The cost effective alternative to heat treatment

Report on Vibratory Stress Relief

Prepared by Bruce B. Klauba
Product Group Manager

CAMERON
COMPRESSION SYSTEM DIVISION

Oklahoma City, OK

The Compression Systems Division of CAMERON (formerly COOPER COMPRESSION, COOPER ENERGY SERVICES, and COOPER TURBOCOMPRESSOR) is a leading manufacturer of reciprocating and centrifugal compressors. When three (3) 151" L, cast iron Compressor Frames (manufactured in China) displayed distortion after final machining, it became evident that the Chinese manufacturer's thermal stress relief treatment had not been effective. Because the Frames had already been final machined, CAMERON needed to find a way to save them from becoming scrap. VSR Technology's resonant frequency vibratory stress relief process proved to be the answer to saving the Frames.

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VSR SETUP

Each Frame had an overall rectangular envelope of 151" L X 82" W X 38" H, and weighed 11,800 lbs. Also, one side of each Frame had a 20" "gap", ie, a vacant center space approximately half the width of the workpiece.

Each Frame was placed on 3 Isolation Load Cushions. One Load Cushion was placed at the center of the long continuous (opposite the "gap") side, (*see* **Figure 1**). The other two Load Cushions were placed on the opposite long side, on either-side of the 20" gap (*see* **Figure 2**)

Figure 1: Compressor Frame setup for VSR Treatment. One Isolation Load Cushion (circled) is centered along continuous (non-gap side) side of frame. The Vibrator (circled) was mounted above it. MX-8000 Console with touch-screen PC and USB keyboard visible on the left (circled).

This Load Cushion arrangement minimized damping of the workpiece, and thus promoted resonances, a key requirement of effective vibratory stress relief. Flexure of the workpiece is absolutely necessary to relieve stress, and resonance is the most efficient means of achieving stress-relieving flexure.

An Accelerometer (sensor whose output is proportional to acceleration), was placed on a corner of the workpiece, far from the vibrator, so as to best detect resonance. Based on Newton's 2nd Law, **F = ma**, where **F** is force, **m** is mass, and **a** is acceleration, acceleration has repeatedly shown to be the best parameter to gauge workpiece amplitude.

Figure 2: "Gap" side on left is ≈ 20". A Load Cushion was placed on each side of the gap (not visible), about 12" from the outer edge of the Frame. The Accelerometer can be seen in the foreground (circled), with its connecting cable leading to the VSR-8000 Console.

The Vibrator was clamped securely to the workpiece near the center of the "continuous" side (*as shown* Figure 1), and oriented so its Axis of Rotation (AOR) was horizontal, and parallel with the minor axis (width) of the workpiece. Other orientations were tried, but this orientation was found to generate both the greatest number and the highest intensity resonances, without causing peaks in the power curve – evidence that the Vibrator is well-positioned and oriented. An incorrectly located Vibrator or one adjusted to excessive unbalance results in large peaks in the power curve, which can trigger the VSR System's motor protection.

Initially, the Vibrator's unbalance was adjusted to 0.4 in-lbs (10% of the available 4.0 in-lbs), but to increase the resonant response, this was adjusted to 0.8 in-lbs (20%). This setting provided the acceleration levels (measured in "g") required for stress relieving, and allowed a Pre-Treatment Scan to be performed (*see* **Figure 3**).

VSR TREATMENT

The Treatment was performed by tuning the vibrator speed upon the resonance peaks identified in the Scan, starting with the largest amplitude resonance (≈ 4500-RPM). Progress of the Treatment is detected by growth of the resonance peak to higher amplitudes (growth commonly produces the greatest percentage of change), and/or shifting of the resonance peak in the direction of lower RPM (shift commonly produces the weaker percentage of change). The time to perform the first Treatment, including Pre- and Post-Treatment Scans, was 90 minutes.

Growth of resonance peaks ranges from ≈ 10% (mild response) to 100% or more (strong response). Peak shifting varies from a ≤ 1% to ≥ 5%. Although peak growth is the more sensitive parameter to monitor, both growth and shift parameters are monitored during the Treatment.

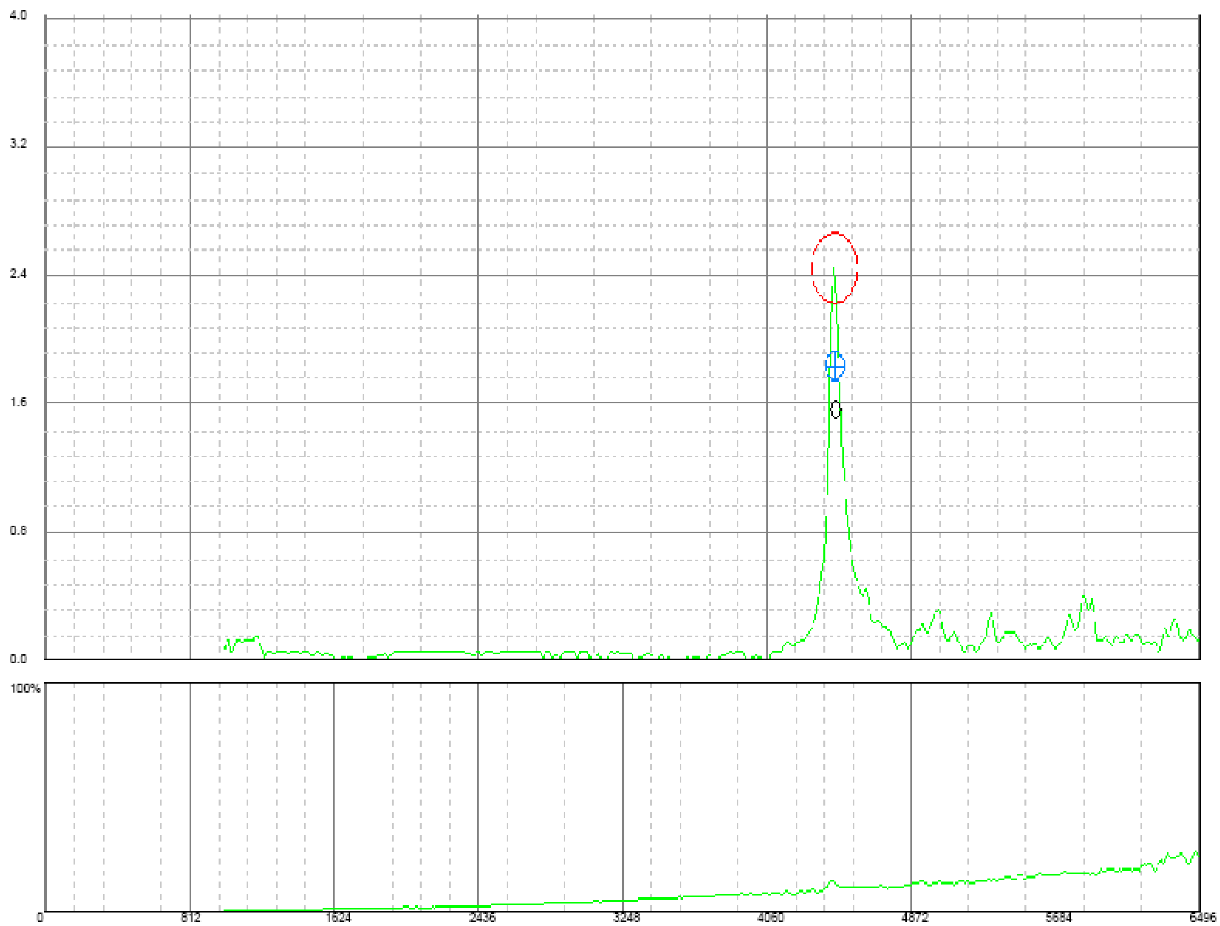

Figure 3: Pre-Treatment Scan, Workpiece 1. VSR Treatment Charts have two sections: An upper section that displays acceleration, and a lower section that displays vibrator power. Each section shares a common horizontal axis, which is RPM. In this Chart, the RPM range is 0 – 6496-RPM (calibrated on the touchscreen PC as 6500-RPM). The acceleration range (upper vertical) full scale is 4.0g. The full-scale is adjustable on the VSR-8000 System from 1g thru 50g. The vibrator power (lower vertical) is fixed, with 100% being 3-HP or 2.3-kW. Pre- and Post-Treatment Scans are done at a rate 10-RPM/second, a sufficiently slow rate for the Scans to be accurate, high-resolution depictions of the workpiece's resonance pattern. The resonance pattern does change, due to stress relief.

While tuned upon the large, ≈ 4500-RPM resonance, peak growth (fast at first, then slowing-down until reaching stability) took place over a 15-minute period. Total growth on this peak was slightly more than 20%. This change was documented during the Post-Treatment Scan (*see* **Figure 4**).

Figure 4: Workpiece 1, Treatment 1. The Pre-Treatment Scan plotted in green as shown in Figure 3, with the Post-Treatment Scan, plotted in red, superimposed upon it.   Most of the treatment time was spent on the large peak at ≈ 4500-RPM (15-minutes), with each of the peaks to the right of this large peak being tuned upon for 2-3 minutes, to determine if additional peak growth or shifting could be generated. The small peaks yielded little change.

A second Treatment was performed, with the Accelerometer repositioned and reoriented. After testing a few different locations and orientations, an ideal Accelerometer location was found directly above the one shown in Figure 2, and the sensor was oriented so as to be sensitive to amplitude in the direction of the workpiece's major axis (length of workpiece). This new positioning yielded better resonance data for the higher RPM resonance frequencies located at 5000, 5600, and 5800-RPM (*see* **Figure 5**). Note that the large resonance shown in Figures 3 & 4 is much shorter in Figure 5.

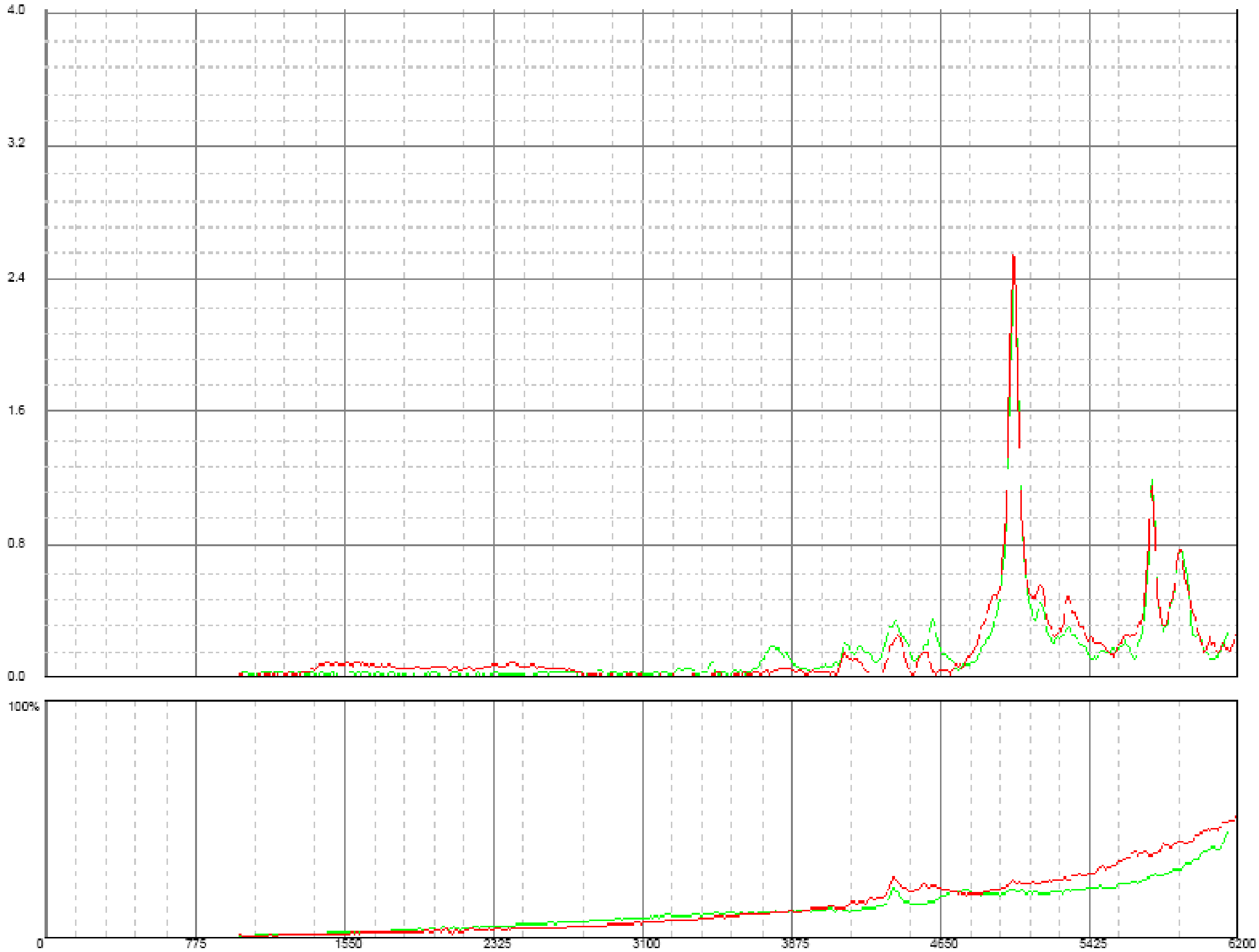

Figure 5: Workpiece 1, Treatment 2. Relocation and re-orientation of the Accelerometer enabled high RPM peaks to be easily detected. However, little peak growth or shift took place, as evidenced by the similar Pre- and Post-Treatment Scans.

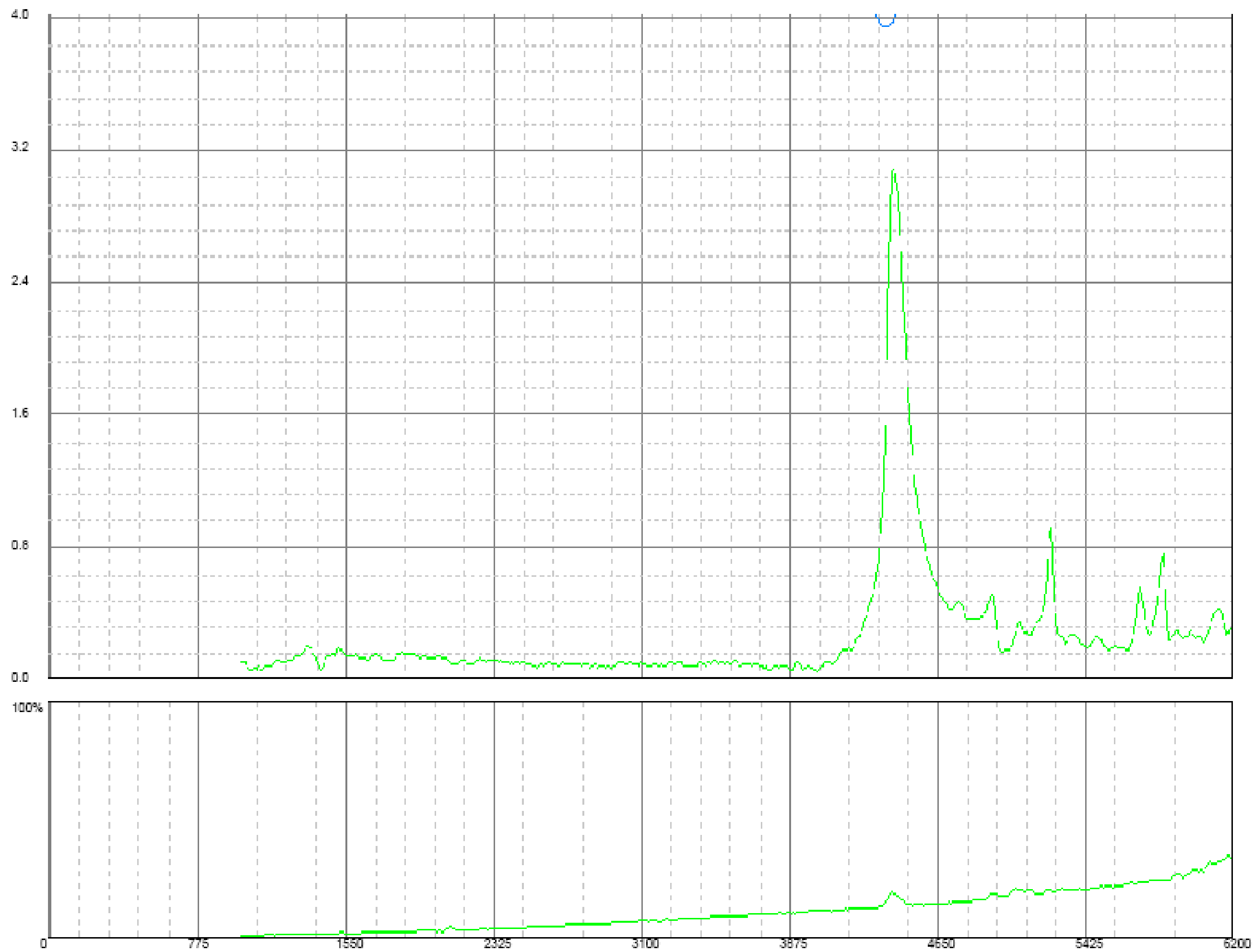

Figure 6: Workpiece 2 also received two Treatments, with repositioning and reorienting the Accelerometer the only difference between the Treatments (same as Workpiece 1). Figure 6 shows the Pre-Treatment Scan, and Figure 7 shows the Treatment in progress using this Pre-Treatment Scan. This VSR Treatment displays a growth of 20% in the height of the large resonance peak, about the same as Workpiece 1.

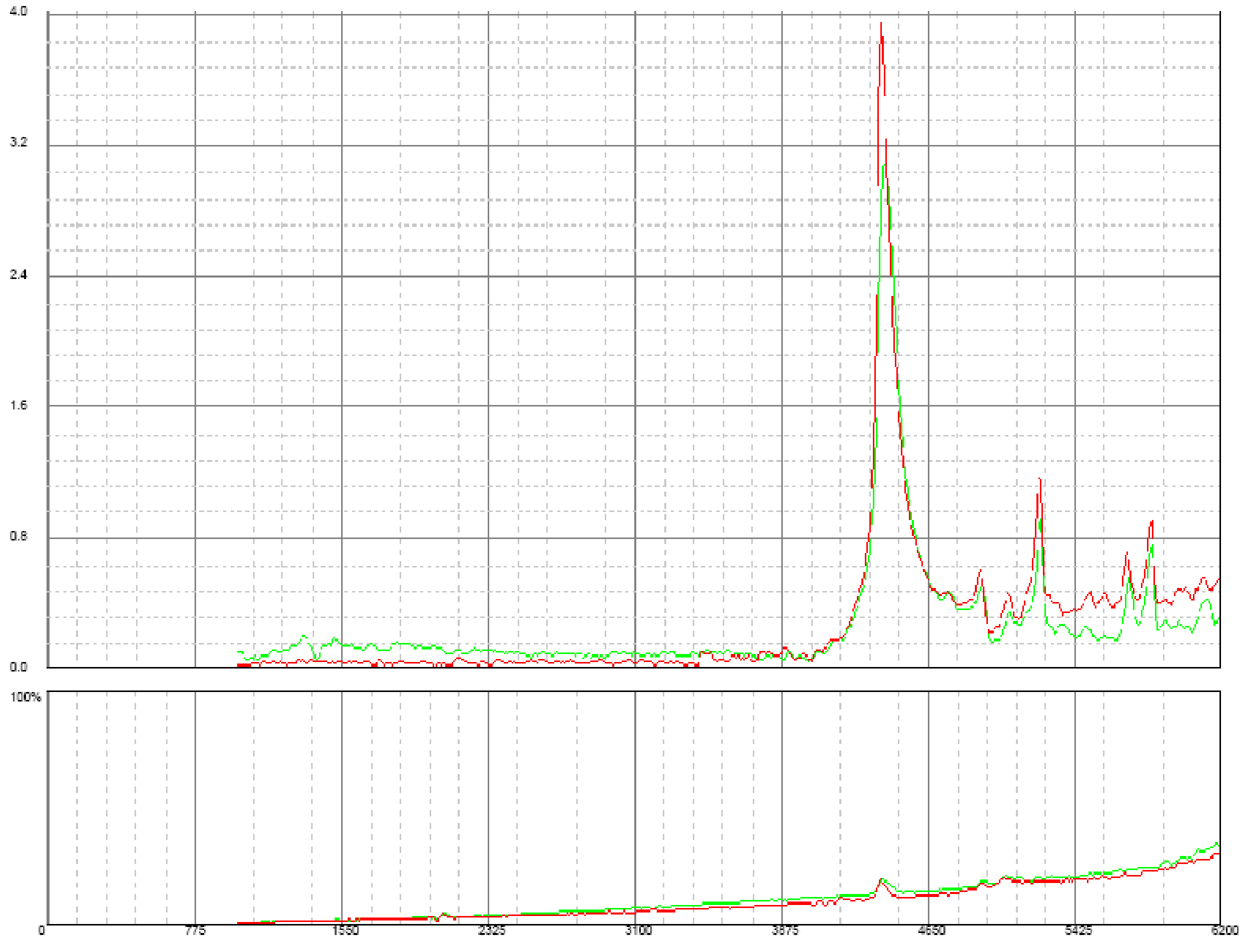

Figure 7: Workpiece 2, Treatment 1. Here the growth of ≈ 20% seen in Workpiece 1 is seen again. Peak growth of this degree is clear indication that these workpieces were dimensionally unstable, but, with VSR Treatment, would now be much more dimensionally stable and predictable.

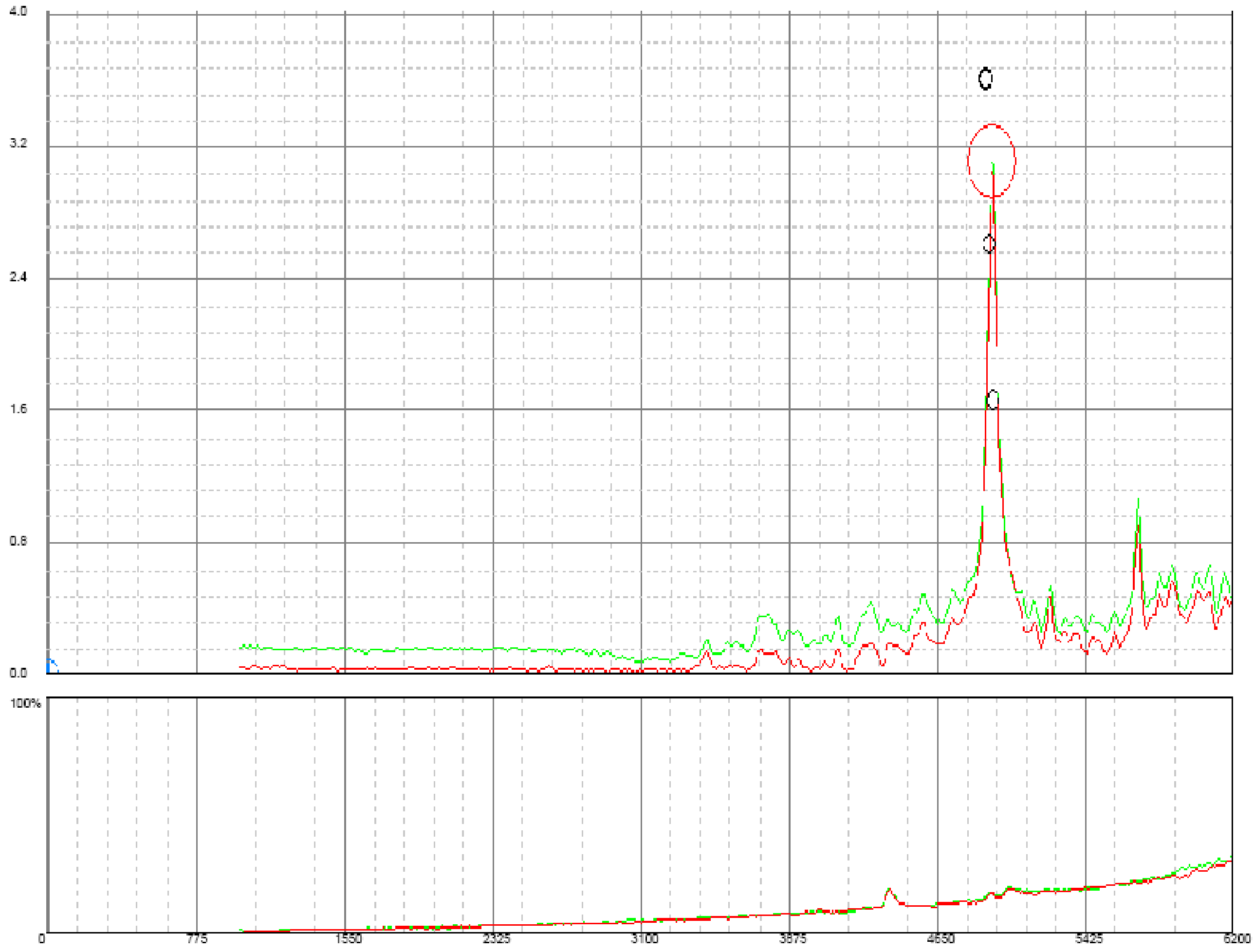

Figure 8: (Workpiece 2, 2nd Treatment) shows the second Treatment (using the different Accelerometer location), with very little change in the resonance pattern, which indicates that little additional stress relieving occurred during this Treatment, in all likelihood because Treatment was very effective.

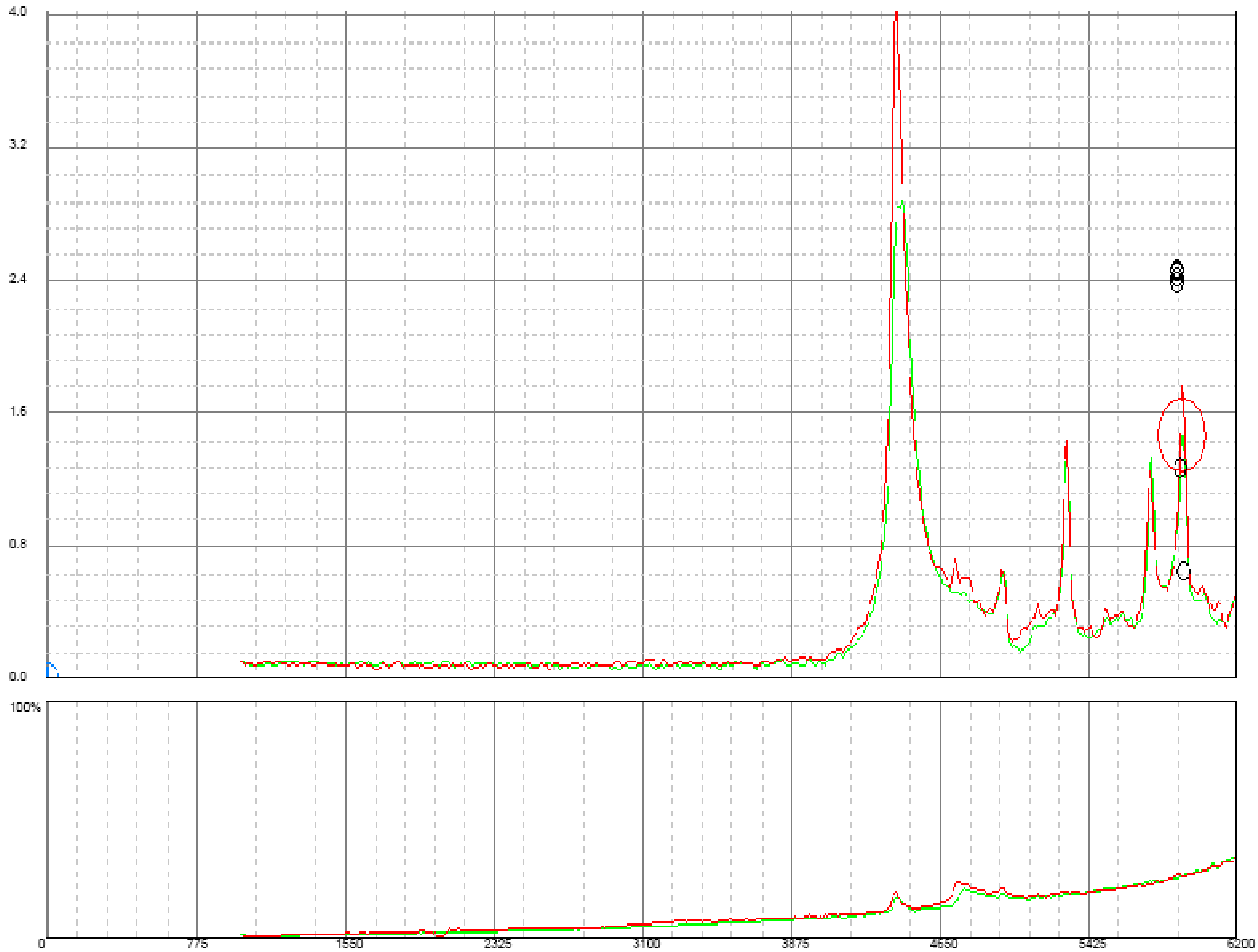

Figure 9: Figure 9 shows the 1st VSR Treatment done on Workpiece 3, again we see a significant change in resonance pattern; Figure 10 shows the 2nd Treatment done on Workpiece 3, as expected it displays little resonance pattern change

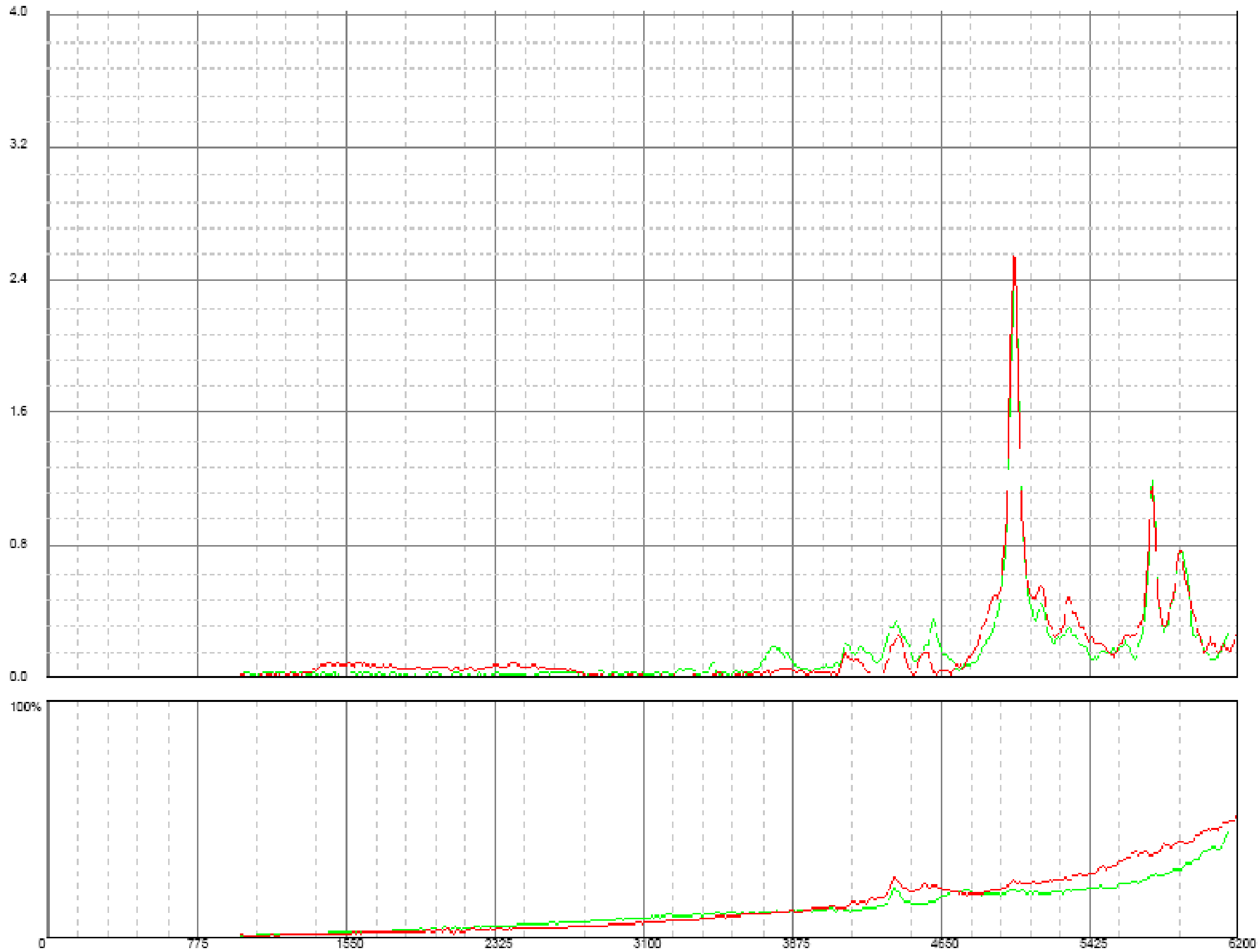

Figure 10: Workpiece 3, Treatment 2. Virtually no growth or shifting of resonance peaks indicates highly stable workpiece.

CONCLUSIONS

As a result of the clear change in resonance patterns, seen especially during the first VSR Treatments of each of the three workpieces, it is clear that these Frames were dimensionally unstable, but will now display excellent dimensional stability.

Instability of a resonance pattern is a de facto indicator of dimensional instability. Now, VSR Technology's VSR-8000 System, with its high-output, tightly-controlled vibration, and highly sensitive and repeatable instrumentation, combined with the correct setup and Treatment procedures, the resonance patterns of precision metal structures can be rapidly and consistently rendered stabile. And, as evidence proves: *Resonance Pattern Stability equals Dimensional Stability.*

To check dimensional accuracy, CAMERON inserts a crankshaft into a Frame, and places sensors on the Frame which are capable of detecting movement as little as a few ten thousandths of an inch. The QC requirement is no more than 0.001" (one thousandth of an inch) of movement taking place during turning of the crank with the Frame free-standing.

Within 30 days of the job, CAMERON performed their test on the first of the three Compressor Frames, and reported less than 0.0005" (five ten-thousandths of an inch) movement. This Compressor Frame was assembled, tested and inspected under load, and shipped to the customer. The other Frames are expected to behave in a similar manner.

Bruce Klauba has a degree in Physics and a Level II Vibration Analysis Certification from the American Society of Non-Destructive Testing (ASNDT). As a pioneer in the cause and effect of Vibratory Stress Relief, Mr. Klauba was named chief inventor (*Klauba et al.*) in U.S. Patent 4,381,673, which is both an equipment and process patent describing advances in the technology. He has authored numerous articles and original research papers on the subject, which have been published in leading magazines and periodicals. Published papers include:

1. "Use and Understanding of Vibratory Stress Relief", *Productive Applications of Mechanical Vibration*, 1983, American Society of Mechanical Engineers.
2. "Vibratory Stress Relief: Methods used to Monitor and Document Effective Treatment, A Survey of Users, and Directions for Further Research", 2005, *Trends in Welding Research*, ASM International.

A co-author in both papers, Dr. C. Mel Adams, is a leading authority in metallurgy and co-founder of MIT's Welding Research Department. In addition, Mr. Klauba has extensive experience in designing, building, and troubleshooting Industrial and Commercial Electrical Controls with a focus on extending the performance and reliability of Electric Motors and the systems they power.