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W. H. You
Samsung Electronics Co. Ltd.

D. Y. Kwon
Samsung Electronics Co. Ltd.

S. K. Ko
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W. H. You, D. Y. Kwon, S. K. Ko
Refrigerator Design, Home Appliances Business
Samsung Electronics, Suwon, Korea

ABSTRACT

A suction valve is a very important element in reciprocating compressor. And because of the shape of the reed valve its reliability is taken up a subject for discussion and sometimes it is main source of bad product. Because the reliability of the suction valve is directly related to the stress acted on it, the stress and reliability analysis should be carried out in design stage.

In this study, the maximum stress and the maximum impact value acted on the suction valve of reciprocating compressor were analyzed by using the commercial nonlinear dynamic structural analysis program LS DYNA3D. The stress acted on the suction valve was measured by the experiment of bolted-case test using the strain gage. In order to investigate more accurately the motion of the valve in air, the displacement of the valve was measured by the laser sensor and the stress of the valve was measured by the strain gage in open-shell state. These were used in making relations between the displacement and the stress.

The displacement-stress relationship was used in measuring the displacement of the valve in real cycle. And the maximum impact value was analyzed by experiment.

The maximum stress analyzed by FEM was compared with the allowable stress of the material of the valve. The maximum impact value analyzed by FEM and the experiment was compared with the allowable impact value of the material of the valve.

INTRODUCTION

Recently, with the Ozone Depletion Potential the compressor using non-CFC refrigerant is developed actively. And with the Global Warming Potential the trial for decreasing consumption of energy is expanded to the direction of reducing energy input and to the direction of increasing EER of the compressor.

These situations act as factors which give bad effect on dynamics, noise and vibration of the compressor. Moreover, the Valve should be designed optimally in respect of high effiency, low noise and vibration level. Say again, the adoption of non-CFC and the trial to increase effiency lead to more flexible valve.

It is very difficult to predict the displacement and stress of the valve in design stage. There is many research work about prediction of P-V diagram considering the characteristics of valve, the results become more accurate to experimetal results. But in most case the valve is modelled as 1-DOF mass-spring-damper system, it is not able to predict the stress acted on the valve based on this 1-DOF model.

In this study the suction valve is modelled as 1-DOF system in order to predict P-V diagram. In order that the maximum displacement of the suction valve predicted from 1-DOF model is equal to the maximum displacement of the center of the valve port zone obtained from LS DYNA3D analysis, iterative simulation is carried out. And the maximum stress and displacement of the suction valve is obtained from LS DYNA3D simulation and compared with the results from experiment.

STRESS ANALYSIS OF VALVE

The stress acted on the suction valve of the reciprocating compressor is classified as Fig. 1. In case of Fig. 1(a) the bending stress acts on the valve by the pressure difference when the piston moves from TDC position to BDC position(STATE 1), Fig. 1(b) explains that the impact stress occures when the valve slaps the valve port in the piston position near the BDC zone(STATE 2). Fig. 1(c) shows that the bending stress acts on the suction valve when the high pressure acts on the suction valve in the piston position near the TDC zone before the discharge valve is opened(STATE 3). To find which is most dangerous among these states is very important and the reliability of suction valve is verified by this procedure.

In modelling the reciprocating compressor mathematically, generally the suction and discharge valve are assumed as 1-DOF mass-spring-damper system like Fig. 2. In this case to find the stress acted on the valve is impossible, it is possible only in the case of assuming the valve as a continuous system.

If the displacement of valve be predicted, in spite of assuming the valve as 1-DOF system, the stress on the valve can be found by iterative control of the external force in order that the equivalent displacement by the commercial analysis package is equal to the displacement of 1-DOF system.

In this study, the displacement of the suction valve was predicted by the prediction program of performance self-developed using special mathematical model. In this mathematical model the suction valve and discharge valve were assumed as 1-DOF system, the maximum displacement of suction valve was 3.06mm as a result of simulation. On the base of this result the numerical analysis was performed iteratively in order that the maximum displacement of valve in center of port zone by using the LS DYNA3D was equal to the maximum displacement of 1-DOF system.

Fig. 3 shows the pressure of cylinder which was used in LS DYNA3D analysis. this pressure of cylinder was obtained from the experimet of Bolted-Case. Fig. 4 shows the stress distribution on the suction valve in each state by LS DYNA3D analysis, table 4 represents the maximum stress and position in each state.

EXPERIMENT

In order to prove the accuracy of the result predicted by the numerical analysis, the experiment was performed as follows. Fig. 5 shows the experimental scheme.

In order to measure the stress acted on the the suction valve, the strain gage was attached to the valve surface. The strain gage signal and laser sensor signal were measured simultaneously in air like Fig. 6, the strain gage signal was calibrated by the laser sensor signal. The calibration data was used as reference data in measuring the displacement of the valve in real cycle. Because it is impossible to measure the displacement of the valve using the laser sensor in real cycle, the strain gage signal measured in bolted-case is converted to the displacement signal by using the calibration date.

It is impossible to find the displacement of the valve in all position using only the displacement signal converted from the strain gage signal. In this study the displacement and velocity of the valve was obtained in any position by assuming that the valve motion obeys the 1st mode obtained from LS DYNA3D. Fig. 7 shows the displacement of valve in center of port zone which was obtained by converting the strain gage signal to the displacement signal. Fig. 8 shows the velocity of valve in center of port zone.

RESULTS

(1) The maximum stress(bending stress) --- STATE 1

Table 2 shows the maximum stress by FEM and the maximum displacement by FEM and experiment in STATE 1 by assuming that the valve motion obeys the 1st mode obtained from LS DYNA3D. The table shows that the results of FEM are similar to the results of experiment. The maximum bending stress in STATE 1 is lower than the allowable stress of SUS(7C27Mo2) in case of the reversed bending stress, so the valve is reliable.

(2) The maximum impact value --- STATE 2

The allowable impact value of SUS(7C27Mo2) is 1.64 at number of load cycles 10^7. Table 3 shows the maximum impact value at STATE 2. It shows that the result by FEM and by experiment are lower than the allowable impact value, so the valve are reliable.

(3) The maximum stress (bending stress) --- STATE 3

The maximum stress in STATE 3 is 330MPa in center of port zone as shown in Fig. 3(c). The maximum bending stress in STATE 3 is lower than the allowable stress of SUS(7C27Mo2) in case of the reversed bending stress, so the valve is reliable.

CONCLUSION

The conclusion of this study is as follows:

(1) The numerical analysis and experiment are similar to each other, the reliability of the valve can be verified in design stage when using the method suggested in this study.

(2) The valve treated in this study is reliable, because the bending stress is lower than the allowable stress and the impact value is lower than the allowable impact value.

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(3) J. Park, J. Seo, H. Kang and J. Do, "Prediction of the Valve Stresses of Rotary Compressor Using Finite Element Method", International Compressor Engineering Conference at Purdue, pp. 169-174, 1994.

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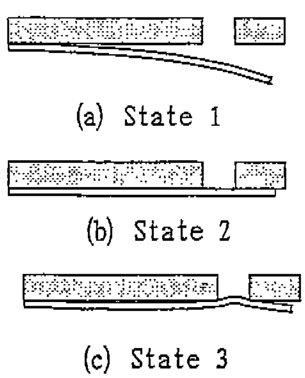


Fig. 1. Stress State of the Valve

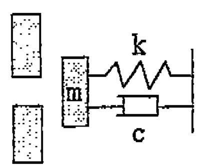


Fig. 2. Simplified Model of the Valve

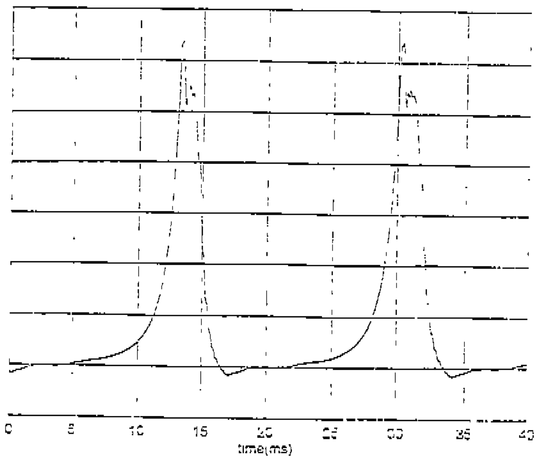


Fig. 3. Measured Pressure in Cylinder

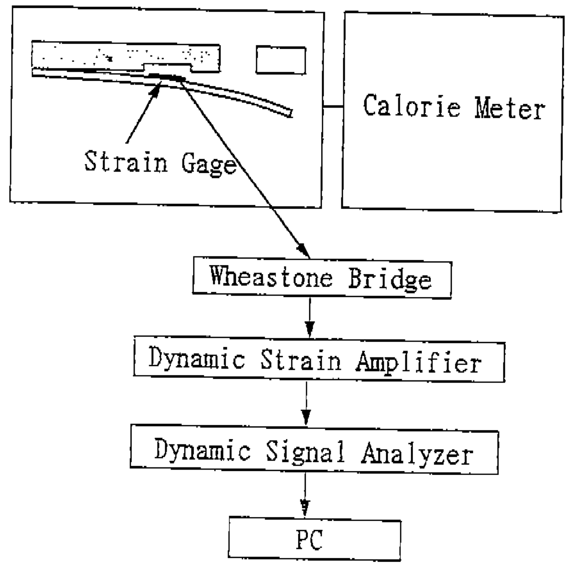
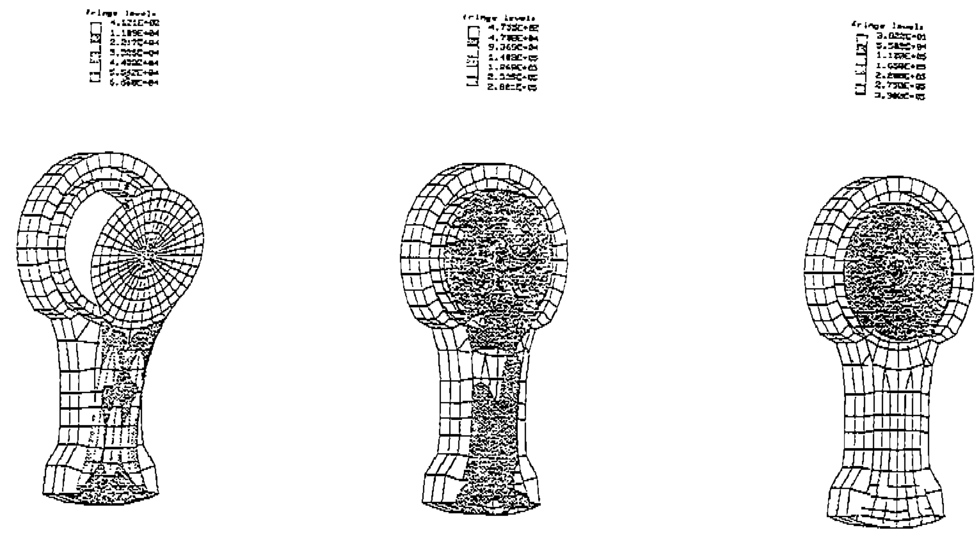


Fig. 5. Schematics of Experimental Setup



(a) State 1

(b) State 2

(c) State 3

Fig. 4. Stress Distribution in Valve

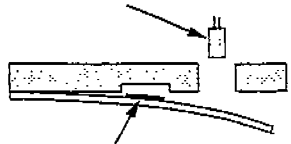


Fig. 6. Experimental Setup (in Air)

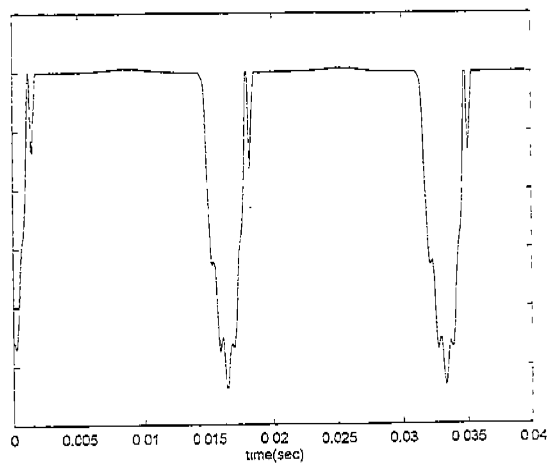


Fig. 7. Measured Displacement of Valve by Strain Gage (Center of Valve Port Zone)

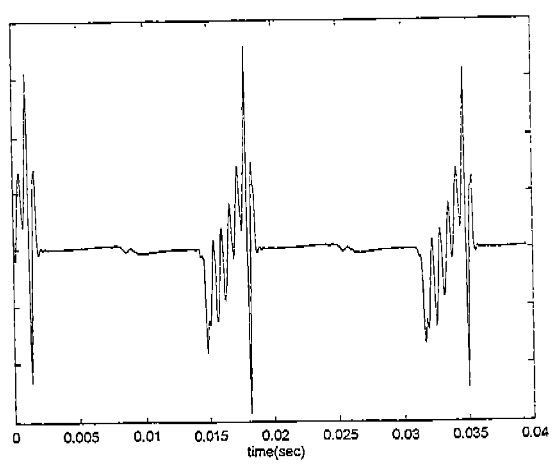


Fig. 8. Measured Velocity of Valve by Strain Gage (Center of Valve Port Zone)

Table 1. Maximum Stress at Each State by FEM

State	State 1	State 2	State 3
σ_{max} (MPa)	66.5	280.1	330.0
position	Edge of Neck	Center of Port Zone	Center of Port Zone

(Ref.) Allowable Stress of SUS(7C27Mo2) : 790MPa

Table 2. Maximum Dissplacement and Stress at State 1

Position		A	B	C
δ_{max} (mm)	FEM	3.06	2.50	0.40
	Experiment	2.69	2.01	0.67
σ_{max} (MPa)	FEM	8.0	10.0	31.0

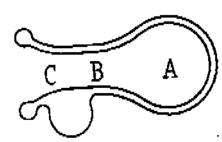


Table 3. Maximum Impact Value at State 2 (Center of Port Zone)

	FEM	Experiment
Impact Value	1.0	0.94
Allowable Impact Value of SUS(7C27Mo2) 1.64		