Report on Vibratory Stress Relief

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VULCAN MACHINERY
Wilkes-Barre PA

5-ton Welded Steel Alloy Rings

VULCAN MACHINERY chose AIRMATIC INC's VSR Technology Group to stress relieve welded, heavy-walled, 5-ton steel rings in preparation for precision machining. Using a VSR-8000 System, the job was done on-site at the fabrication shop, and resulted in stable and accurate precision components.

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VULCAN MACHINERY, a manufacturer of kilns, dryers, furnaces and related equipment, is located in Wilkes-Barre, PA. When they subcontracted TRI-ALLIANCE FABRICATION to produce 12' dia, 5-ton welded rings, used as wheels ("tires") for a dryer drum, the VSR Process was considered the only practical means of stress relieving the workpieces. These Rings consist of an outer ring, 4" thick, 15" long, made of 8630 steel, and an inner ring, 3" thick, made of ASTM 516, Grade 70. The two Rings were welded together under a preheated condition, and the VSR Process was employed soon after cool down. A VSR-8000 System was used to perform stress relief on these critical components.

VSR SETUP

The workpiece was placed on 3 Isolation Load Cushions. Two of the cushions were placed 3' apart; the other placed 180° away, midway between the two closely-spaced, opposite side cushions. This arrangement fully supported the workpiece, while minimizing damping, thus enabling maximum flexure to occur during Treatment – a fundamental principal of the VSR Process.

The vibrator was mounted to the inner ring above one of the closely-spaced cushions. Initially, the Vibrator was oriented so that its axis-of-rotation (AOR) was horizontal. Later, for a second Treatment, the Vibrator was oriented so that the AOR was vertical. The VSR Setup used to perform the second treatment is shown in the Figure 1 photo.

Two VSR Treatments were performed on the workpiece, due to its ring shape. Unlike rectangular shapes, or long, shaft-shaped components, rings have two resonant modes that are almost impossible to excite with a single orientation of a rotary vibrator. With the Vibrator's AOR oriented horizontal, the Ring's bending and twisting modes can be excited. Since both of these modes result in axial deflection (in the direction of the Ring's central axis), this is referred to as an *axial* vibrator orientation. The other resonance mode requires the Vibrator be oriented with the AOR vertical. This allows excitation of the Ring's elliptical modes, and causes radial deflection; this is referred to as a *radial* vibrator orientation.

A unique feature of the BL-8 Vibrator is its two sets of mounting flanges, which enables a fast and easy change from axial to radial orientation, enabling all modes of vibration to be addressed.

An Accelerometer (a sensor whose output is proportional to acceleration) was placed on the Inner Ring, positioned ≈ 90° from the Vibrator. This location was judged most likely to provide the greatest amplitude during VSR Treatment, because it was furthest away from the Load Cushions.

The BL-8 Vibrator's unbalance (adjustable from 0.2 to 4.0 in-lbs) was adjusted to 1.0 in-lbs for the trial run performed by the 8000 System's Quick Scan mode. This allows the operator to sample and then select the correct vibrator speed range (10 to 8000-RPM), so workpiece resonances (harmonics) are attained. Based on the Quick Scan, a setting 1.5 in-lbs was selected.

The VSR-8000 System uses resonant frequency vibration to stress relieve and thereby stabilize precision metal components. Independent research has shown that, although near-resonant (ie, sub/non-resonant) and even random vibration can achieve some degree of stress relief, resonant frequency vibration is the most effective form of vibration. Furthermore, by using resonant frequency vibration, the progress of stress relief treatment can be most easily monitored. This is because the major change in resonance pattern most commonly seen during effective stress relief is the growth response of the resonance peaks. By tuning upon the tops of the resonance peaks, their height can be accurately recorded and monitored. Without tuning directly upon the top of a resonance peak, the exact height of a peak can only be approximated which forces the operator to guess at treatment progress.

A secondary change in the resonance pattern is the shifting response of the resonance peaks, normally in the direction of lower frequency. Exceptions occur when the workpiece undergoes significant change in shape during Treatment, which is indicated by a shift of resonance peaks to higher frequency.

Figure 1: **3 Isolation Load Cushions (circled) support the 5-ton welded Ring, two are near the Vibrator on right, one is opposite in left foreground, positioning that minimizes workpiece damping. Vibrator (circled upper-right, inside) was securely clamped with orientation in the radial AOR during this 2nd Treatment. Accelerometer (circled on left, inside), is positioned in the area of maximum amplitude.**

VSR Treatment

After the unbalance setting of 1.5 in-lbs was found to generate some resonance peaks, a Pre-Treatment Scan, at a slower (10-RPM/sec) scan rate, was performed. This slower scan rate assures a high-resolution recording of the precise resonance pattern of the workpiece. The Pre-Treatment Scan is shown in Figure 2.

VSR Treatment Charts display two curves: An Acceleration v RPM curve, which shows the resonance pattern of the workpiece, and a Vibrator Power v RPM curve, which is used to choose Vibrator location and unbalance setting.

The VSR-8000 System displays the acceleration amplitude of the workpiece. Acceleration measurement is used, rather than deflection or velocity, because it is proportional to the force the workpiece undergoes, based upon Newton's 2nd Law: F = ma (where F is force, m is mass, and a is acceleration.) Acceleration has been shown to be the most scientifically based parameter to use when monitoring a vibratory stress relief treatment.

Large peaks in the power curve indicate that the Vibrator was not only causing large workpiece amplitude, but that the Vibrator was being subjected to large amplitude. The BL-8 Vibrator utilizes a 3-HP (2.3 kW), brushless DC motor, capable of speeds up to 8,000 RPM, yet is very compact, and lightweight (only 45 lbs [≈ 20 kg]). This not only makes the Vibrator highly mechanically reliable, since it has no brushes or commutator (which are prone to damage and poor performance if vibrated), but also enables it to be tuned on far larger resonance peaks in the power curve than any brushed motor could tolerate.

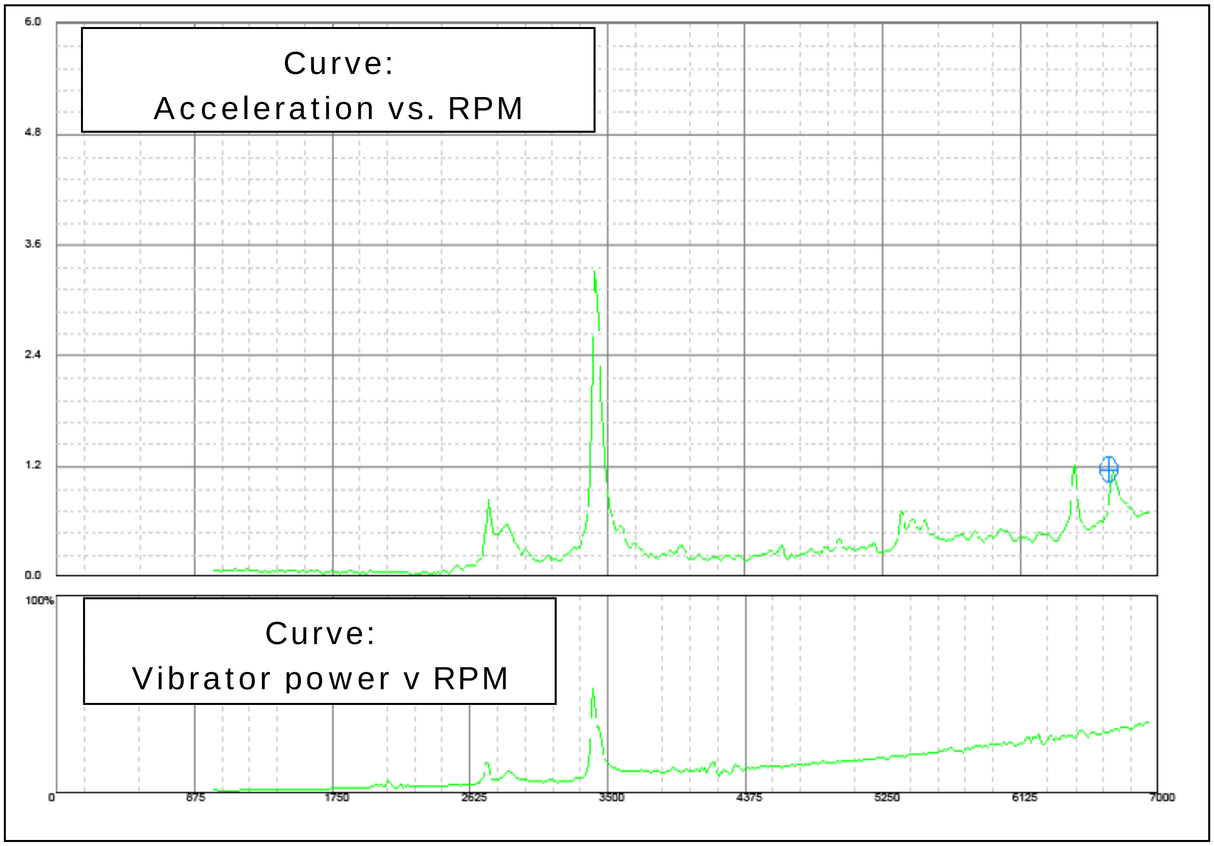

Figure 2: Pre-Treatment Scan. This data is the base-line that the operator uses to judge progress of VSR Treatment. At a rate of 10 RPM / sec, it took 10 minutes to make this 1000 – 7000 RPM chart. Peaks at ≈ 2700, 3400, 6500 and 6700 RPM are shown. At the time that this screen displayed on the VSR-8000's touch-screen PC was saved, the VSR Treatment had started: The circled blue cross on the right (above the right-most peak) shows that the Vibrator was tuned to this peak. Pre-Treatment Scans are recorded in green, since the workpiece is "green", ie, not yet treated.

Each of the peaks was tuned upon for 15 - 20 minutes, which was sufficient time to cause the peaks to grow and then stabilize.

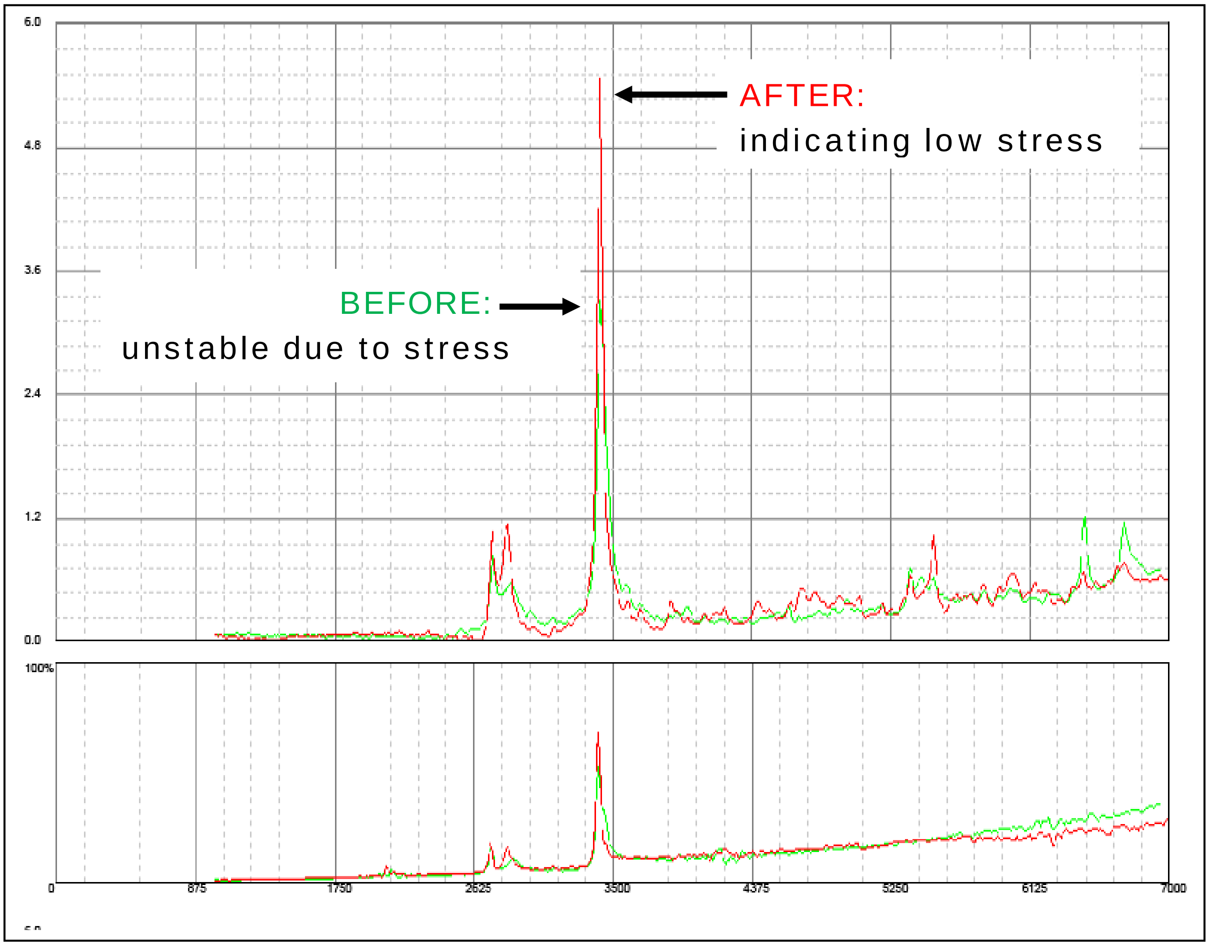

Figure 3: A Post-Treatment Scan documents changes in resonance pattern, due to stress relief. Little change took place while this peak was being treated, but the larger peaks at 2700 and 3400 grew quickly, increasing more than 40% during Treatment periods of 8 minutes each. No further growth occurred.

A second VSR Treatment was done using a radial AOR vibrator orientation. This was easily accomplished using the other set of vibrator mounting feet. The VSR Treatment Chart for this Treatment is shown in Figure 4. Note that the resonances at 2700-RPM and 3400-RPM are very short, but the resonances at higher frequencies, especially 5400, 6700, and 6900-RPM are much larger. The orientation of the vibrator was the only change made.

Tuning upon each of these peaks for ≈ 10 minutes apiece was sufficient to cause them to stabilize. Peak growth was ≈ 15%, far less than the 40% growth of the 1st VSR Treatment.

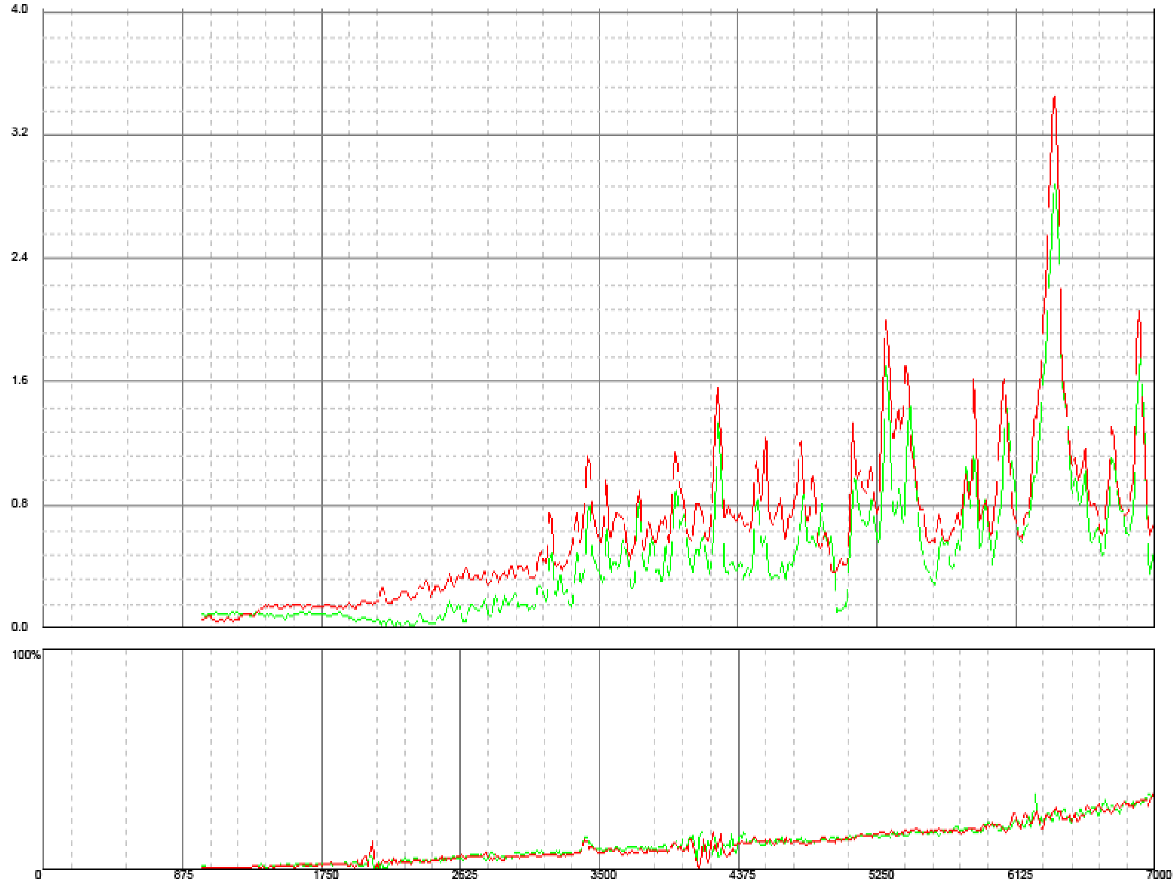

Figure 4: **2nd VSR Treatment using radial AOR caused some additional growth to a totally different collection of peaks than displayed on the 1st Treatment. Stability of the new resonance pattern was achieved in roughly half the time as the 1st Treatment.**

Conclusion

The welded Rings were sand blasted and sent to the machine shop, where they were machined to exacting dimensional accuracies, within .003" without incident. Such welded Rings with multiple pass, circumferential welds have a great deal of residual stress, and are prone to go out-of-round if not properly stress relieved. The ease of machining and achievement of target dimensional accuracies was clearly the result of using the VSR Process.

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.