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ABSTRACT

In a scroll compressor it is generally accepted that a check valve is necessary to prevent reverse rotation of the scrolls. Many designs utilize the discharge plenum of the compressor for placement of the valve. In this region the valve is subjected to discharge pulsations and their resultant forces. It is necessary to gain an understanding of the flow induced forces and valve movement in order to achieve proper valve function with minimal performance and sound degradation.

This paper describes the methods used in a theoretical and empirical analysis of a scroll check valve.

INTRODUCTION

The purpose of a check valve in a scroll type compressor is to prevent the reverse rotation of the scroll elements without adding significant compressor noise. Reverse rotation is caused by the pressure differential between the discharge and suction plenum pressures when the compressor is shut down or a power interruption occurs.

The prevention of reverse rotation immediately upon interruption of compressor power is desirable. If reverse rotation is allowed, damage to the compressor may occur due to insufficient lubrication. Additional damage to the compressor can occur if the compressor is re-energized while the scroll elements are being driven in reverse by the pressure differential, as would occur during a brief power interruption to the unit. If this were to happen the compressor may continue to operate in reverse, and could result in the ultimate failure of the compressor. Even if compressor failure were not to occur, unacceptable noise will result.

Additionally, it is necessary to place the check valve as close to the discharge port as possible in order to reduce to a minimum the volume of discharge gas available to drive the scrolls in reverse after the valve has engaged. It is for this reason that externally mounted, commercially available check valves are unacceptable. However, placing the valve over, or sealing on, the discharge port subjects the valve to pulsations inherent to the scroll compression process. Large pulsations occur due to over or under compression wherever the compressor operates off the designed pressure ratio. These pulsations can cause the excitation of the valve resulting in increased compressor noise. Adding to the complexity of the check valve response is the fact that the discharge pulsations change dramatically with a change in compressor operating conditions.
Common solutions for scroll compressor check valves include reed

valves, free floating valves, and ball type valves. Although these designs can perform satisfactorily in the prevention of reverse rotation, they all produce varying degrees of noise at specific regions within the compressor operating envelope. One inherent benefit of scroll compression is quiet operation, a feature of increasing importance to the consumer. In order to take full advantage of this benefit it is desirable to reduce if not eliminate the acoustic impact of the check valve without reducing its effectiveness.

THEORETICAL ANALYSIS

The theoretical analysis involves the investigation of a free floating type check valve as illustrated in Fig 1.0. This type of check valve was selected for analysis because of a direct correlation of the valve response to the gas pulsations and, more importantly, flexibility of the design that allows various mass and damping configurations. The discharge gas pressures were obtained using pressure transducers mounted near the discharge port of a scroll compressor.

The motion of the check valve was analyzed using a simple spring/mass/damper system subjected to the force of the discharge gas on a fixed area. The effective area of the valve exposed to the flow must be larger than that of the scroll discharge port, but smaller than the internal diameter of any tube or counterbore that may be used to guide the tube in the vertical direction. The area used in the following analysis was 0.50 square inches. In this case the valve was allowed to travel from the scroll discharge port to a vertical distance of 0.30 inches, guided inside a counterbore of limited radial clearance. For a damped vibrational system subjected to a periodic forcing condition of a general type, the differential equation of motion would be as follows:

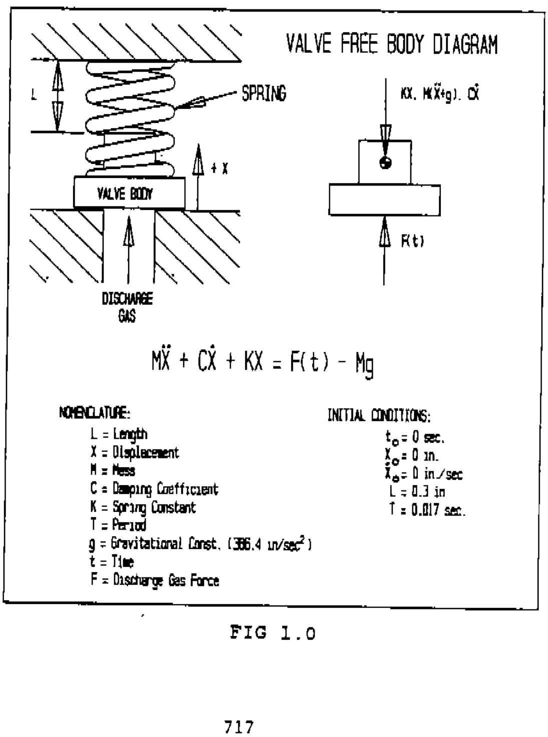

FIG 1.0

Three compressor operating conditions were selected in the analysis in an attempt to fully describe the forces exerted on the valve. These conditions and their resulting forces (using the fixed area described above) are displayed in the following figures.

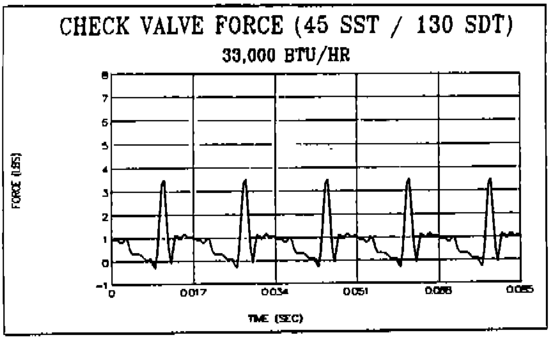

FIG 2.1

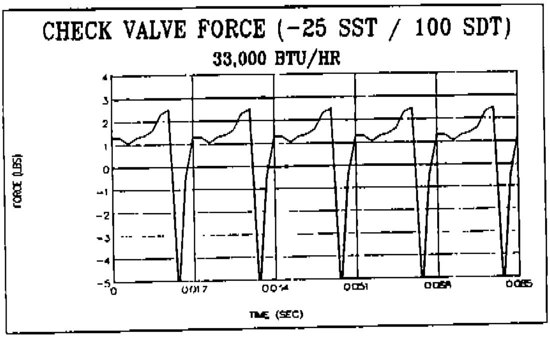

FIG 2.2

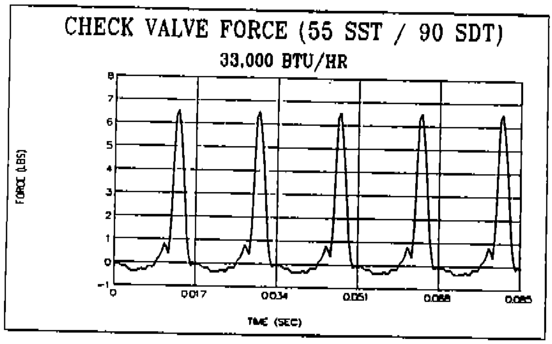

FIG 2.3

The resulting forcing functions are irregular in form and cannot be expressed as an explicit function. It was therefore necessary to evaluate the forcing function and the differential equation using finite difference methods. Using this method, a computer model was developed allowing various spring constants, damping coefficients, and forcing functions to be entered. The values for the spring constant (k) and the damping coefficient (c) were set at small non-zero values in order to simulate a free floating valve moving in the discharge gas flow with no external springs present (see fig 3.0). It was also necessary to incorporate the impact of the valve at both limits of travel. A perfectly elastic collision was assumed, thus the velocity was reset to zero and the acceleration vector reversed in direction at each instantaneous impact point. The following displacements were generated in figures 4.1 - 4.3.

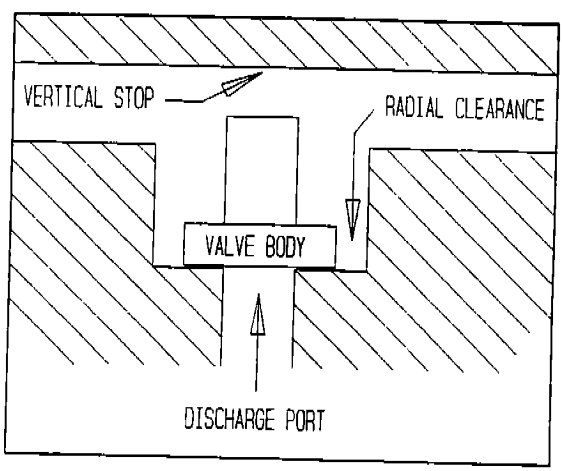

FIG 3.0

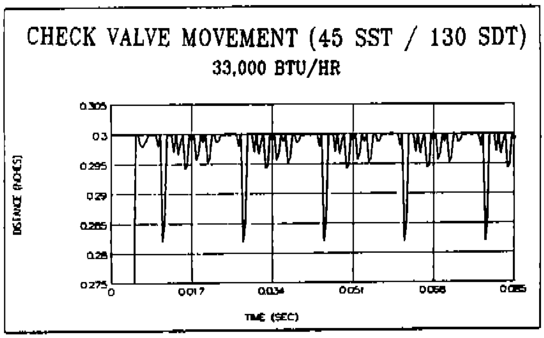

FIG 4.1

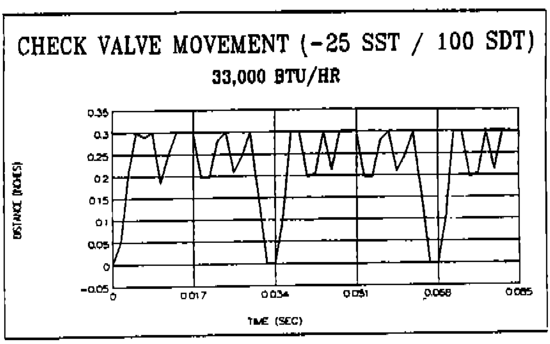

FIG 4.2

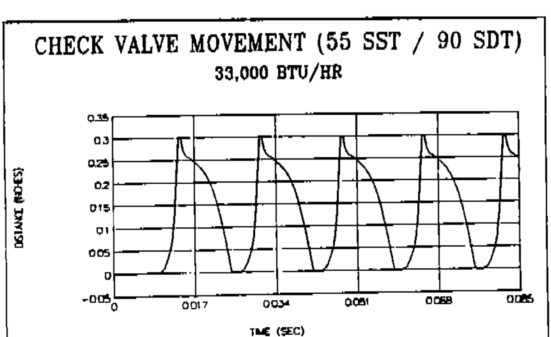

FIG 4.3

As expected the valve response was different at each condition in both shape and total displacement. It should also be noted that the simulation predicts contact between the valve and at least one surface at each of the three conditions investigated. Since impact of the valve (and any other component) is considered unacceptable from an acoustic viewpoint, further investigation was necessary. The simulation was modified in order to explore the motion of the valve under various spring forces.

In this investigation a spring force was found that would limit the travel of the valve in a manner such that contact with any surface was eliminated at the baseline condition of 45F SST/ 130F SDT. It was, however, desirable to eliminate check valve noise at all three of the compressor operating conditions. The simulation was therefore further modified to loop through a large number of spring constants in an attempt to determine one that would not allow contact with any surface at all three conditions. A further constraint was introduced; that the spring constant could not be so great that the valve would fail to open. The result of this variable spring constant loop was a failure to find any one spring constant that would satisfy the requirements at all three conditions. Two additional loops were run; one in which the mass of the valve and the spring constant were varied, and a second where the valve was additionally allowed to contact the discharge port. These loops yielded the same result; no solution given the constraints.

It was therefore determined that while a spring assisted free floating type check valve (and consequently reed and ball valves) may perform satisfactorily in the prevention of reverse rotation, they are likely to produce unacceptable noise at various conditions within the compressor operating envelope.

EMPIRICAL ANALYSIS

To verify the results of the simulation program, the actual vertical movement of a check valve was measured in an operating scroll compressor. The compressor and valve were modified to match the same effective valve area, radial clearance, and vertical travel as that in the simulation. The vertical movement of the valve was monitored using a proximity transducer. The transducer was mounted above the valve and targeted on a metal plate fixed to the top of the valve as illustrated below in fig 5.0.

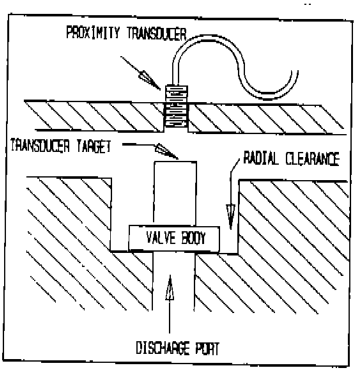

FIG 5.0

A trace of the valve movement without a spring was recorded at a compressor operating condition of 45 deg SST/130 deg SDT. The trace of the actual valve movement versus the corresponding simulation results can be seen in figures 5.1 and 5.2 respectively.

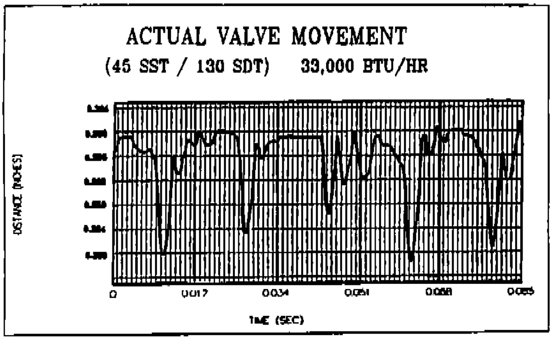

FIG 5.1

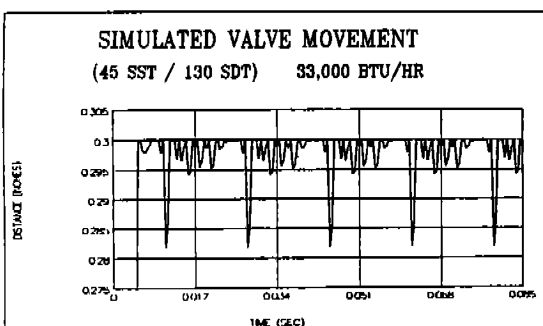

FIG 5.2

Both traces display a similar mode shape and magnitude of the largest periodic displacement. The calculated percent error of the measured versus the predicted displacement was 5.7%.

The operating conditions of -25 deg SST/100 deg SDT and 55 deg SST/90 deg SDT were also tested; however, the limited range of the proximity transducer would not allow measurement of the total valve movement. A further acoustic investigation at these operating conditions was performed, confirming that the valve was contacting both limits of travel as predicted using the computer model.

The check valve was also modified with various springs of different spring rates in an attempt to eliminate the excessive noise due to the impact of the valve. All spring configurations that were tested produced an unacceptable level of noise.

SUMMARY

A computer simulation program was developed modeling the movement of a check valve in a scroll compressor mounted directly over the discharge port. The results from the computer model were verified with the actual recorded displacement of a valve in an operating compressor. Both the simulation and actual measured results demonstrated the complex nature of the valve response for the type tested. The simulation was cycled through a large number of spring constant and valve mass variations in search of a combination that would eliminate valve contact and resulting valve noise.

It was determined that although a spring assisted floating type check valve may perform satisfactorily in the prevention of reverse rotation, it is likely to produce unacceptable noise at various conditions within the compressor operating envelope.