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2-Way Coupled FSI Simulation for Reciprocating Compressor Reed Valve

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***Abstract*—This paper describes the multi-physics FSI simulation approach to study the valve flutter which happens in reciprocating compressor reed valve. Area of study involves the compact variable compression (CVC) compressor which is operated by swash plate mechanism i.e., the rotation of the engine shaft is converted into reciprocating motion of the piston by swash plate. Both inlet and outlet valves have reeds which operate based on the difference in pressure between manifold and cylinder. During suction stroke, the piston movement increases the volume of the compression chamber. When the pressure inside the cylinder drops below the suction pressure, gas enters the cylinder via the inlet valves. The piston reaches the lower dead centre, reverses its movement and starts to compress the cylinder gas. Inlet valves closes and the gas undergoes an isentropic compression. When the piston approaches the top dead centre the pressure inside the compression chamber forces the outlet reed valves to open and the gas is delivered to the discharge pipe. Finally, the piston reaches the top dead centre, outlet valves close and the cycle starts again. In this simulation, real-time thermodynamic behavior of fluid inside the cylinder and structural behavior of the reed valve is predicted using coupling between ANSYS Mechanical and FLUENT. When FSI occurs, fluid flow deforms a physical structure, which in turn changes the fluid flow. This 2-way interaction loop continues through multiple cycles, which helps in predicting the more realistic fluid flow across valves and helps in studying the flutter behavior. The fluid pressure causes the reed valve to deflect which in turn will influence the flow structure and again the change in flow structure will influence the deflection of reed valve. This phenomenon is taken care by setting up the problem as FSI (Fluid Structure Interaction) simulation. This 2-way interaction is carried out every time step to make the simulation more realistic and accurate. In the process we can capture the fluttering of the valve if it happens for given conditions. Traditional fluid flow does not account for this interaction, so simulation results may be incomplete and even misleading. The resulting prototype from traditional flow would not perform as expected, and it is an expensive and time-consuming. That is why Fluid-Structure Interaction (FSI) approach is important to study the valve flutter phenomena.**

Keywords*— Multi-physics simulation, Fluid-Structure Interaction, compact variable compression (CVC), Reciprocating compressor and Reed valve.

I. INTRODUCTION

When the compressor is running at higher RPM's, insufficient fluid flow through suction reed valve might result in flutter phenomena causing unwanted noise during compressor operation. In actual test set-up it is very difficult to visualize and study this flutter phenomenon due to inaccessibility to interior of the compressor. Hence, virtual test simulation of reed valve operation using FSI approach is very close to reality and more helpful in optimal valve design and reduction in noise levels. FSI simulation approach is more accurate and very close to reality as it considers the interactions between the fluids and the structures that surround them.

II. FSI BASED SIMULATION APPROACH/METHODOLOGY

During suction stroke of the compressor, piston moves from TDC to BDC which creates suction in the cylinder making the reed valve to open and allow fluid flow into cylinder.

The change in the geometric domains derived from the deformation of the structure is taken into account by directly moving the solid mesh and updating the fluid grid according to the new solid interface position.

Throughout the valve opening, new fluid elements will appear between the valve and the seat. Since there is no re-meshing but the fluid mesh is just deforming, extra elements are needed under the valve, which first perform as rigid seat and later as fluid. The immerse boundary technique allows this change in the nature of an element thanks to a modification in its viscosity.

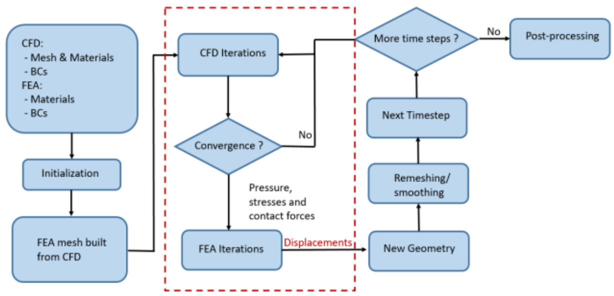

Fig. 1. Coupling strategy for FSI Simulation

III. PROBLEM SET-UP

The domain includes part of inlet manifold, cylinder, piston, inlet/outlet valve and cylinder head which accommodates both inlet and outlet valve seat (Schematically shown in Fig. 2).

In this simulation, piston is positioned close to the TDC to start with. Mesh is generated using hexahedral and prism elements in the CFD model. There are 2 dynamic mesh zones in the CFD model, the first zone is to capture the motion of the inlet valve and second zone to capture the movement of the piston which is done using the layering option of Fluent.

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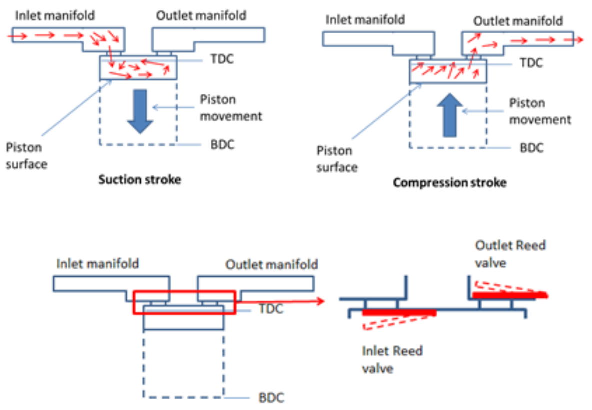

Fig. 2. Operation of Reed Valve

IV. RESULT

Several "monitoring" points are considered to extract pressure or valve displacement data from the model. One pressure monitoring point is located inside the cylinder, and one pressure monitoring point is located in the discharge plenum. Two displacement monitoring points are located on the suction and discharge valves respectively to determine valve movement. FSI simulation results are shown below for one complete swash plate/shaft rotation.

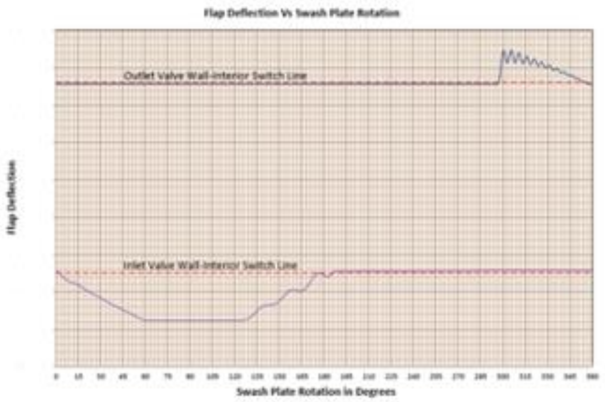

Fig. 3. Predicted valve behavior

Fig. 3 shows the simulation results for the valve lift created from ANSYS FSI simulation (y-axis and other result values are shaded intentionally in the above figures due to confidentiality). The bottom curve in chart shows the opening and closing of the suction reed valve whereas the upper curve for the discharge valve during one complete suction and discharge stroke of the compressor. Whereas Fig. 4 shows the PV diagram for one complete suction and discharge stroke of the compressor.

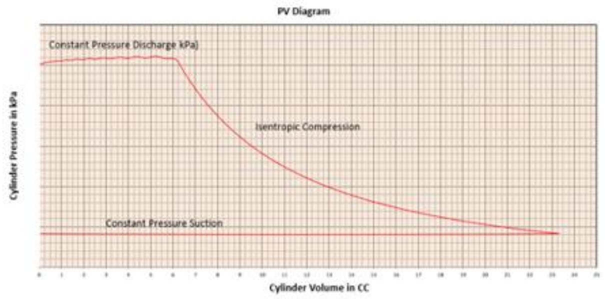

Fig. 4. PV- Diagram of one complete cycle

V. CONCLUSIONS

A methodology has been developed to capture the operation of reed valves during suction and compression strokes using Fluid-Structure Interaction method. The results of the simulation can help the designers to identify the areas of improvement and to reduce noise arising due to flutter.

With the help of FSI simulation, we can accurately capture and plot the pressure variation at the suction & discharge valve regions. Also, the mass flow rate and reed valve displacements can be monitored closely over a given period of time which helps us to understand the flow dynamics and vibration characteristics of reed valve. Pressure pulsations at suction and discharge valves are studied which is helpful in optimizing the reed valve and hence to reduce valve flutter/noise. Even various suction port shape variations are tried out to study the flow and vibration characteristics.

VI. FUTURE WORK

Currently the FSI model is validated for a compressor operating speed of 5000RPM and it needs to be validated for the entire operating range of compressor (i.e., @ 1500, 3000 and 8000 RPMs). Also, for simplicity only one cylinder/valve system is considered for the FSI simulation and needs to be extended to another 5 sets of cylinder/valves to predict more accurately the compressor flow dynamics and performance.

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