The cost effective alternative to heat treatment

Report on Vibratory Stress Relief

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McLANAHAN CORPORATION is a manufacturer of large equipment used in the Mining, and Pit and Quarry Industries. They have been successfully using VSR TECHNOLOGY Equipment on large, dimensionally critical components since 1996. In December 2003, VSR TECHNOLOGY was invited to the plant to demonstrate its newest model, the VSR-8000 System on a Crusher Frame Component, which was a new, more rigid form of McLANAHAN's previous designs.

The new VSR System's features, including advanced data processing software installed in a user-friendly, touchscreen computer, and a high-performance vibrator driven by an ultracompact 3 HP brushless DC motor, not only made the VSR Treatment both easy to perform and monitor, but also generated an extremely clear VSR Treatment Chart, unambiguously certifying the effective procedure.

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VSR TECHNOLOGY's VSR 8000 System was demonstrated to McLANAHAN CORPORATION on a 12,000lb. mild steel, rectangular shaped weldment fabricated of 3" thick plate stock. The workpiece was a component of a heavy-duty Crusher Frame, used in the Mining Industry. Several journals and flat surfaces with tight tolerances would be included in the machining cycle.

McLANAHAN has been using a VSR 752 System for several years, and the System has an established track record of making components more predictable through the machining and assembly process. When compared with parts that had not been stress relieved, VSR workpieces are more dimensionally stable during rough machining, and this improved stability is an indication of greater predictability during subsequent machining operations. This allows a tightening of achievable dimensional accuracies. Tolerances can then be tightened which result in improved machine shop throughput. Movement of non-stress relieved parts causes not only additional machining costs (both for set-ups and machining cycles), but also the increased risk of distortion, which, unfortunately, is usually discovered during assembly. However, due to the greater rigidity of this new frame component, VSR TECHNOLOGY GROUP was invited to demonstrate its newest system – the VSR 8000.

The VSR 8000 System has a number of significant performance and operation improvements over earlier models. These include:

- The BL 8 Vibrator has a speed range of 10 – 8,000 RPM. (The MV 2 Vibrator Range: 500 – 6,000 RPM).
- The BL 8 Vibrator has speed regulation of 0.03%. (The MV 2Vibrator: 0.8% speed regulation).
- The super reliable, 3 phase, brushless DC motor in the BL 8 has 6 times the HP of the MV 2 Vibrator. Further, the Vibrator's motor is protected against: (1) phase loss; (2) servo feedback loss; (3) over power; (4) over temperature. (The MV 2 Vibrator uses a high quality, brush type DC motor.)
- The BL 8 Vibrator's unbalance range is 33% wider than that of the MV 2 Vibrator.
- The graphic display of VSR Treatment Chart (on a 12.1" touch screen computer), can be printed or stored for future reference. (The 752 System uses an XY Plotter to display and record data.)
- Both workpiece Acceleration and Vibrator Input Power are plotted vs. RPM. This power plot helps determine the most effective location to place the Vibrator on the workpiece. (The 752 System only plots Acceleration vs. RPM.)
- Pushbutton control (both actual and virtual), of all functions, including adjusting the Vibrator's speed in increments of 1 RPM. (The 752 System uses a 10-turn potentiometer to control speed).

- High performance data processors clarify the Accelerometer signal which makes the graphic display of the Treatment Chart extremely easy to read and interpret.

Operating the VSR 8000 System was easily learned, the controls so “user friendly”, and the data generated was so clear and easy to understand, that the Operators of McLANAHAN's VSR 752 System were comfortable using the System within minutes of start-up (see Photos 1 & 2, pg 7).

SETUP

The workpiece was placed on three isolation load cushions: One cushion centered along one long edge; the other two spaced 5' apart, each 2.5' off the center line, on the opposite long side (as seen in Photos 1 & 2, pg 7). This cushion placement allowed only minimal dampening of the workpiece, which promotes the greatest variety of resonance activity, including bend and torsional resonances, along with numerous harmonic resonance frequencies. Because the ends of the workpiece are high amplitude locales (anti-nodes), the load cushions were placed far in from the corners, since placement under the ends or corners causes a dampening of the required workpiece flexure.

The BL 8 Vibrator was placed in the center of the workpiece, widthwise, and about 1' from center, lengthwise, as shown in Photo 4, pg 8. This Vibrator mount orientation enables the Vibrator’s axis of rotation to be parallel with the length of the workpiece. This assures that the Vibrator’s excitation will be driving both vertically and across the width of the workpiece, since lengthwise resonances are not important to stress relieving. VSR TECHNOLOGY’s Vibrators are able to generate an increased axial direction force output at low radial force output because of their unique unbalance weight design. This enables the Vibrators to excite, or drive, the workpiece in all three directions, which is critical to maximum effectiveness.

The Accelerometer was placed near a corner of the workpiece, and oriented so that is was most sensitive to vertical deflections.

After two trial runs, using the System's "Quick Scan" feature (a 2 minute, full range scan to verify both the locations and the heights of resonances), the Vibrator’s unbalance was set at 40% of maximum (4.0 in lbs), and it was run at speeds up to 6000 RPM (8000 RPM available). The speed was increased to 6400 RPM after a Pre-Treatment Scan was performed, because additional peak activity was seen at just off-scale of the 6000 RPM Scan. The 6400 RPM Pre-Treatment Scan can be seen in Photo 5, pg 8 (both on the Computer Screen, and in print form on the shelf above the Screen). A copy of this Pre-Treatment Scan is reproduced on page 9. Pre-Treatment Scans are displayed in green since, before treatment, the workpiece is in a "green" condition.

VSR TREATMENT

The VSR Treatment was performed by tuning the Vibrator to the various peaks displayed in the acceleration vs. RPM graph (upper plot) on the Computer Screen. The Vibrator's RPM was jogged at 50 RPM/Sec close to the peaks, using the "increase" and "decrease" pushbuttons (upper two pushbuttons to the right of computer screen in Photo 5, pg 8. Finetuning was then executed using the same controls. Vibrator RPM is jogged when the pushbutton is held down, but is changed in 1 RPM increments when the pushbutton is pumped.

The blue Cursor (an X inscribed in a circle), is the real-time RPM and acceleration indicator. Tuning vibrator speed to a peak is quite easy, since the Cursor will follow the recorded resonance pattern. The operation is similar to tuning a digital radio except the VSR 8000 has several thousand settings. Positioning the Cursor on a peak is similar to tuning to a radio station's signal. The Pre-Treatment Scan shows the real-time Cursor, it indicates that the Vibrator was tuned to the peak at § 4800 RPM when the Scan screen was printed.

The VSR Process causes a change in the resonance pattern, which is displayed as growth in the resonance peak(s), and/or shifting of the major resonance peak(s) to a lower RPM. A frequent, but less common response, is a decrease in the heights of minor peaks. As the vibratory process proceeds, a slow down in the rate of change occurs, and, when these changes stop occurring, stability has been achieved. During VSR Treatment of this workpiece, all three responses occurred, and were readily identifiable.

Monitoring of the data was easy, although the Cursor, on one peak, rose off the vertical scale. This off-scale event occurred for two reasons:

- The height of a peak when precisely tuned upon during Treatment (as compared to the peak height recorded during a Scan), can be higher, due to workpiece inertia. Even if the Vibrator is tuned exactly upon the resonance, the mass of the workpiece takes as much as 30 seconds to fully respond. (This is analogous to propelling a train to full speed. Although the engine is delivering sufficient power and at the constant rate needed to reach full speed, time is needed before full speed is achieved.)

- Growth of the resonance peaks. Most of the peaks grew when dwelled upon and tracked. Most dramatic was the peak near 4800 RPM, which started out at < 1.6g (1.1g during scan), but ended up > 5.5g (3.2g when scanned). This peak, as others, was very narrow, with a peak-width of only 3 RPM. When shifting took place, which was often, and more frequent when the peak began being treated (dwelled upon), both the acceleration data and the height of the blue Cursor decreased. Pumping the RPM "decrease" pushbutton (black with white "down" arrow) 2-4 times, enabled the peak to be re-tuned upon, which increased the acceleration, and caused the Cursor to rise to equal or higher levels.

As can be seen in Photo 5, pg 8, on the right of the Computer Screen is an array of pushbuttons, the upper two are RPM (Increase, then Decrease), below that are: (1) the Operation buttons: Manual (amber) and Auto-Scan (blue); (2) the Start (green) and the Stop (red) buttons for the Vibrator.

To the right of these pushbuttons are (from top to bottom): (1) the AC disconnect switch; (2) the Vibrator motor socket; (3) the AC inlet.

To the left of the Computer Screen (from top to bottom) are: (1) a pair of USB jacks from the Computer; (2) the Accelerometer input; (3) the Vibrator's speed sensor socket.

The Enclosure, when open, meets NEMA 3 and 12 standards. When the Enclosure lid (seen in the upper portion of Photo 5) is lowered and latch secured, the Enclosure meets NEMA 4 standards. All connections and controls are covered and protected when the lid is secured. Opening the Enclosure simply requires releasing two locks, one on each side of the Enclosure, and then lowering the hinged front panel, which can be seen in the lower portion of Photo 5, pg 8.

After the resonance peaks stabilized, the Post-Treatment Scan was performed and recorded in red.

The acceleration peak that corresponds with the peak in the power curve (§ 4600 RPM) had increased significantly during Treatment. This caused some difficulty in performing the Post-Treatment Scan, since the now much larger power peak kept triggering the System's motor protection feature (latter, the factory programmed sensitivity setting was found to be set too low).

Because of the problem, the VSR Treatment Chart shown on page 10, was later made by assembling the images of the Pre-Treatment Scan and two Post-Treatment Scans. This Chart, even though shown in composite form and with a gap where this power peak had been, clearly shows the changes in the resonance pattern that took place during VSR Treatment.

One method of gauging the overall change in peak height is to add the heights of all the peaks of the Pre-Treatment Scan, and then compare that total with the total of the peak heights from the Post-Treatment Scan. On this job, the calculation shows an increase > 22%
in peak height, which is typical for workpieces treated with VSR TECHNOLOGY Equipment. Peak shifting occurred consistently less, averaging a little more than 1%. which is, also, typical of most of VSR Treatments.

The instrumentation in the Console used to generate this data is not only highly accurate but, more importantly, highly repeatable:

- RPM data is gathered from the Vibrator's 600 pulse/revolution resolver. A 2 MHz quartz clock is the reference used to generate the vibrator speed data, with both accuracy and repeatability errors of < 0.01 RPM, far below the Vibrator's speed regulation).

Thus, the changes in resonant peak locations (measured in RPM) were § 300 times larger than the VSR 8000 System's RPM resolution power.

- The Accelerometer Amplifier has a range up to 50g and accuracy and repeatability errors of < 0.1% full scale. Since the signal from the Accelerometer is ground referenced, the actual voltage of "ground" is tracked, and adjustments are made automatically; this feature minimizes the effects of operating in noisy machine shop or fabrication shop environments.

Therefore, the changes in resonant peak heights (measured in g's) were 200 – 1000 times larger (depending on the peak) than the VSR 8000 System's acceleration resolution power.

Based on the response during VSR Treatment, the workpiece should suffer no dimensional instability problems during machining. As has been demonstrated on many large, precision, metal components, a significant change in resonance pattern (caused by resonant vibration), which eventually slows down and stabilizes, is a clear indication of effective stress relief, ie,

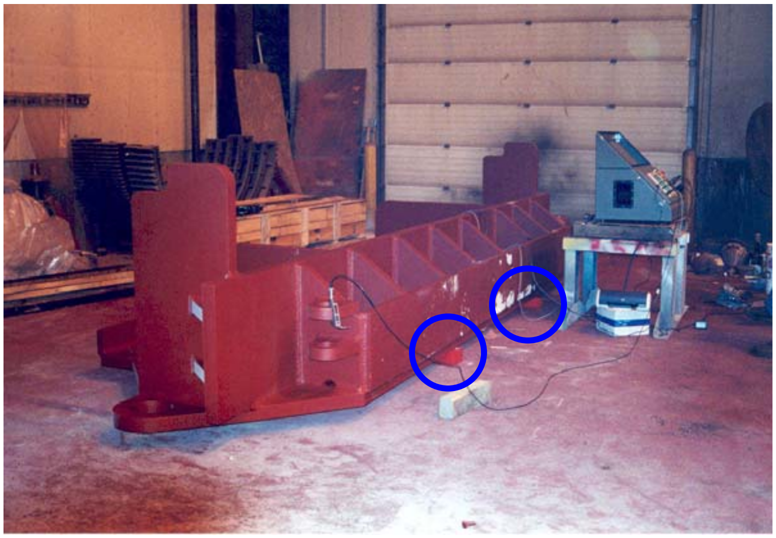
RESONANCE PATTERN STABILITY = DIMENSIONAL STABILITY

The enhanced clarity of the resonance pattern data, combined with the automation of the Process, makes the VSR 8000 System the state-of-the-art alternative to the increasingly impractical use of thermal stress relief.

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.



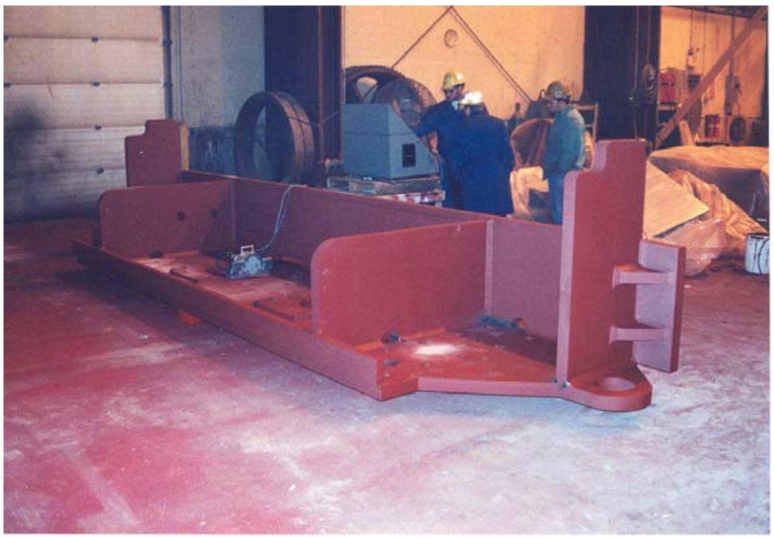


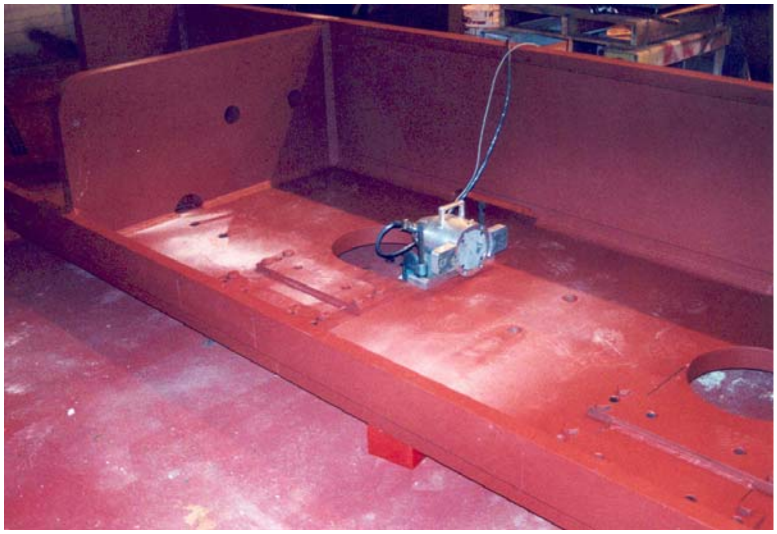
PHOTO 1 & PHOTO 2

Treatment SETUP. Two Load Cushions (orange & circled) can be seen beneath the workpiece along one of its sides and one load cushion along the other. The Cushions are placed far from the corners/ends of the workpiece, so as to minimize damping over the full range of workpiece resonances.

PHOTO 3

A low amplitude node (one of many), on the workpiece. To make the node visible, Oil Dry or sand (or similar) is sprinkled on the workpiece while the Vibrator is tuned upon a workpiece resonance peak. The sand is driven off high amplitude locales towards areas of low amplitude, which, during resonance, is the Nodal Pattern. Understanding and finding Nodal Patterns can be helpful in achieving an effective System Setup (Load Cushion and Vibrator Placement.

PHOTO 4

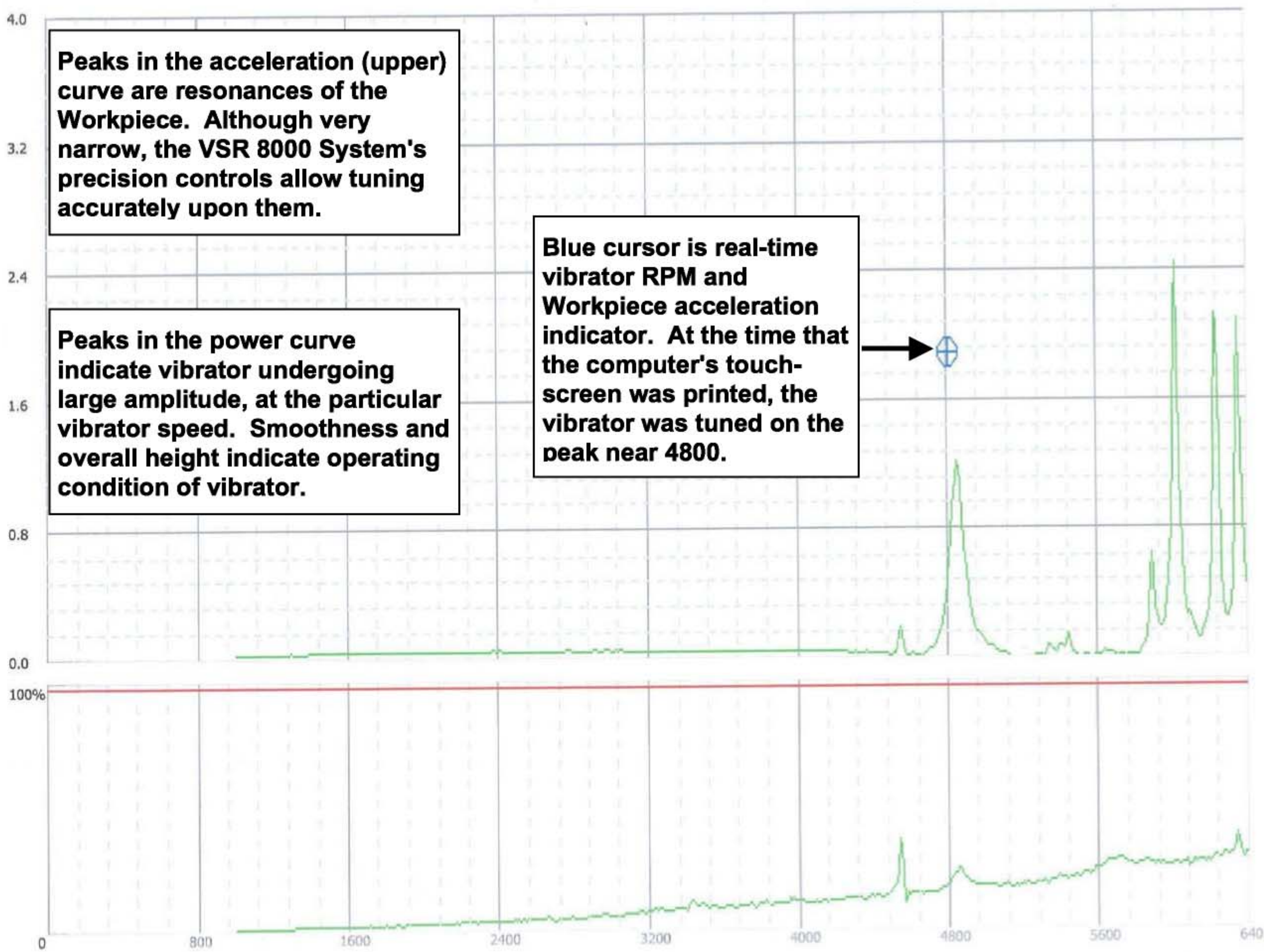


BL8 Vibrator mounted on workpiece. This aluminum-bodied Vibrator has freeze-fit, hardened steel inserts in the mounting feet to eliminate loosening of the vibrator mount. Other features of the BL8 include: a 3 HP, brushless DC, ultra compact motor, massive tapered roller bearings, and dual mount feet so that the vibrator can be oriented to the mount location that enables the most effective treatment.

PHOTO 5

VSR 8000 Control Console with touch-screen computer. The screen displays operating parameters of the VSR Process, along with real-time plotting of workpiece Acceleration and Vibrator Input Power, both vs the Vibrator's RPM. These spectra of behavioral characteristics of the workpiece when subjected to vibration, not only reveal the Vibrator speed(s) needed to perform an effective treatment, but also monitor treatment progress and completion. See *full-page chart on pg 9*.

PRETREATMENT SCAN

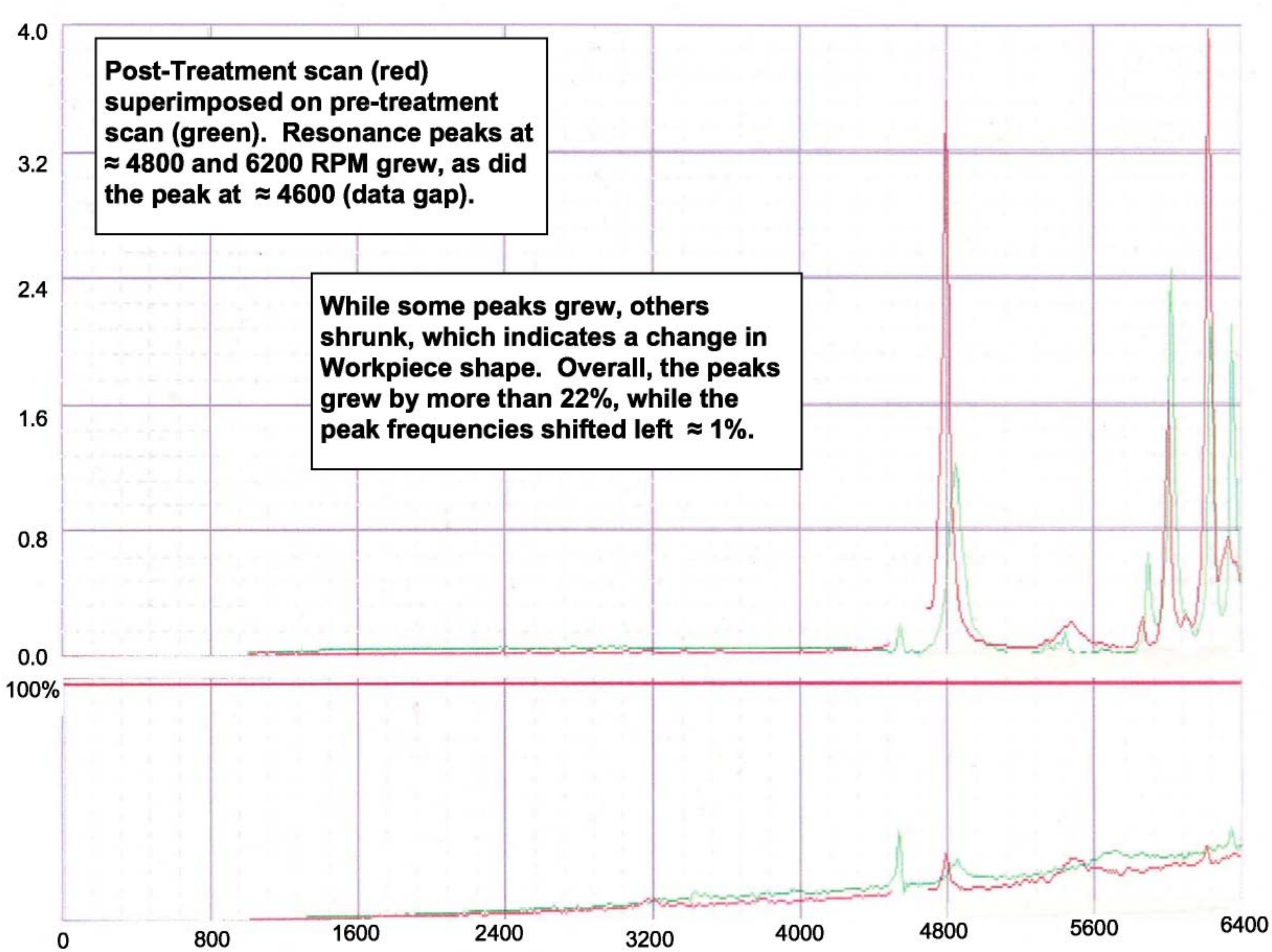


Peaks in the acceleration (upper) curve are resonances of the Workpiece. Although very narrow, the VSR 8000 System's precision controls allow tuning accurately upon them.

Peaks in the power curve indicate vibrator undergoing large amplitude, at the particular vibrator speed. Smoothness and overall height indicate operating condition of vibrator.

Blue cursor is real-time vibrator RPM and Workpiece acceleration indicator. At the time that the computer's touch-screen was printed, the vibrator was tuned on the peak near 4800.

POST-TREATMENT SCAN



Post-Treatment scan (red) superimposed on pre-treatment scan (green). Resonance peaks at ≈ 4800 and 6200 RPM grew, as did the peak at ≈ 4600 (data gap).

While some peaks grew, others shrunk, which indicates a change in Workpiece shape. Overall, the peaks grew by more than 22%, while the peak frequencies shifted left ≈ 1%.