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VSR REPORT

EBCO Industries

Richmond, BC   Canada

Stress Relief Stabilization of

Four Boeing aerospace lifting frames

When EBCO Industries, a full-service job shop located in Richmond, BC Canada had to select the best method to stress relieve a series of welded aerospace lifting frames, they choose Advanced VSR On-Site Service.   EBCO had used the VSR Process previously, and the machining results and end-user customer satisfaction of those projects made the decision straightforward.

The weldments measured roughly 285 X 148 X 35 inches and weighed ~ 8 tons.

Dimensional mapping done before and after major cross-brace removal show modest changes in shape, averaging less than 0.050” (1.27 mm). These results, together with the VSR Treatment Charts are strong indications that these structures should exhibit good dimensional and mechanical behavior.

Report prepared by:
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Advanced VSR Technology

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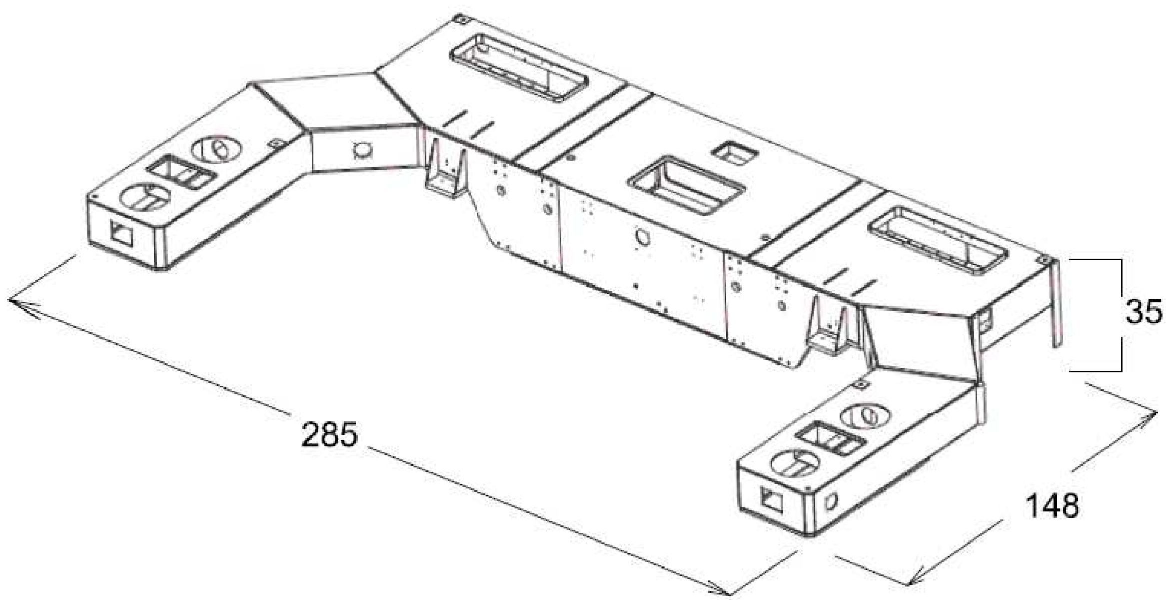

Figure 1: Mild steel fabricated aerospace tool, destined for Boeing, weighs ~ 8 tons.

VSR SET UP

Each workpiece was placed upon four urethane load cushions, two of which were placed relatively close together, acting much as one cushion. Three is the minimum number to determine a plane, and the location of the cushions was far from the ends of the workpiece, thus minimizing damping of the workpiece. Minimizing damping maximizes the modes and intensity of resonance, and hence, flexure. Independent research has shown that maximizing flexure is a key criteria required to maximize the effectiveness of vibratory stress relief. [1][2]

[1] Y. P. Yang, G. Jang and R. Yancey, ASM: Trends in Welding Research 2005, Advanced VSR Technical Library

[2] W. F. Hahn, Vibratory Residual Stress Relief and Modifications in Metals to Conserve Resources and Prevent Pollution, Alfred University, CEER, Advanced VSR Technical Library

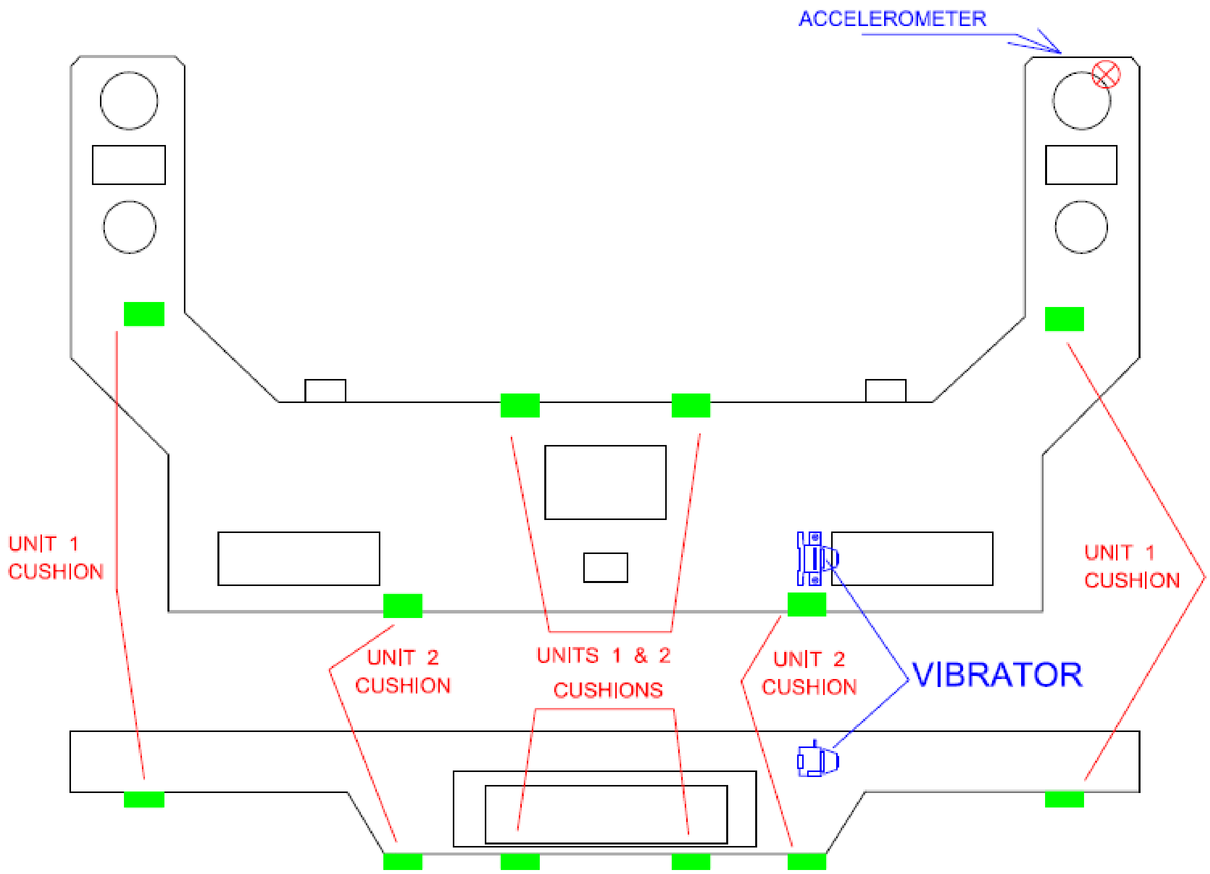

Figure 2: VSR Setup was the same for both Units 1 and 2, with the exception of load cushion locales. The 1st part VSR Processed, Unit 2, used cushions on the interior and the "bottom" (one being near the vibrator). When Unit 1 (2nd part) was setup the same way, the workpiece barely balanced on the cushions, and could be tipped / rocked if either "arm" was pushed down. So the cushions that were near the vibe were moved out to the short portion of the "arms".

The vibrator location was on a very stiff portion, perhaps the stiffest portion, of the workpiece, and oriented so that the AOR (Axis of Rotation) was parallel to the 285" length of the structure. This orientation is most likely to excite the greatest number of modes of vibration of the workpiece.

The accelerometer was placed so as to be most sensitive to vertical amplitude, and located (red circle with X) at the end of the right "arm".

It was determined during the course of treating Part 1 that two VSR Treatments were required, using different unbalance settings. This was due to the disparity in amplitudes of two groups of resonances. The group at higher frequencies could only be reached using a low unbalance setting of 10%, going up to 6900 RPM. The lower RPM group, although visible on the treatment using 10% unbalance, did not respond when treated, but did respond, during a 2nd treatment, when the unbalance was increased to 50%, during which the max speed was limited to 5000 RPM.

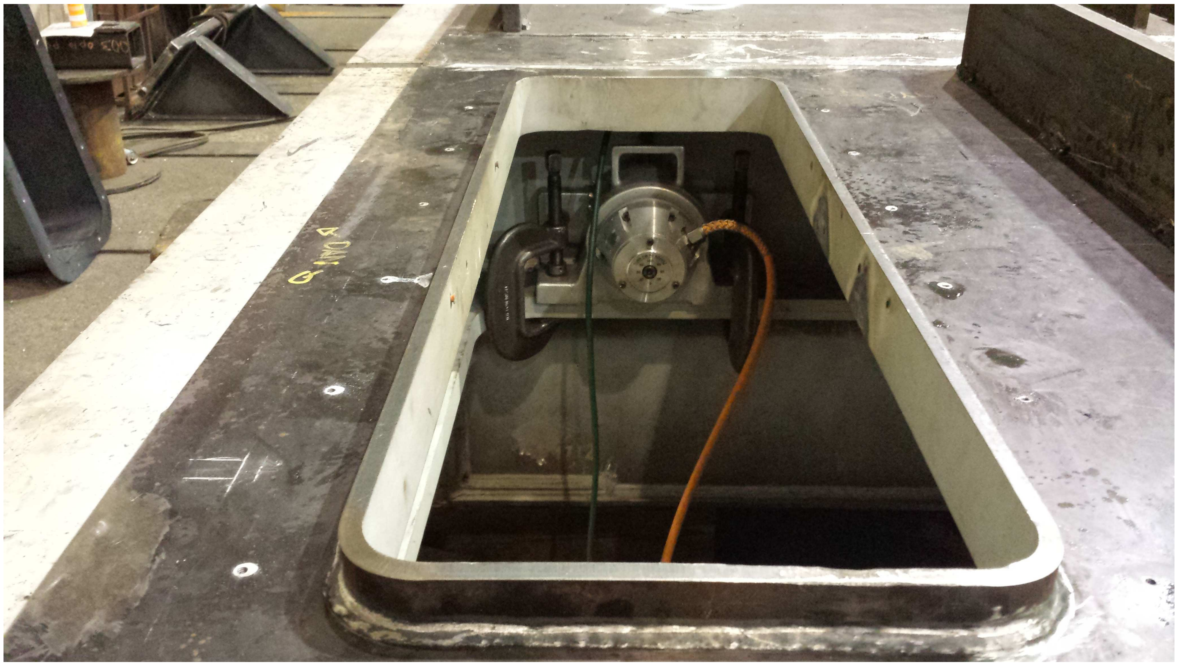

Figure 3: Vibrator was clamped on a "shelf" located near the intersection of many of the fabrication's heaviest plates. This location worked well for treatment, since it generated many resonances throughout the structure, while keeping power levels and power peaks (lower curves on VSR Charts) modest.

VSR TREATMENT

VSR Treatment is accomplished by tuning upon resonances of the workpiece, driving the structure with sufficient load as to begin the migration of millions of grains within the material, propelled by the combination of the residual stress trapped within the material, with the external loading generated by resonance. Resonance is used, since it loads the structure to levels rarely unachieved by using non-resonant vibration.

To begin this process, after the VSR Setup, a Quick Scan thru a vibrator RPM range is performed, and recording is made using the VSR software that displays both the workpiece acceleration and vibrator input power vs. the vibrator RPM. A Quick Scan (QS) is quick, because the scan rate used to generate this data is high: 50 RPM / sec., and thus can be made in less than two minutes. The QS allows a preliminary look at the vibration data, and is used to determine if resonances are being achieved, or if further unbalance and / or RPM range adjustments need to be made to achieve resonance. An example of a QS is Fig. 4.

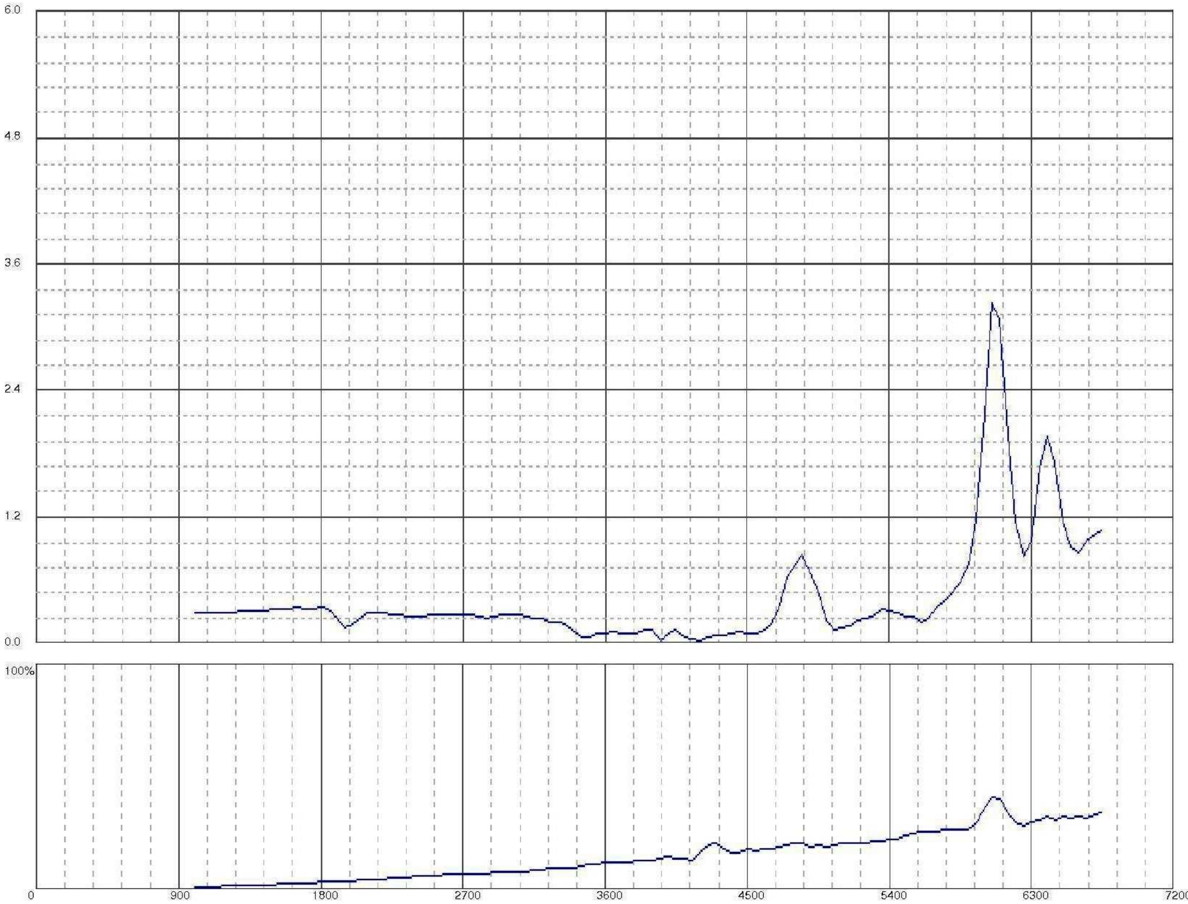

Figure 4: 1st Quick Scan (QS) shows that resonances were achieved. VSR Charts have two portions, an upper workpiece acceleration curve, and a lower vibrator power curve, each of these parameters plotted vertically, vs. a common, horizontal axis of Vibrator RPM. These are essentially spectra, showing above the vibration intensity vs. frequency of the workpiece, and below the power spectra that generated the upper curve. These are recorded simultaneously, and can be recalibrated after being recorded: Both the RPM and acceleration scales can be changed, as required, to display fully the data recorded. Full-scale (FS) for the power is preset (not adjustable) permanently at the power capacity of the BL8 Vibrator's motor: 100% = 2.2 kW.

Note that the green Pre-Scan data in the next image (Fig. 5) is a more detailed version of the QS data shown above. The Pre-Scan is all the data the operator has when performing the treatment.

RPM FS = 7200 RPM
ACC FS = 6 g's
UNBALANCE = 0.4 in-lbs.
POWER FS = 2.2 kW (fixed)
SCAN RATE = 50 RPM / SEC

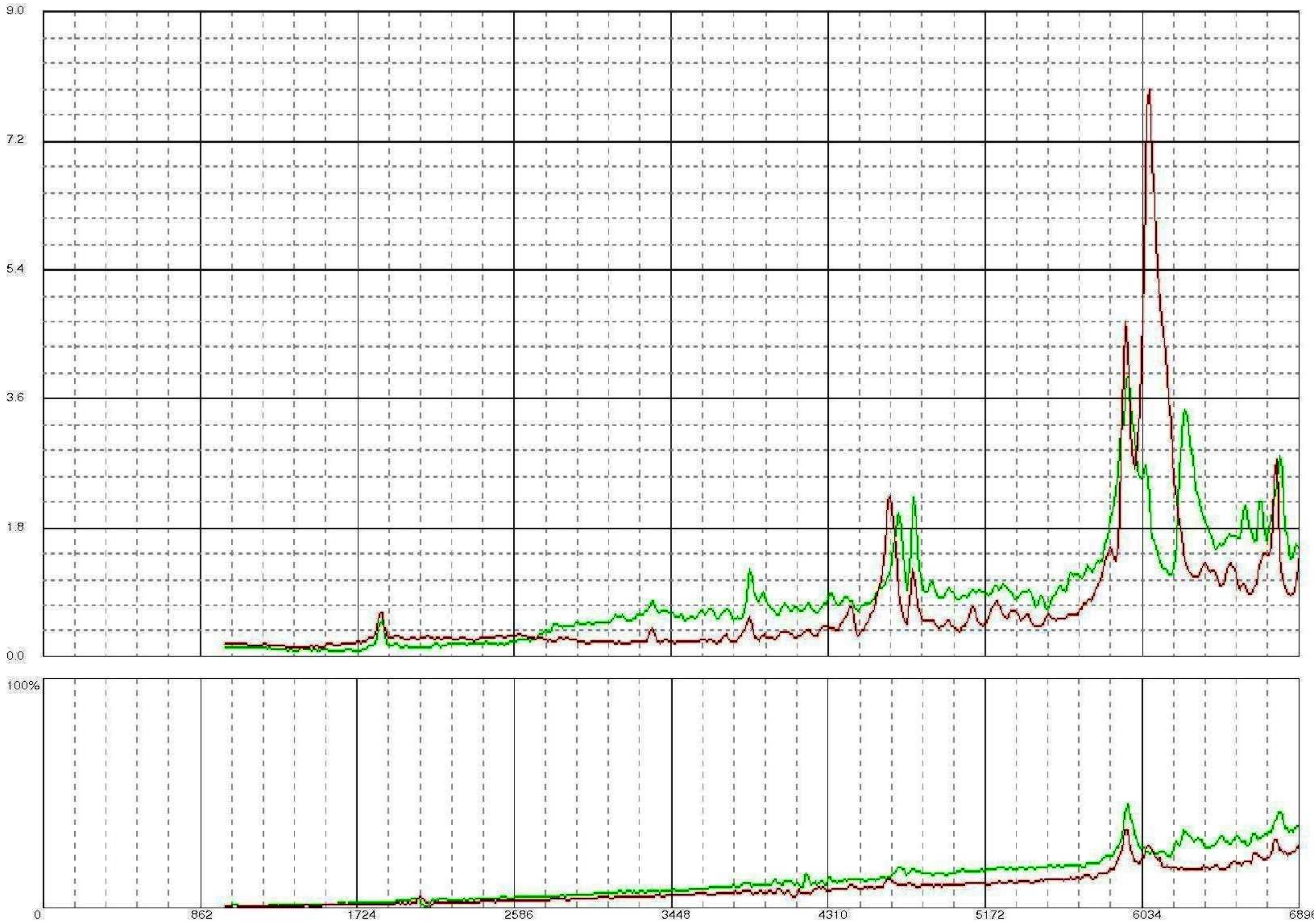

Figure 5: 1st Treatment, Part 1, Unit 1. VSR Treatments consist of two, superimposed scans, the Pre-Treatment Scan, or Pre-Scan, which is green (since the workpiece is "green"), which is then used as a reference to tune the vibrator, while watching the real-time data change (both on the chart, in the form of a cursor) and upon the console's digital displays of acceleration and RPM. Peaks in the green curve most typically grow to higher levels, shift to the left, or some combination of each of these, during stress relief. Vibration should take place as long as such data is changing.

Initially an acc scale of 6 was used (like the QS), but the large peak at ~ 6 KRPM grew off scale during treatment. After the Post-Treatment Scan was done, this peak was "chopped-off", but was seen again after recal'ing the acc FS to 9 g's. Treatment time on this peak was ~ 20 mins. Peaks in the lower frequency range (to the left of the big peak) of this chart changed little during treatment, even thou they were tuned upon for several minutes. These were found to respond, if increased by changing the unbalance from 10 to 50 %. See Figure 6.

RPM FS = 6900 RPM
ACC FS = 9 g's
UNBALANCE = 0.4 in-lbs.
POWER FS = 2.2 kW (fixed)
SCAN RATE = 10 RPM / SEC

Treatment is done by tuning on and dwelling upon the peaks identified in the Pre-Treatment Scan. The VSR-8000 System has very tight speed regulation (± 0.02%). The Vibrator can be tuned in increments of 1-RPM. This enables the Operator to tune the Vibrator directly on the resonance peaks, resulting in maximum flexure, and thus the maximum stress relief using vibration.

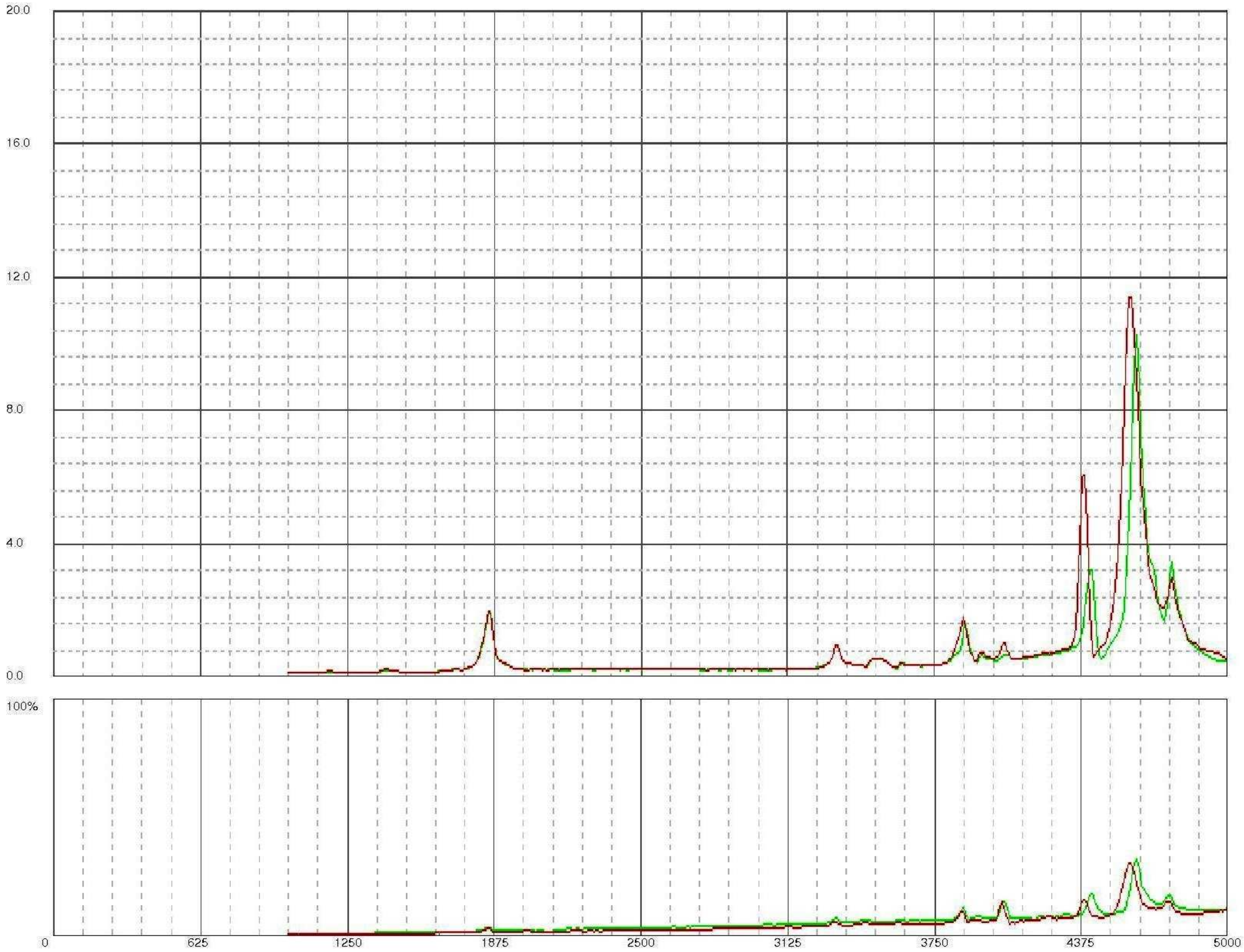

Figure 6: 2nd VSR Treatment, Part 1, Unit 2. Resonances in the low RPM range, that were driven too weakly during the 1st treatment, were able to respond when driven 5 times harder during the 2nd treatment. Again, green is before, red is after treatment, with the difference caused by dwelling upon the resonance peaks, tracking them as they change, until stability is reached. Stability of vibe data indicates stability of the workpiece. Treatment time between Pre- and Post-Scans was ~ 35 minutes.

RPM FS = 5000 RPM

ACC FS = 20 g's

UNBALANCE = 2.0 in-lbs.

POWER FS = 2.2 kW (fixed)

SCAN RATE = 10 RPM / SEC

Typical resonance peaks displayed on VSR Charts are fairly narrow, the peaks shown on these charts being no exception. The VSR System features very tight servo-control of the Vibrator, resulting in speed regulation of roughly 0.03%, and the ability to tune the vibrator in increments of ONE RPM. This allows accurate depiction and monitoring of changes in a resonance pattern, even if subtle.

FIRST WORKPIECE RESULTS

After two VSR Treatments were performed, the two braces that spanned the two “arms” of the workpiece were removed. Prior to removal, punch marks were made on the two inside corners adjacent to the span, 2” in from the end and inside plates. An additional punch mark was made at the center, again 2” in from the edge. Measurements were made (shown in green on Fig. 8) mapping the gross distances across the span, so as to track distortion that took place upon brace removal. After the braces were removed, the measurements were taken again (displayed in red). The changes that took place indicate that the span pulled in slightly. Changes are noted in blue.

Typically fab shops look upon such data as an initial test of the effectiveness of a stress relief treatment, effective treatments yielding at most, modest dimensional change. Experience has shown that the VSR Process often renders a metal structure very predictable, behaving almost like a perfect spring: Remove load, it returns to “zero”.

Figure 7: After the two VSR Treatments, which completed the stress relief, braces spanning the space between the structure’s “arms” were cut. Dimensions had been mapped of a triangle spanning the braced area, and these dimensions were taken again after brace removal. Results shown in Fig. 8

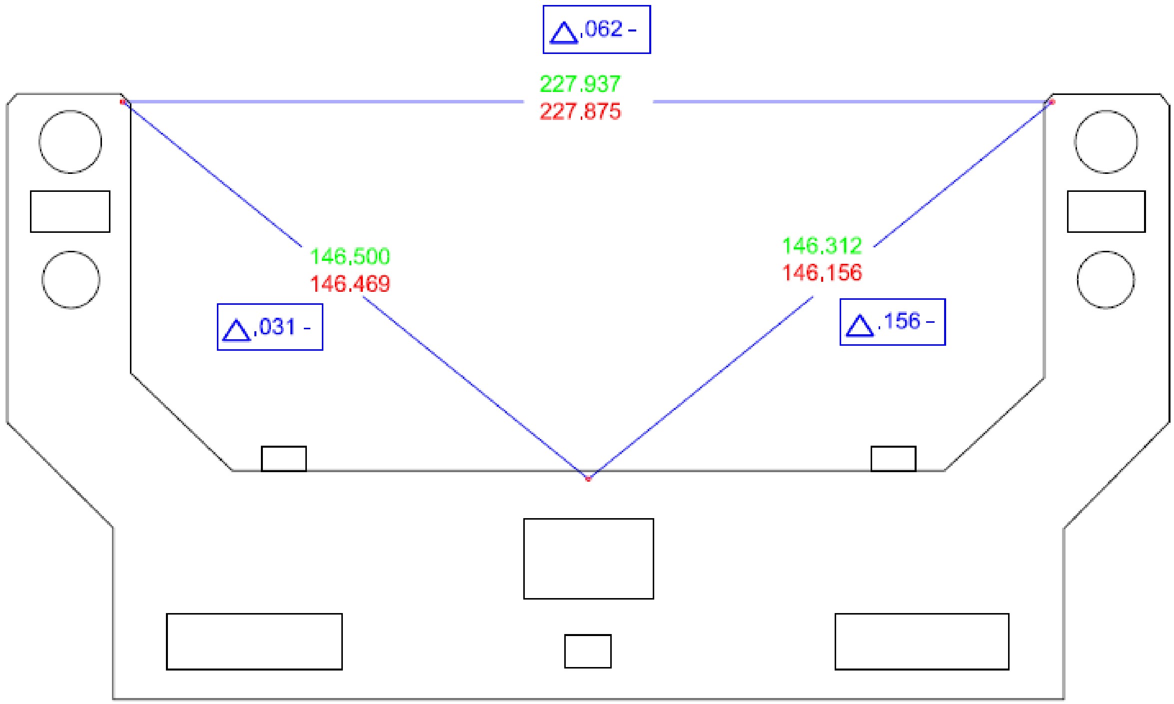

Figure 8: Dimensional measurements made before and after VSR Treatment and major brace removal of Part 1, Unit 2 show nominal change. Punch marks were made 2" inches inwards from the inside corners of the workpiece "arms", and at a midpoint on the structure's main body. Green data is as welded, with braces intact; red is after VSR Treatment and brace removal. Blue boxes show net differences, the minus signs after the numbers indicating the change (delta) was negative, i.e., net reduction in dimension.

Part 2, Unit 1 VSR Treatment

The same setup was attempted to setup the 2nd workpiece, however an issue with balance upon the cushion required a relocation of two of the cushions. These changes are documented in Figure 2. After relocating the cushions, and lowering the unbalance once again to 10%, a VSR Treatment was performed, the results shown in Fig. 9.

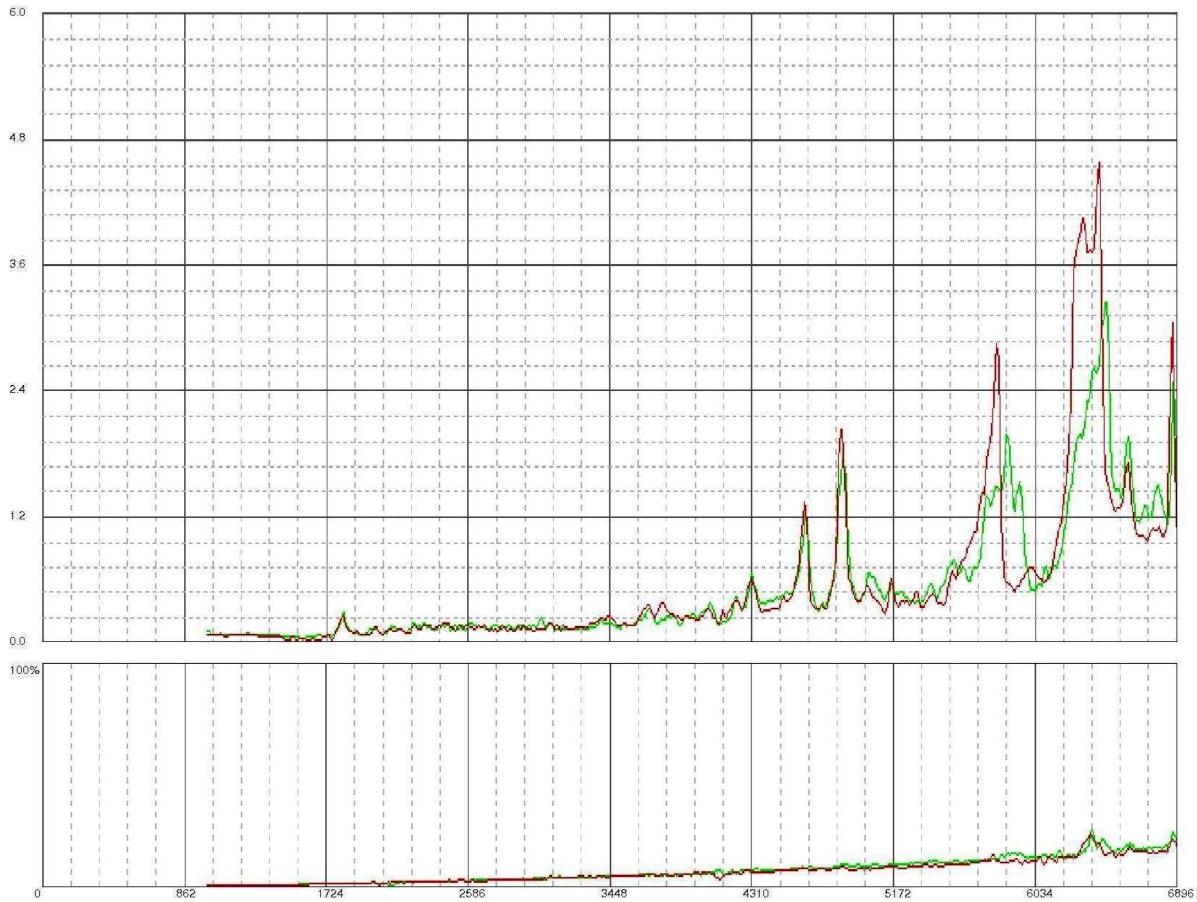

Figure 9: 1st VSR Treatment of Part 2, Unit 1. Approximately doubling of the height of the peaks in the 5 – 7 KRPM range are classic changes in resonance pattern seen during the VSR Process.

RPM FS = 6900 RPM
ACC FS = 6 g's
UNBALANCE = 0.4 in-lbs.
POWER FS = 2.2 kW (fixed)
SCAN RATE = 10 RPM / SEC

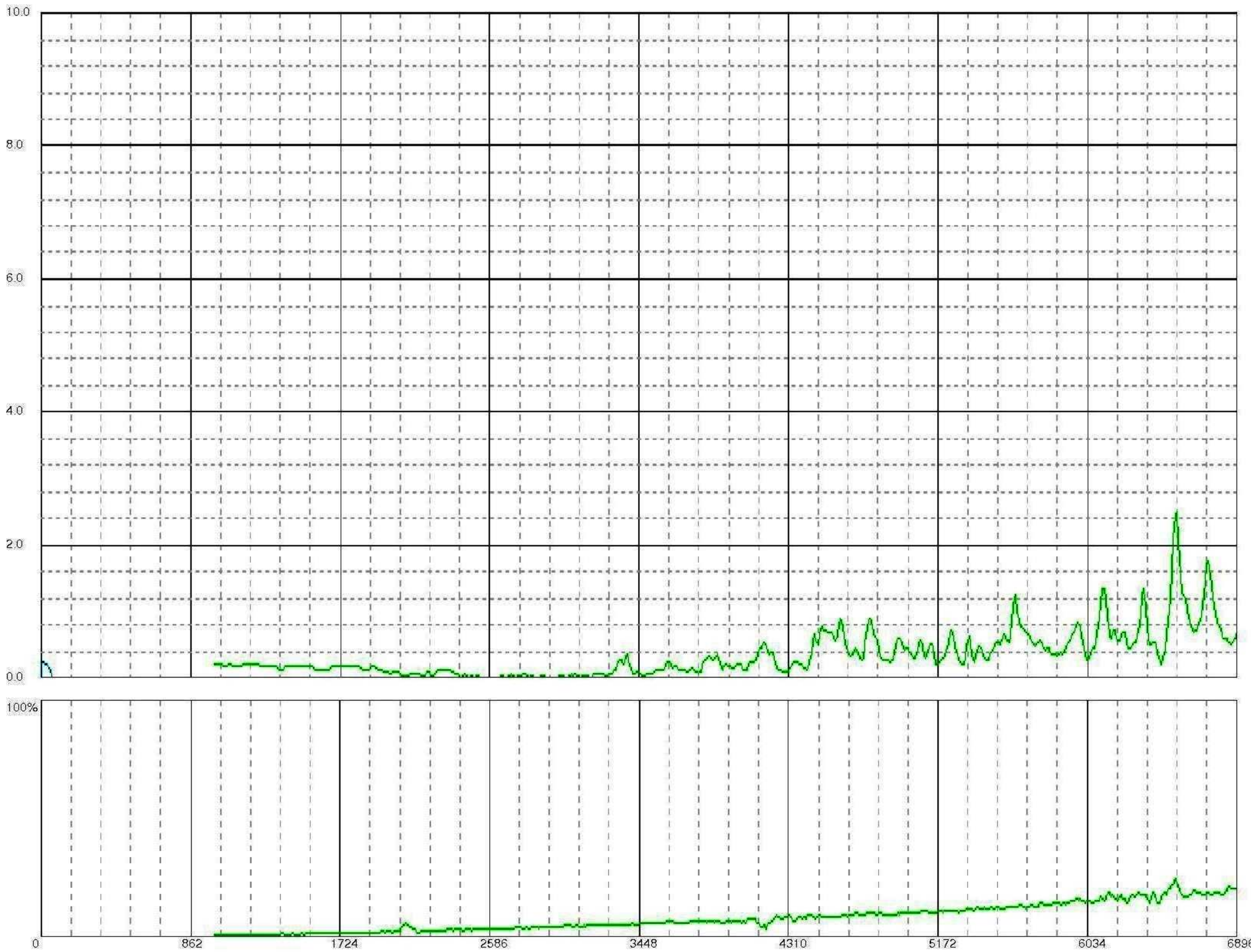

Figure 10: 1st Pre-Scan of Unit 3. This chart was recorded with too large an FS, forcing to the data to be in the low portion of the acc scale. However, distinct peaks can be seen in the region above ~ 5.3 KRPM. An ACC FS of 4 – 6 g's would have made the data more visible.

RPM FS = 6900 RPM

ACC FS = 10 g's

UNBALANCE = 0.4 in-lbs.

POWER FS = 2.2 kW (fixed)

SCAN RATE = 10 RPM / SEC

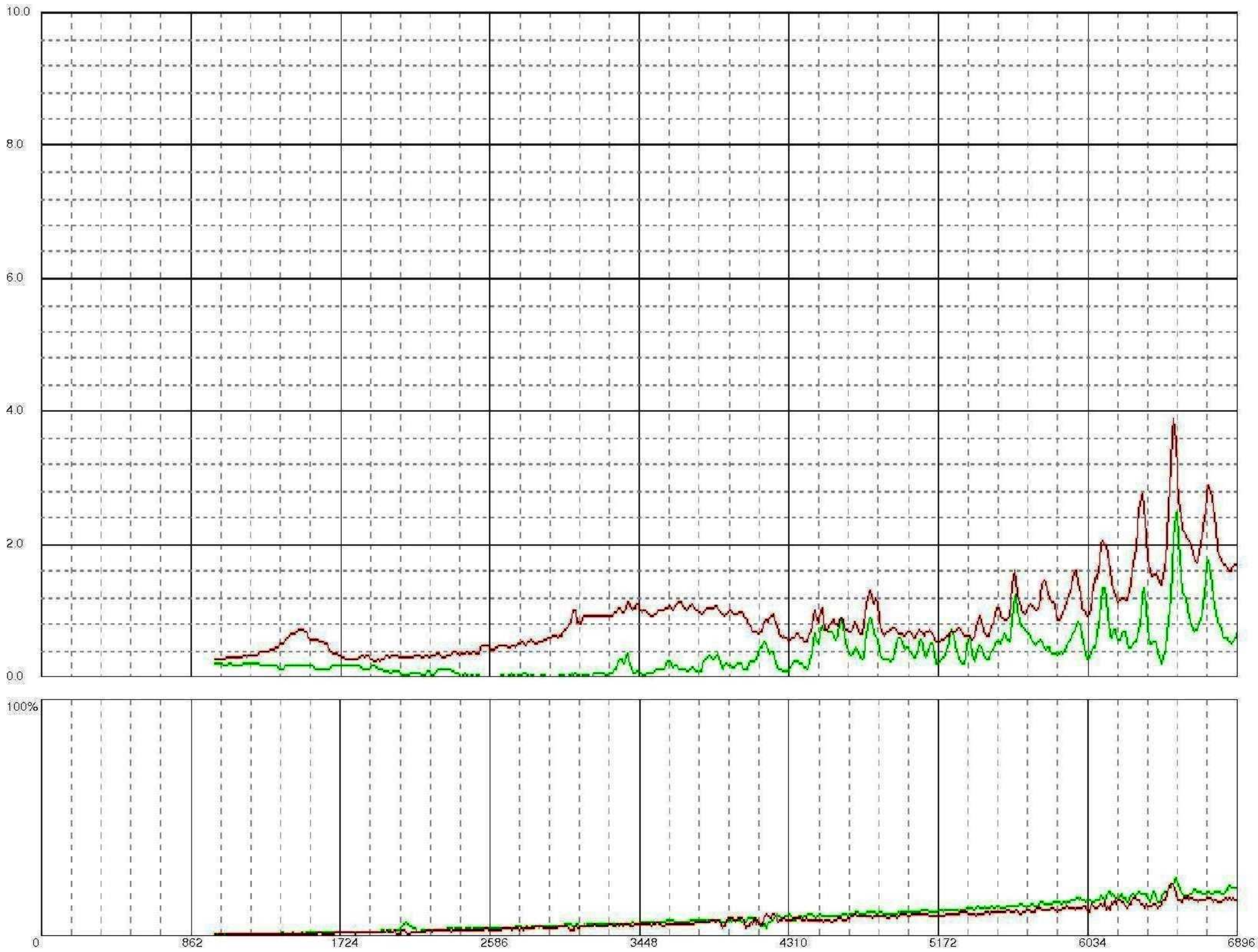

Figure 11: 1st VSR Treatment of Unit 3. Peaks in the upper RPM range, beyond 6 KRPM, all grew by between 30 and 80 %. (Note: Chart should have used acceleration FS of 5 or 6 g's, rather than 10.)

RPM FS = 6900 RPM

ACC FS = 10 g's

UNBALANCE = 0.4 in-lbs.

POWER FS = 2.2 kW (fixed)

SCAN RATE = 10 RPM / SEC

Figure 12: Pre-Scan of Unit 3 using 40 % unbalance. Distinct peaks in the 4.3 – 5 KRPM range can be seen.

RPM FS = 5000 RPM

ACC FS = 10 g's

UNBALANCE = 1.6 in-lbs.

POWER FS = 2.2 kW (fixed)

SCAN RATE = 10 RPM / SEC

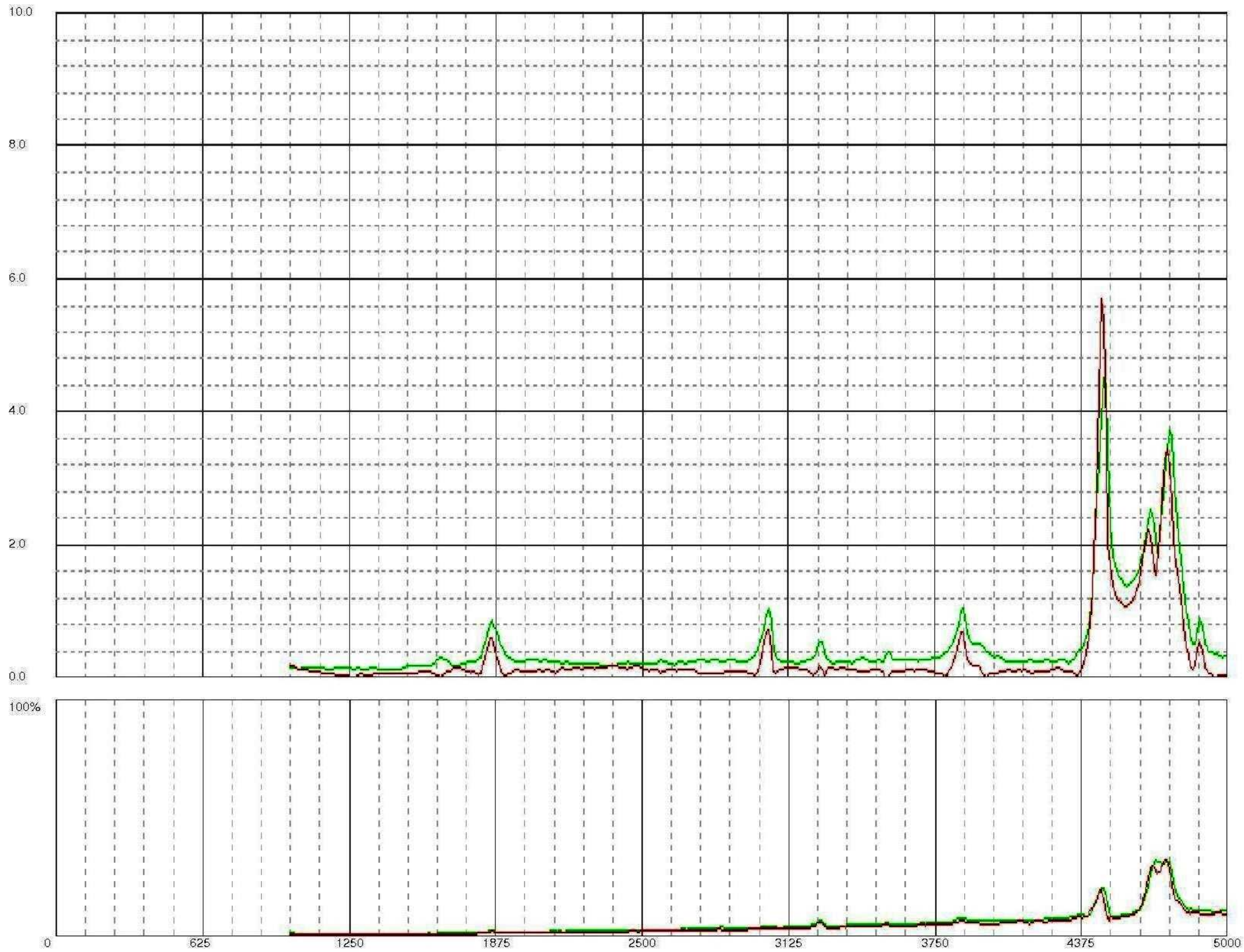

Figure 13: VSR Treatment of Unit 3 using 40 % unbalance. Distinct peaks in the 4.3 – 5 KRPM range have all changed, with the largest change being peak growth at 4450 RPM of more than 25%.

RPM FS = 5000 RPM

ACC FS = 10 g's

UNBALANCE = 1.6 in-lbs.

POWER FS = 2.2 kW (fixed)

SCAN RATE = 10 RPM / SEC

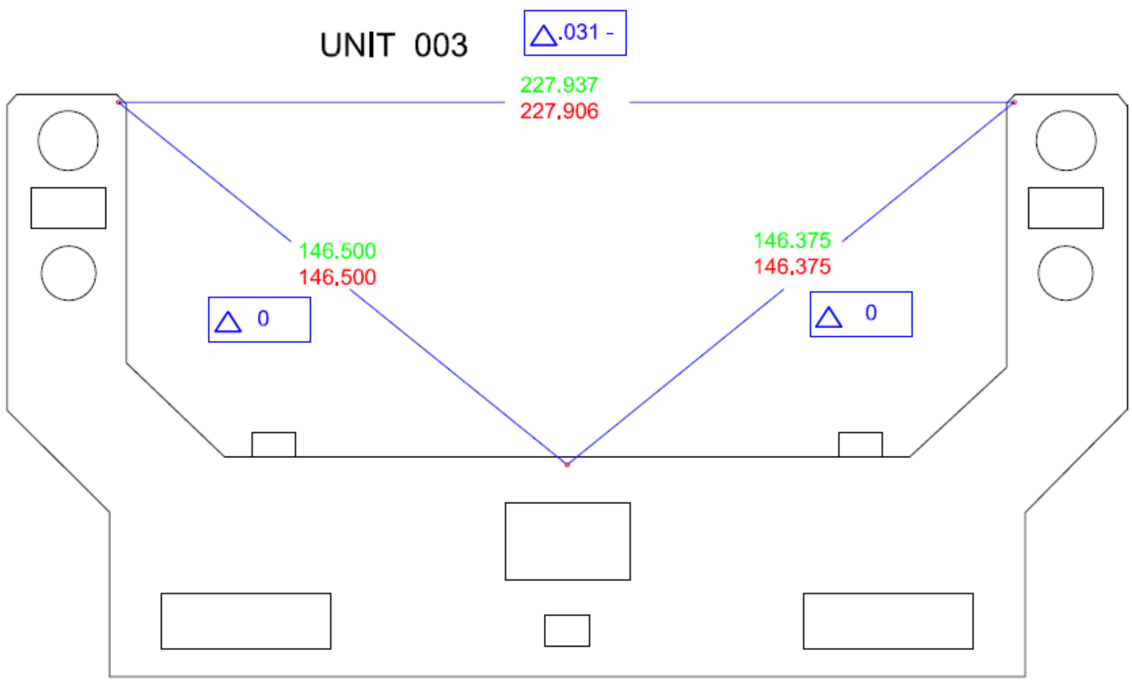

Figure 14: Dimensional map of Unit 3 before and after brace removal shows very subtle (almost immeasurable) change in dimensions.

Figure 15: 1st Pre-Scan, Unit 4. Similar to earlier initial (base-line) scans, done at 10% unbalance, the data reveals significant resonances in the 6 – 6.9 KRPM range

RPM FS = 6900 RPM

ACC FS = 10 g's

UNBALANCE = 0.4 in-lbs.

POWER FS = 2.2 kW (fixed)

SCAN RATE = 10 RPM / SEC

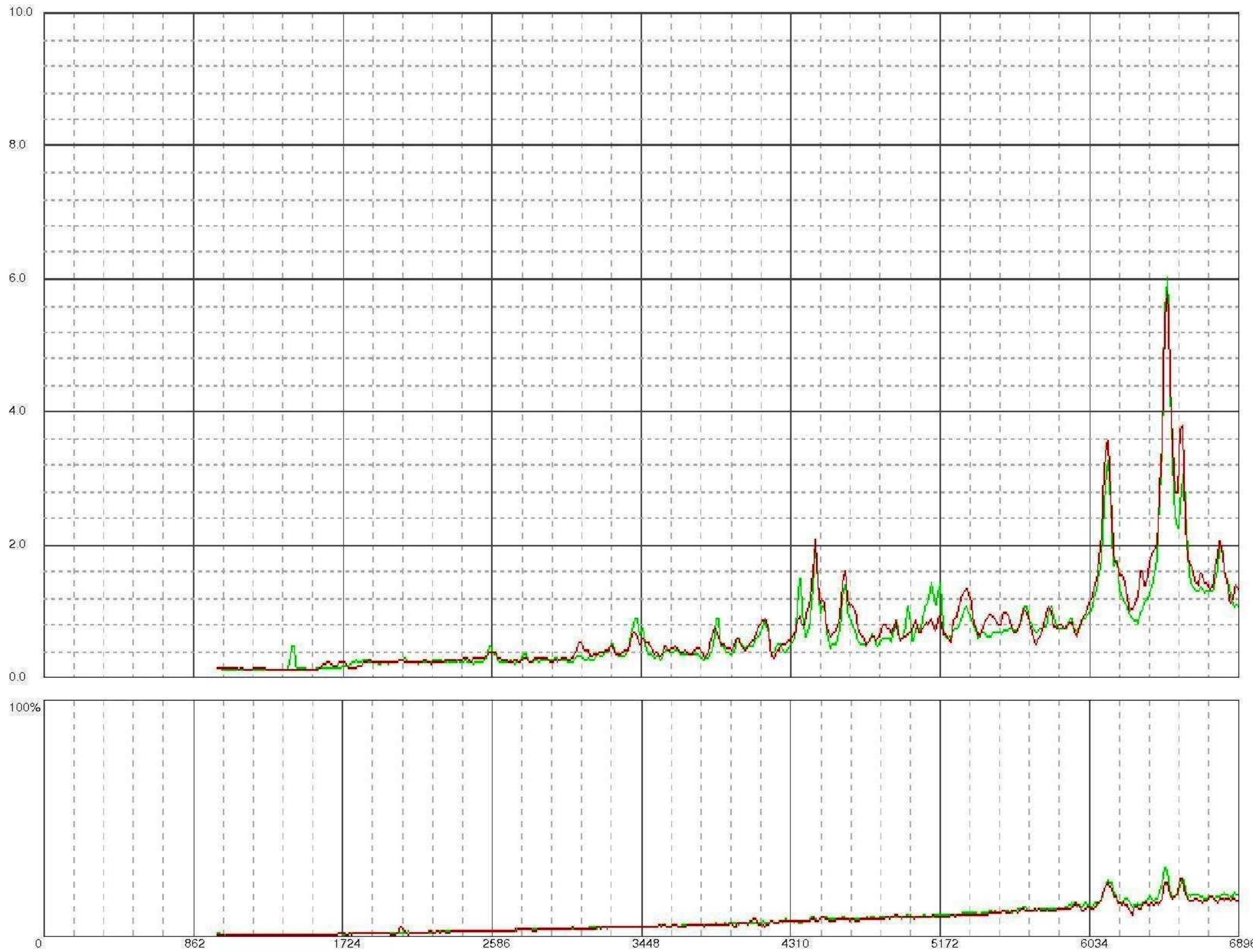

Figure 16: 1st VSR Treatment, Unit 4. Although the change in resonance pattern is somewhat more subtle than earlier, peak growth can be seen in the resonances at 6140 and 6540, growing (respectively) 12 and 33 %.

RPM FS = 6900 RPM
ACC FS = 10 g's
UNBALANCE = 0.4 in-lbs.
POWER FS = 2.2 kW (fixed)
SCAN RATE = 10 RPM / SEC

Figure 17: 2nd Pre-Scan, Unit 4. Distinct, 6 g tall peaks near 4500 RPM, plus two others at higher RPM are clear locations for performing VSR Treatment.

RPM FS = 5200 RPM
ACC FS = 10 g's
UNBALANCE = 1.6 in-lbs.
POWER FS = 2.2 kW (fixed)
SCAN RATE = 10 RPM / SEC

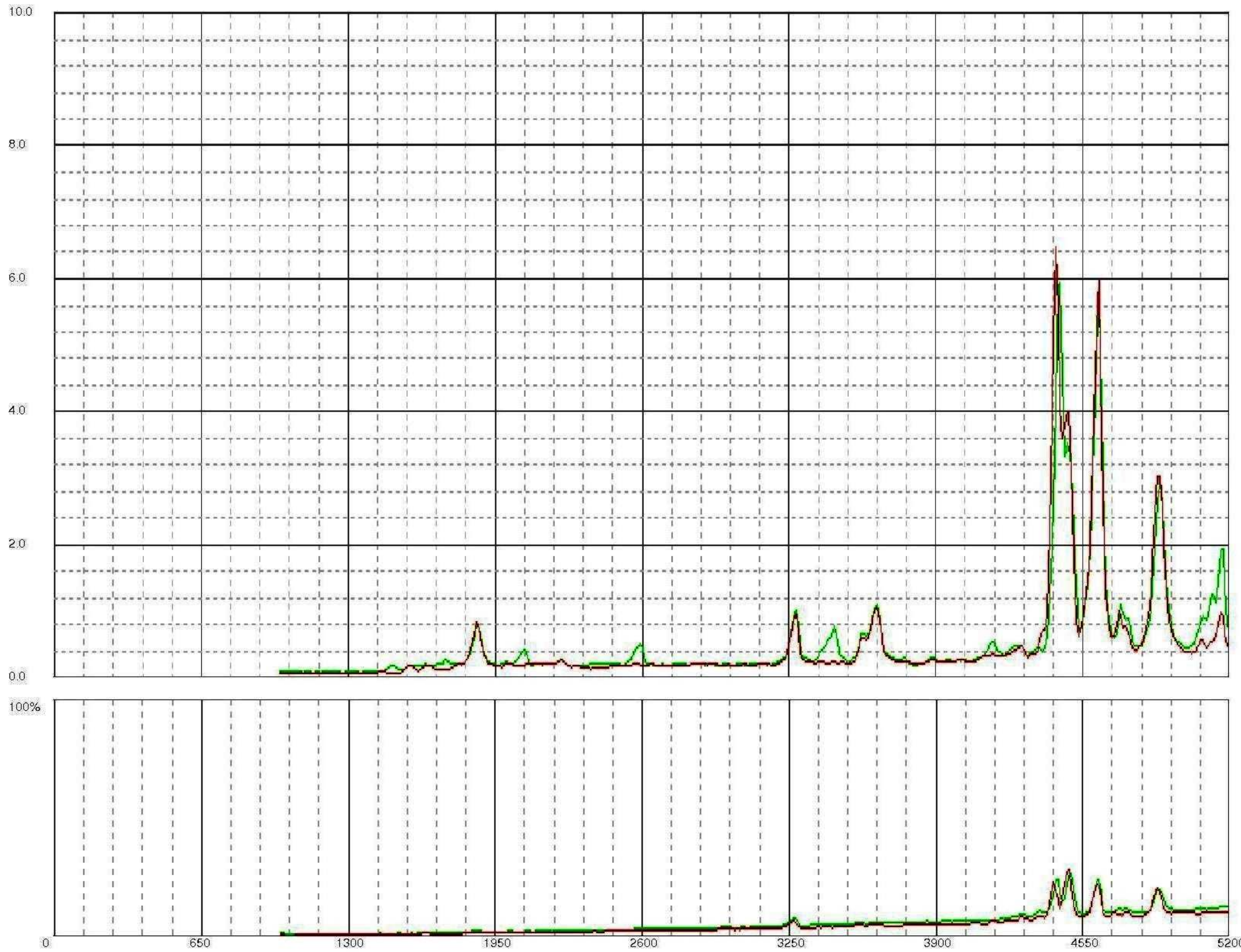

Figure : 2nd VSR Treatment, Unit 4. Distinct, 6 g tall peaks near 4500 RPM showed subtle peak growth and shifting, as did the peak at ~ 4900 RPM. Peak at 5200 RPM showed decrease with treatment. Typically this is an indication of a change in shape of the workpiece.

RPM FS = 5200 RPM
ACC FS = 10 g's
UNBALANCE = 1.6 in-lbs.
POWER FS = 2.2 kW (fixed)
SCAN RATE = 10 RPM / SEC

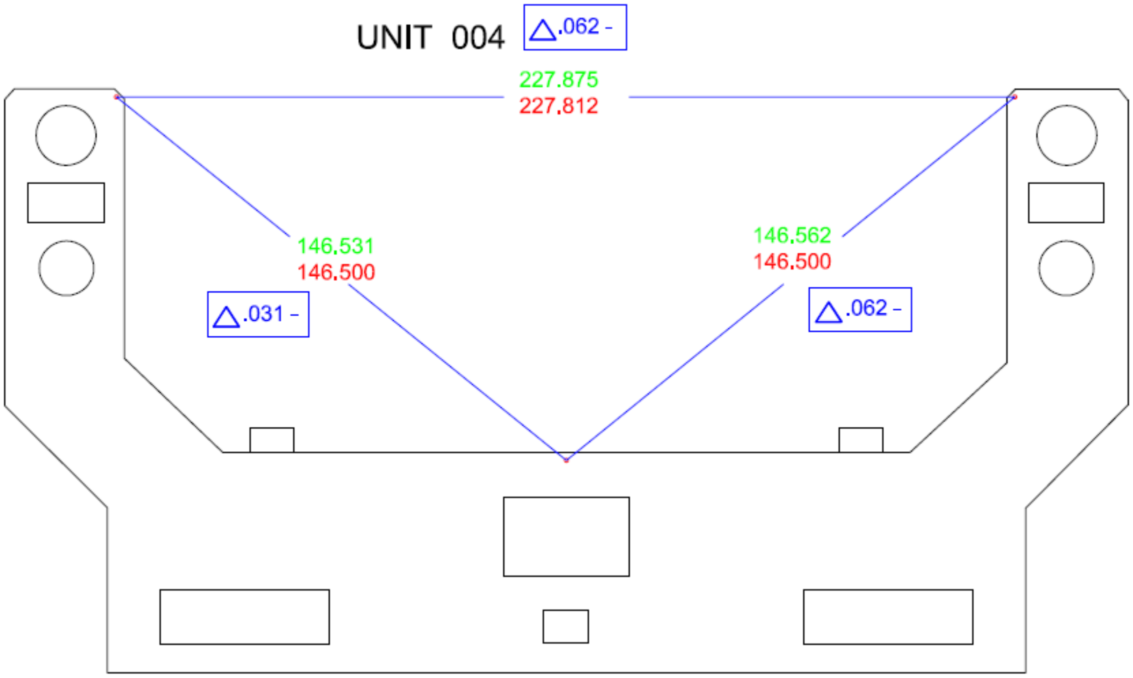

Figure 18: Dimensional map of Unit 4 before and after brace removal shows modest change in dimensions.

SUMMARY OF DIMENSIONAL RESULTS AND CONCLUSION

The average dimensional change seen during brace removal was less than 0.05", which is the first indication that these fabrications are dimensionally stable. Obviously further measurements after transport, on-site setup and utilization will supply final results, but there is every indication, based upon both the VSR Chart data and dimensional mapping that these fabrications will exhibit very good dimensional accuracy, and thus will perform both their function fully for the end-user.