2)	deg	460
Diameter of bypass hole 2 (D_{m2})	mm	0.75
Distance of bypass hole 2 (d_2)	mm	1.2
Involute angle of bypass hole 2'($\phi_{2'}$)	deg	640
Diameter of bypass hole 2' ($D_{m2'}$)	mm	0.75
Distance of bypass hole 2' ($d_{2'}$)	mm	1.2

Table 4: Parameters of bypass holes: Case B

Parameters	Unit	Value
Involute angle of bypass hole 1 (ϕ_1)	deg	340
Diameter of bypass hole 1 (D_{m1})	mm	0.75
Distance of bypass hole 1 (d_1)	mm	1.2
Involute angle of bypass hole 1'($\phi_{1'}$)	deg	520
Diameter of bypass hole 1' ($D_{m1'}$)	mm	0.75
Distance of bypass hole 1' ($d_{1'}$)	mm	1.2
Involute angle of bypass hole 2 (ϕ_2)	deg	700
Diameter of bypass hole 2 (D_{m2})	mm	0.75
Distance of bypass hole 2 (d_2)	mm	1.2
Involute angle of bypass hole 2'($\phi_{2'}$)	deg	880
Diameter of bypass hole 2' ($D_{m2'}$)	mm	0.75
Distance of bypass hole 2' ($d_{2'}$)	mm	1.2

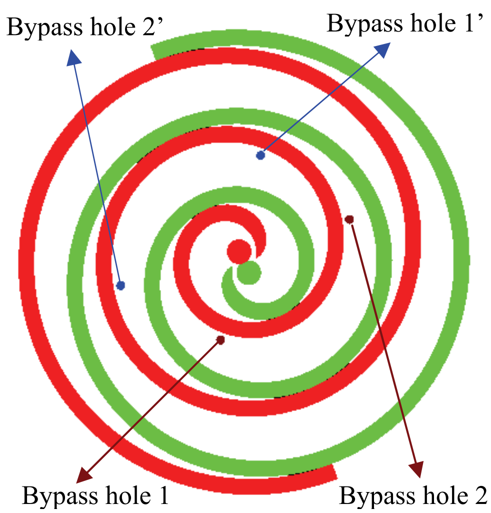

Figure 7: Position of bypass holes: Case A

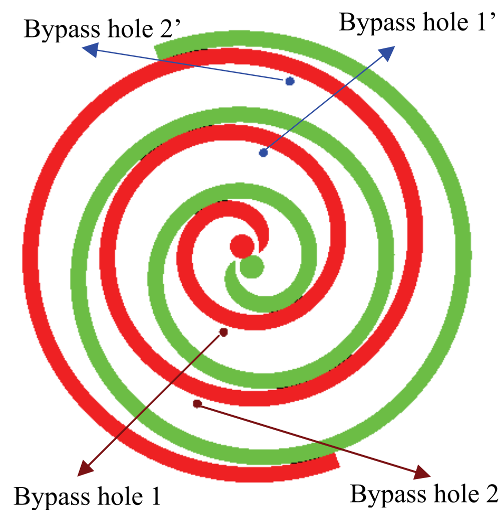

Figure 8: Position of bypass holes: Case B

Table 5: Parameters of bypass holes: Case C

Parameters	Unit	Value
Involute angle of bypass hole 1 (ϕ_1)	deg	340
Diameter of bypass hole 1 (D_{m1})	mm	0.75
Distance of bypass hole 1 (d_1)	mm	1.2
Involute angle of bypass hole 1'($\phi_{1'}$)	deg	520
Diameter of bypass hole 1' ($D_{m1'}$)	mm	0.75
Distance of bypass hole 1' ($d_{1'}$)	mm	1.2
Involute angle of bypass hole 2 (ϕ_2)	deg	620
Diameter of bypass hole 2 (D_{m2})	mm	0.75
Distance of bypass hole 2 (d_2)	mm	1.2
Involute angle of bypass hole 2'($\phi_{2'}$)	deg	800
Diameter of bypass hole 2' ($D_{m2'}$)	mm	0.75
Distance of bypass hole 2' ($d_{2'}$)	mm	1.2

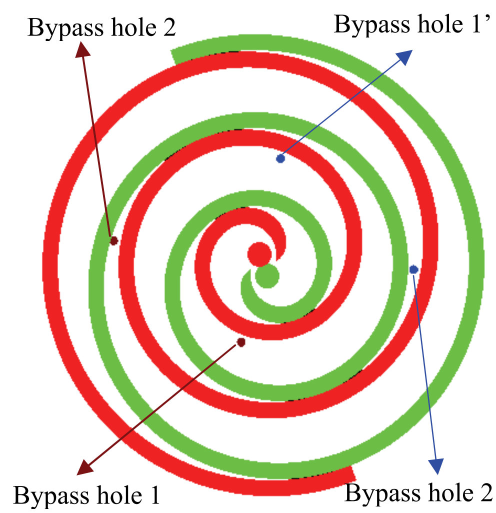

Figure 9: Position of bypass holes: Case C

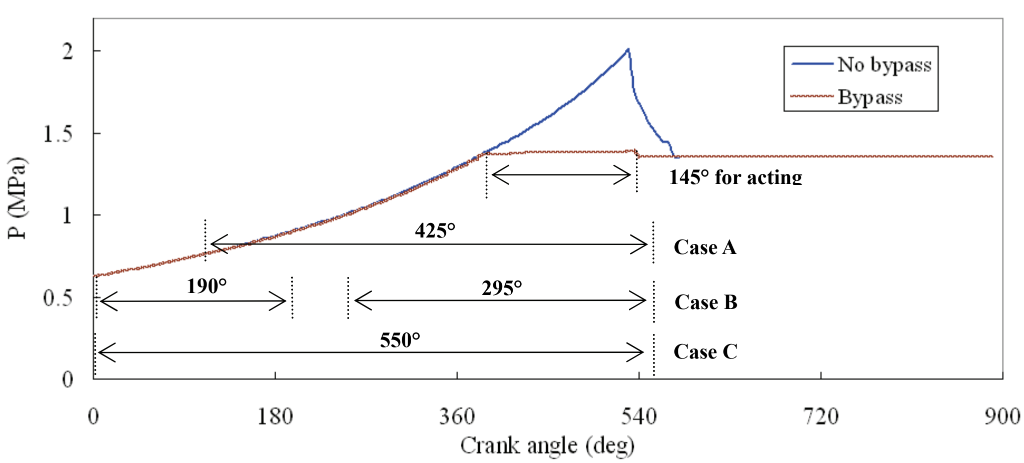

Figure 10: Working cycle at different cases

6. CONCLUSIONS

A bypass mechanism in STC has been constructed and integrated into a simulation process in this paper. From the simulation results and analysis, some conclusions are described as follow:

1. The uncovered areas of each bypass holes and intervals can be simulated
2. The η_C can be lifted from 2 to 10 % at different operating conditions by using bypass mechanism.
3. One pair of bypass holes only produce limited function and two ones can match up the design requirement by refining the arrangement of them.
4. If the uncovered interval can be designed throughout the whole working cycle, the influence of over-compression caused by different operating conditions can be eliminated.
5. Besides over-compression, liquid slug can be avoided entirely by arranging bypass holes suitably in the STC.

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