

## Vibration Issues on Compressors With a Wide Speed Range

### Introduction

One approach to achieve capacity control in a reciprocating compressor is to utilize an engine or variable frequency drive motor to change the compressor speed (and thus flow). Designers of reciprocating compressors should note that a wide speed range can cause additional challenges in minimizing vibration, especially on the scrubbers.

This application note discusses vibration related problems and solutions for reciprocating compressor applications with a wide speed range. Attention to these issues early in the design is recommended to avoid future problems.

### Resonance Can Create High Vibration

The easiest method of minimizing vibration is to avoid resonance. Resonance occurs when an excitation force occurs at the same frequency as the structure's Mechanical Natural Frequency (MNF). Many forces act on the compressor (as illustrated in Beta's web training video - module 1). The forces act at different orders of compressor speed – with the 1<sup>st</sup> and 2<sup>nd</sup> orders often having the highest forces.

Figure 1 and 2 show the speed range for a fixed speed compressor operating at 1200 rpm and a variable speed compressor operating at 900 to 1200 rpm. As is shown by these figures, the variable speed compressor covers a much larger frequency range compared fixed speed compressor. Avoiding resonance for a variable speed is more difficult than a fixed speed compressor. In practice, the frequency range that must be avoided is at least 10% greater than the actual compressor speed since there will be some resonant response even if the mechanical natural frequency is not exactly the same as compressor speed. This 10% increase in frequency makes avoiding resonance even more difficult on a variable speed compressor compared to a fixed speed compressor.

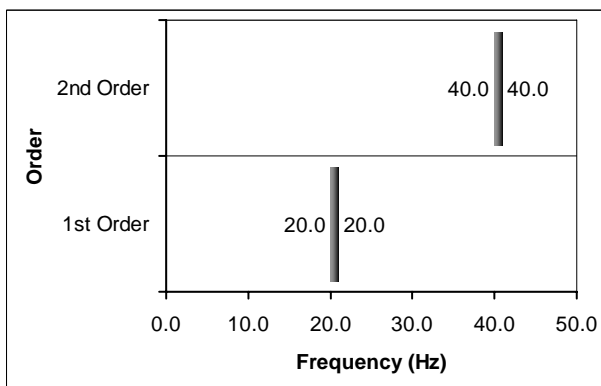


Figure 1: Fixed Speed Compressor  
(frequency for 1X and 2X Run Speed)

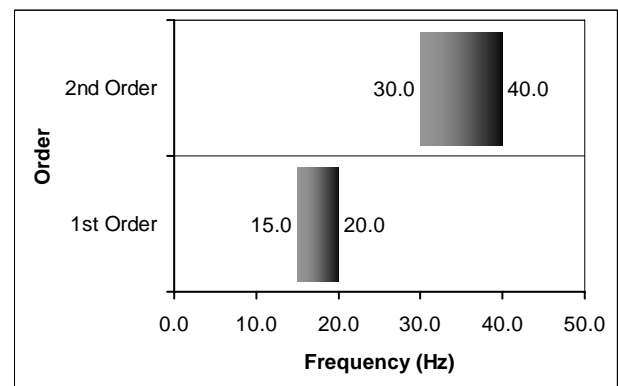
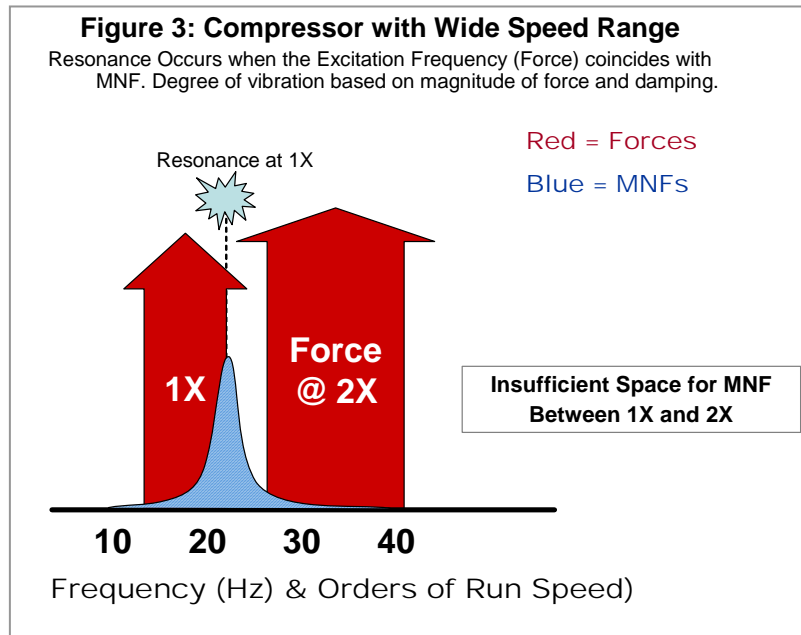


Figure 2: Variable Speed Compressor  
(frequency range for 1X and 2X Run Speed)

Figure 3 shows an example of the MNFs for a vessel on the compressor package superimposed on the speed range for a variable speed compressor. This example shows there is a resonance at 1<sup>st</sup> order of compressor speed

When resonance occurs, the vibration can be amplified up to 30 times. The amount of damping affects the vibration level at resonance. Damping refers to how the mechanical system absorbs or “dampens” the vibration. Higher damping will reduce the magnitude of vibration. Lower damping will result in higher vibrations. The damping for the system or a typical component on a compressor skid cannot be calculated at the design stage, and it depends on many variables. Damping values used in the design stage are based on typical values measured on real systems.



Scrubbers often have MNFs close to the 1<sup>st</sup> or 2<sup>nd</sup> order of compressor run speed, resulting in resonant conditions.

An API 618 study will analyze the pulsation and mechanical system. The mechanical analysis involves calculating the MNFs of the compressor cylinders, pulsation bottles, and close coupled scrubbers and piping, and identifying potential resonant areas.

### **Solutions:**

When a scrubber resonance is identified in a design study, the following options are available.

1. **Scrubber Re-Design:** As outlined in Application Note #1a and 3, the API guideline requires the MNF of scrubbers (and other components) to exceed 2.4 times compressor run speed. This will require attention to height vs. diameter ratio. Beta has developed a software tool to assist packagers design scrubbers to meet this MNF target.

The scrubber re-design also includes a specific design for the scrubber base and skid below the scrubbers. The scrubber base design details have been developed in the form of a standard drawing that is available to packagers for their initial package design.

The modified scrubber design may be a cost adder for the packager/customer. As a result, for many projects the scrubber design is not changed; instead another solution is pursued.

2. **Bracing:** If re-designing the scrubber is not possible, or does not provide a sufficient change in the MNFs, the next solution is to add braces to raise the scrubber MNF. Additional gussets and skid beams may also be required.

This is not a popular solution and is often rejected by the customer or packager because of aesthetics, operating requirements or cost.

3. **Inter-tuning:** This approach is to tune the MNF of the scrubbers between the 1<sup>st</sup> and 2<sup>nd</sup> order of compressor speed to avoid resonance (see Figure 4). Note that for a variable speed machine, the speed range results in a wide range of frequencies to avoid, thus making inter-tuning very difficult.

Although the preferred practice is to modify the scrubber designs or add bracing, often it is not accepted by the customer. As a result many of units are designed with inter-tuned scrubbers.

In spite of inter-tuning not being Beta's preferred design approach it has often been successful in practice. For some variable speed units there is enough of a frequency span between the top of 1<sup>st</sup> order and the bottom of 2<sup>nd</sup> order inter-tuned. Inter-tuning is not possible in all cases so the alternative is to tune the scrubber mechanical natural frequency to be at the bottom of the speed range. Designing the scrubber mechanical natural frequency to the lower end of the speed range has the following advantages:

- Operating requirements are generally focused at the higher run speeds.
- Emission regulations often result in penalties when engines run at slow speeds (higher emissions).
- Some engine systems do not operate well at lower speeds, especially at higher elevations.
- Some of the inherent compressor unbalanced forces are reduced at lower speeds, reducing vibration amplitude to acceptable levels.

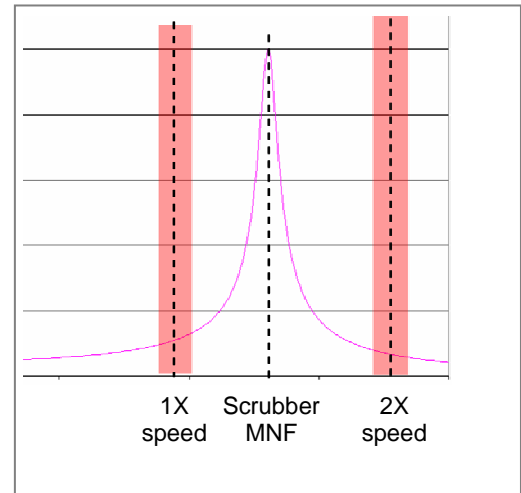
The disadvantage of inter-tuning scrubbers is that there can sometimes be high vibration when the unit is started. Inter-tuning does not necessarily guarantee vibrations will be acceptable since the dynamic forces may be high or the static stiffness of the scrubber low resulting in high vibration. Field modifications are then required to reduce vibrations.

***Note that customers need to approve the inter-tuned approach since it can create higher risk than increasing the MNF above 2.4 times run speed.***

## Recommendations

Beta offers these recommendations for consideration:

- Packagers and their customers need to be aware of the challenges associated with variable speed drive compressors.
- Early in the design/bidding process, provide an option for the customer to use modified scrubber designs to avoid vibration problems.
- If this is rejected, then assume that bracing is required. Provisions must be made to allow for bracing either on the compressor skid or to the foundation outside of the compressor package footprint.
- Beta will recommend bracing or modified scrubbers. Inter-tuning option will require a waiver from the customer/packager that highlights the risk of field problems.
- Perform a start-up check to assess the vibration levels across the required speed range. If vibrations are found in the startup check, the following modifications may be required
  - Block out a speed range and/or implement other measures for capacity control
  - Add brace to overtune the scrubber or add a damping element to reduce the resonant response



**Figure 4: Inter-tuned scrubber**