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REDUCED NOISE VALVE DESIGN FOR A ROTARY COMPRESSOR

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ABSTRACT

Valve impact on its valve stop in a rotary compressor is shown to be a dominant noise source. Excitation is shown to be centered at the valve stop natural frequency. Two valve stop profile design approaches are discussed that reduce the valve stop excitation by altering the valve contact process. Experimental results show overall noise reductions.

INTRODUCTION

Experimental and analytical noise source identification studies on a rotary compressor have shown valve stop ringing to be a contributor to the radiated sound spectrum. Impact of the valve on the stop causes the stop to ring at its fundamental natural frequency. This vibration is transferred to the outer shell where it radiates sound to the farfield. Valve stop redesign was undertaken to reduce the ringing while maintaining the structural integrity of the valve and valve stop. Successful designs were defined and tested.

DESIGN PHILOSOPHY

Two related design philosophies were pursued. The first, reduced impact, concentrated on reducing the impact by reducing the momentum transferred to the stop and spreading the impact process out in time. The other focused on a high attitude design, minimum impact, that minimized the impact by shaping the stop so that the valve contact was minimized.

The first design, reduced impact, was specifically configured so that the shape change was minimal; consequently the stress levels in the valve were predicted to stay essentially the same as those of the original design. The minimum impact design was based on a more significant change to the valve stop, where under normal operating conditions, valve/valve stop contact was minimized, while under full contact, expected only for severe conditions, its shape was selected to insure that the valve stress did not exceed its allowable fatigue stress. The advantage of this approach is that, normally the valve contacts the valve stop only within a very small root region.

These two philosophies lead to different designs. The reduced impact approach has less noise reduction potential, but should result in stress levels similar to those of the current design because of its lower height (ie attitude) at the tip. Designs based on both approaches were evaluated.

IDENTIFICATION OF VALVE STOP RINGING AS A SOURCE

The farfield one-third octave band rotary compressor spectrum in Fig. 1 shows the noise in the 2000 Hz. region to be dominant. Narrow band spectra show that the noise field is made up of many tones that are harmonics of the shaft speed. As is clear from Fig. 1, the noise in the 2000 Hz range is dominant. In order to identify noise sources in general, an extensive instrumented compressor noise test was run. The focus of this paper will be on the 2000Hz source which is due to valve stop ringing.

The instrumented compressor had strain gages on the valve stop and, as shown in the time trace in Fig. 2, the strain variation was that of a damped sinusoid. Superimposed on Fig. 2 is the response of a strain gage located on the valve itself, which shows the ringing to start when the valve strain is maximum. This clearly shows that the valve stop was ringing in response to an impulsive impact from the valve. Accelerometer and microphone data further support this finding.

To further verify this mechanism, the valve stop natural frequency was measured(1920 Hz.) and predicted(1932 Hz.). Fig. 3 is a narrow band spectrum of the valve stop strain gage response, and exhibits the expected spectral shape for ringing, with a peak at the 1882 Hz. harmonic, which is the harmonic closest to the stop natural frequency. The slightly lower natural frequency of the valve stop in the compressor is attributed to the effect of the strain gage mass.

ANALYSIS OF IMPACT PROCESS

A finite element valve dynamics study was undertaken to analyze the baseline valve motion during discharge and to determine the contact characteristics between valve and stop. Fig. 4 shows a schematic of the valve and valve stop. The valve, which seals the discharge port, opens as soon as the pressure inside the compression chamber exceeds the pressure in the valve area. Dynamic pressure data was available for these two locations and was used to develop the driving force for the valve motion.

As the valve opens and starts to impact the stop, those portions of the valve which are already in contact with the stop are not allowed to move further in the vertical direction. However portions of the valve which are not in contact with the stop can still move and this situation keeps changing as more and more of the valve touches the stop. This problem is solved using the finite element method with an iterative solution technique.

Results from this analysis produced the displacement history of the valve nodes used in the finite element model. The combination of mass and displacement history for each of the nodes allowed the kinetic energy and momentum at these nodes just before impact to be calculated. In this way, the momentum transferred to the valve stop as a function of time could be predicted. This result is shown in Fig. 5, and shows that most of the momentum is transferred during the final time increment of the valve travel. Reduction of the transferred momentum and lengthening of the impact time leads to reduced excitation and vibration of the stop and reduced noise, as discussed in the next section.

DESIGN - REDUCED IMPACT STOP

Since it has been analytically determined that a large portion of the valve strikes the stop synchronously during the final portion of the contact process, a redesign to modify the stop profile to allow smoother, more continuos impact was undertaken. Also, it can be shown that the shorter the duration of impact, the higher is the harmonic content of the impact excitation. Fig. 6 shows harmonic amplitudes for various time durations of the impact. It can be seen from Fig. 6 that the longer the impact time, the smaller the harmonic amplitudes. Hence it was confirmed that longer lasting impact events reduce the excitation harmonics of the stop. Additionally, reducing the total impact momentum also reduces the total stop excitation.

Thus a modified stop design was developed satisfying the above criteria. Finite element analysis results for this are shown in Fig. 7. It can be seen that less momentum was transferred by the modified stop, and that the impact time was increased.

DESIGN - MINIMUM IMPACT STOP

To reduce impact between the valve and stop, the minimum impact approach is to design a high attitude stop profile so that the impact occurs only after most of the kinetic energy in the valve has been converted into strain energy. The height of the stop is limited by the need to insure that the valve stress not exceed its allowable fatigue stress. The advantage of this approach is that under normal operating conditions, the valve contacts the valve stop only within a very small root region. This reduces impact significantly.

To exploit fully the highest attitude profile of the stop under the allowable stress limitation for the severe operating condition, the stop is designed in such a way that at each contact point with the valve stop, the valve does not exceed its maximum allowable stress. Also, as discussed above, the profile of the stop under normal conditions should be smooth and gradual, so that contact occurs with a longer time interval, causing lower harmonic excitation.

EXPERIMENTAL RESULTS

Versions of each valve stop design were fabricated and installed in the same compressor. Noise tests were performed in an anechoic chamber. Figure 8 shows that both valves significantly reduced the noise relative to the baseline design. As expected, the minimum impact design was slightly quieter than the reduced impact design.

CONCLUSIONS

1. In a rotary compressor, valve stop ringing due to impact by the valve was shown to be a dominant source of noise, with a spectral peak that corresponded to the valve stop first natural frequency.

2. Two design philosophies were defined for valve stop redesign, one seeking to minimize the impact momentum while spreading out the impact time. The other sought to have minimal valve/valve stop contact during normal operating conditions.

3. Experimental results showed that both designs reduced the overall noise,with the minimum impact design giving the largest reduction.

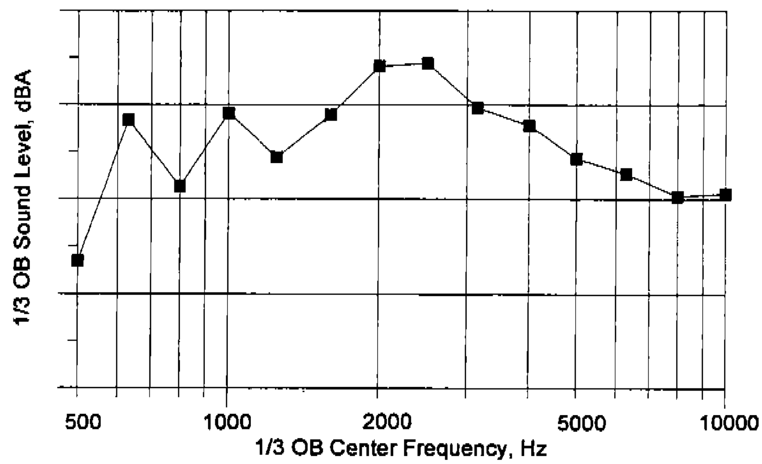

Fig. 1 Baseline Compressor Spectrum

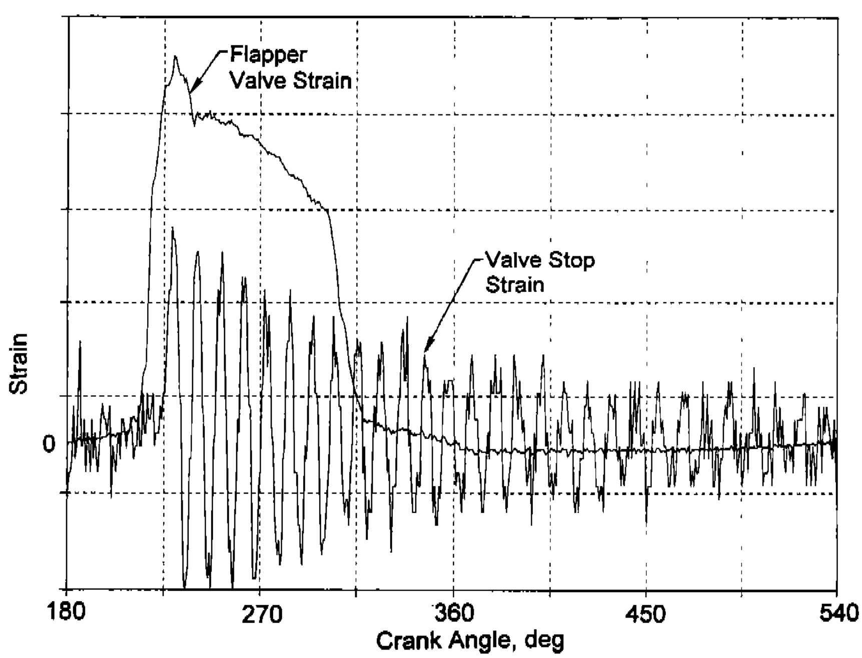

Fig. 2 Valve Stop and Valve Strain Gage Time Histories

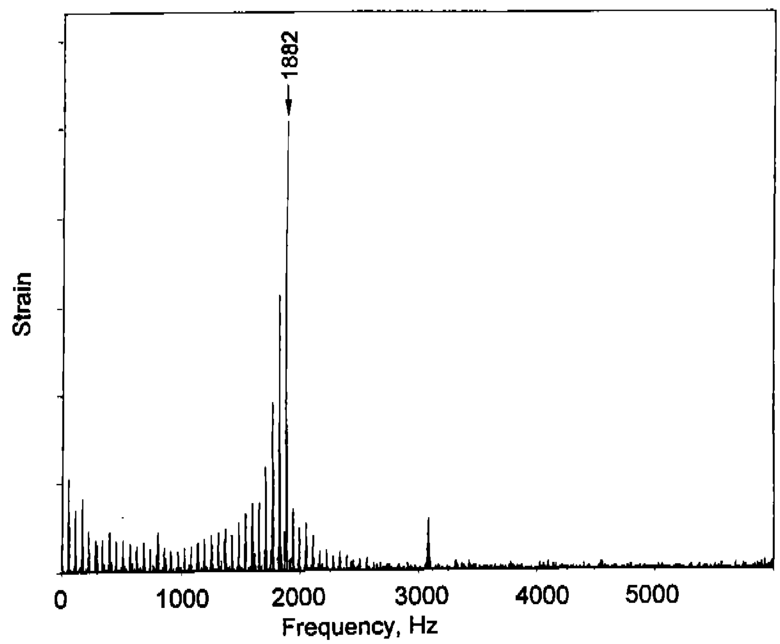

Fig. 3 Valve Stop Strain Spectrum

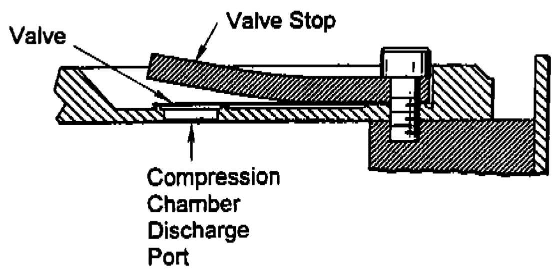

Fig. 4 Schematic of Valve and Valve Stop

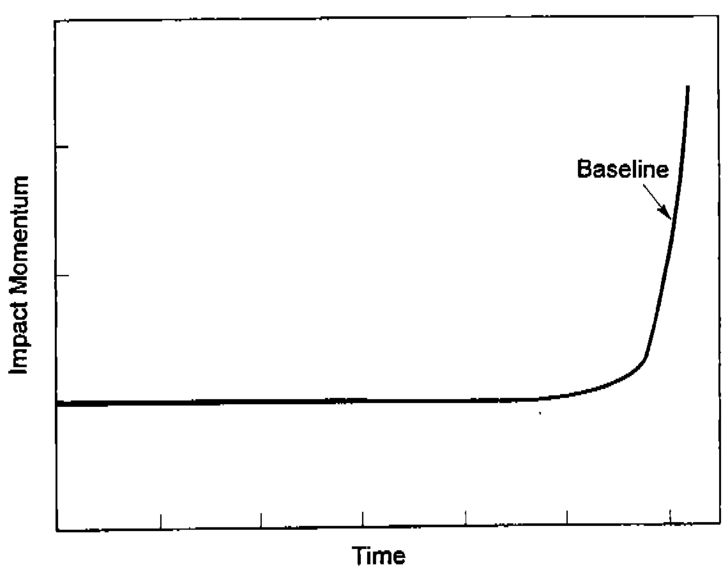

Fig. 5 Predicted Momentum vs Time

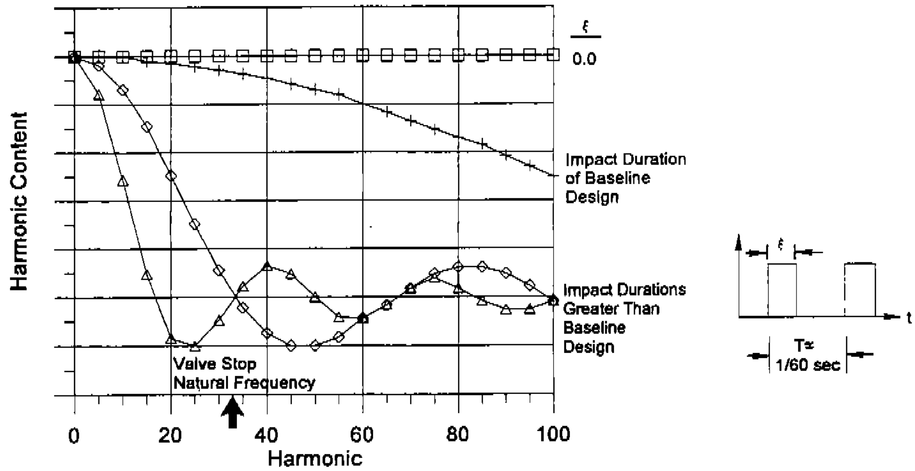

Fig. 6 Harmonic Response of Periodic Square Wave

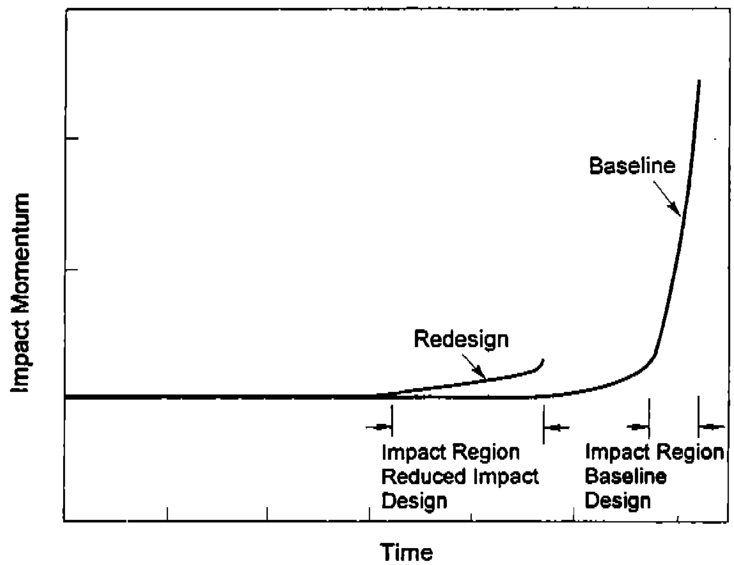

Fig. 7 Momentum vs Time

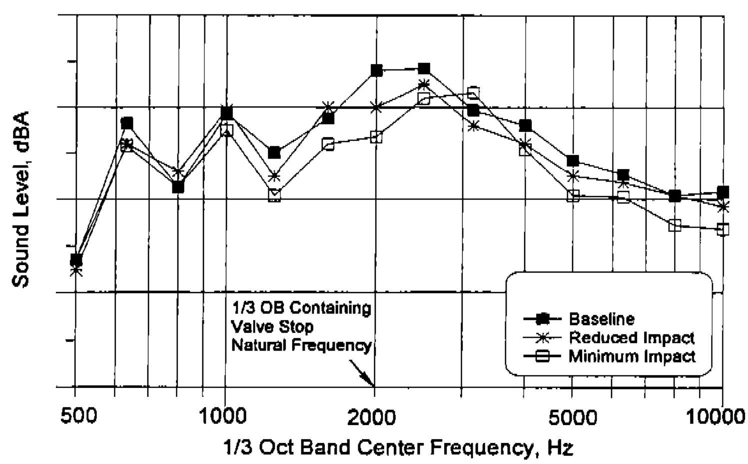

Fig. 8 Measured Spectra, Baseline vs Reduced Impact vs Minimum Impact Designs