The cost effective alternative to heat treatment

Report on Vibratory Stress Relief

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9500 HP FAN HOUSINGS

Large distortion during separation of 9500 HP Fan Housing halves led a large fabrication shop to explore the VSR Process as an alternative to heat straightening. The results obtained using the VSR-8000 System were significant: a ≈ 90 % reduction in the distortion that had plagued CND in the past.

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CND INCORPORATED, Massillon, OH, is a large-scale fabrication shop producing 9500 HP Fan Housings for a TLT BABCOCK for use in large-scale cooling and ventilation applications. A Fan Housing consists of two halves (upper and lower w/base); the halves are mild steel weldments and the assembled unit measures 197"H X 179"W X 43"D, and weighs 17,000 lbs. The Housing fabrication is made using the "back-to-back" fabrication method, in which the two halves are temporarily held together during fabrication with welded steel plates spanning the split-line between them. The assembled Fan Housing weldment is shown in Figure 1.

Figure 1:

9500 HP FAN HOUSING WELDMENT. The split-line runs horizontally through the center. This fabrication technique is called "back-to-back" fabrication since each weldment section acts as a fixture to reinforce the other.

The problem CND needed to address was the distortion that took place after all welding was completed, and the two halves were separated. Separation is done by arc-torch cutting of the welds of the "spanning plates", which join the two halves. Distortion was manifested in two forms:

A. Vertical separation of the upper half from lower half at the outer edges (the inner portions would remain in contact). This separation ranged from "1/2 to 3/4" (5/8" typical).

B. Axial deflection at the outer edges, ie, the upper half moving in one direction axially, the other half moving in the opposite direction. Common distortion was ≈ 1/2".

Distortion was being "corrected" by heat straightening, a technique that, is as usual, generated yet another collection of residual stresses, which made machining operations difficult. These additional induced stresses caused significant distortion of the individual halves during transport to the machine shop.

VSR SETUP

The Setup used to perform the VSR-8000 System Treatment consisted of the following:

1. Positioning the workpiece so that it was "lying down", ie, greatest ground contact in the horizontal plane.
2. Placing three Isolation Load Cushions (each 10"L X 6"W X 4"H) beneath the inner flange surface, just inside the Fan Housing's ID.

3. Locating the Vibrator on the outer flange, on the "base-side" of the split line. The Vibrator was oriented so that its Axis-of-Rotation (AOR) was horizontal, and directed through the workpiece's axial center.

4. Locating the System's Accelerometer on the base of the workpiece, oriented so as to be most sensitive to vertical deflection.

    NB: An Accelerometer, which measures acceleration, was used because its signal is directly proportional to the force the workpiece experiences (Newton's 2nd Law: **F = ma**, where **F** is force, **m** is mass and **a** is acceleration). Using acceleration to measure intensity of vibration has shown to be the most scientific based parameter.

A photo of the VSR Setup can be seen in Figure 3.

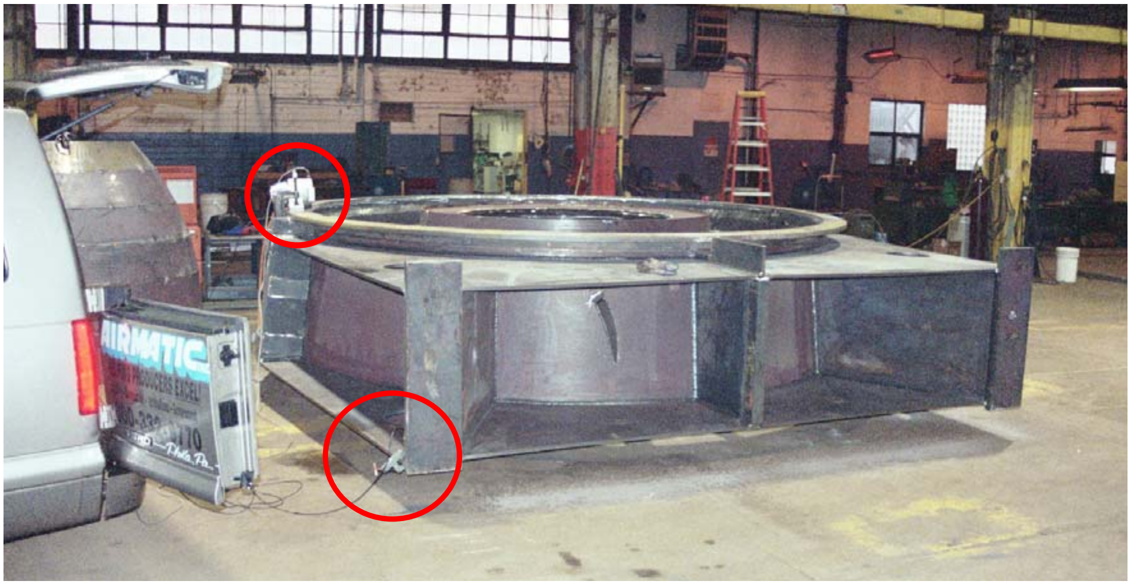


Figure 3: VSR SETUP. Weldment lowered to be aligned with horizontal plane (to minimize damping), and placed on 3 Isolation Load Cushions (not visible) located immediately underneath the flange ID. The Vibrator (circled) is attached to the top flange. Accelerometer (circled) is clamped to base of workpiece, and oriented to be most sensitive to vertical deflection of workpiece during vibration.

The Vibrator's unbalance was adjusted to 5% (min setting) of the available 4.0 in-lb. unbalance, and a procedural Quick Scan revealed minimal resonance peak generation. The unbalance was incrementally increased, first to 10% and then to 20%, to drive the workpiece into the several resonances that were sufficient to perform the VSR Treatment. There criteria used to determine the correct Vibrator unbalance (unbalance is directly proportional to vibrator output force). Because unbalance is directly proportional to Vibrator force output, two criteria are used to determine the correct Vibrator unbalance setting for this type of workpiece:

- Visible resonance peaks must be at least 2g – 3g high
- There is must be a change in the resonance pattern during Treatment, specifically peak growth (commonly the stronger response) and / or peak shifting (the weaker response)

PRE-TREATMENT SCAN

An automatic Pre-Treatment Scan is then run to record the resonance pattern of the workpiece, prior to Treatment. The Scan results serve as a base-line to perform two tasks:

- Tune the Vibrator upon the workpiece's resonance peaks

- Monitor the progress of the VSR Treatment, by noting the changes in growth and shifting of resonance peaks, as they become stronger with Treatment. (These are changes that also take place during PWHT [although not generally documented], or over extended periods of time [Aging], or during long distance transport, all of which cause some degree of stress reduction. **NB**: The relief of stresses during transport was one of several historical paths that marked the discovery of Vibratory Stress Relief).

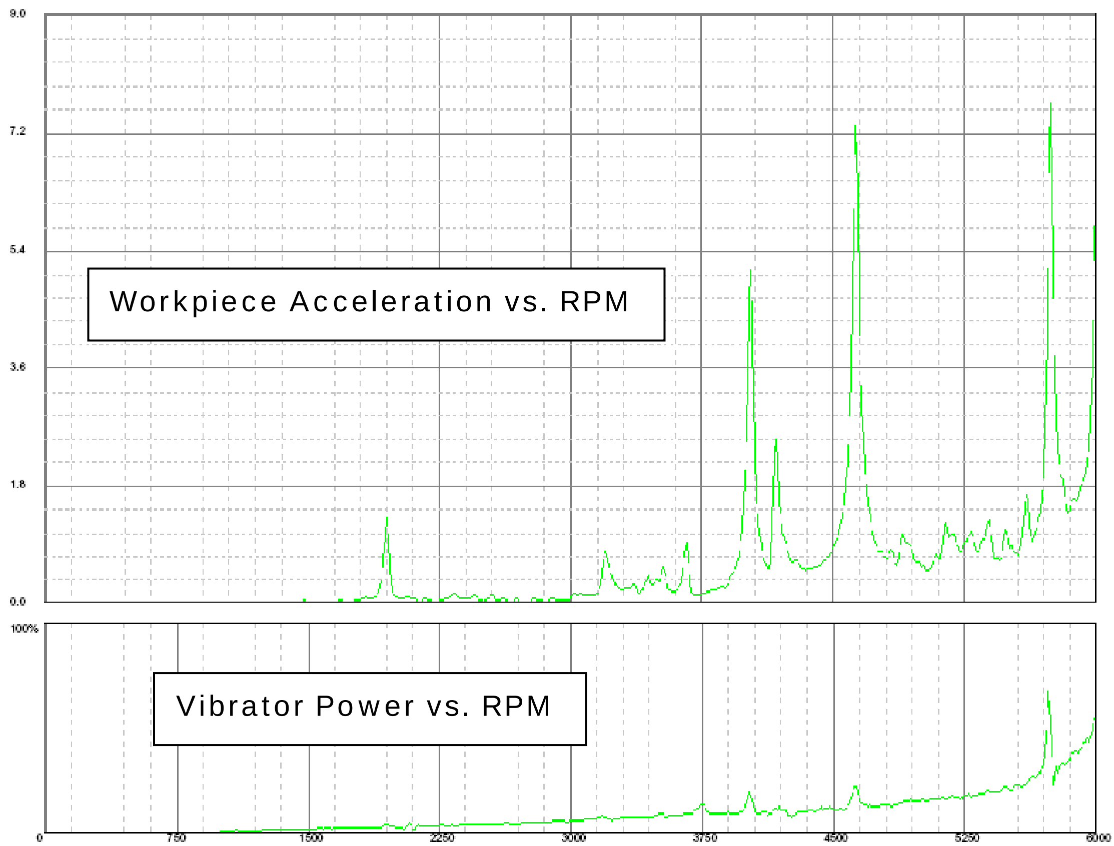


Figure 4: PRE-TREATMENT SCAN-1. Scan results are shown on two charts: Upper Chart shows vertical axis of acceleration, calibrated in "g" (the scientific parameter of acceleration, ie, 32 ft or 10 m / sec /sec); Lower Chart shows vibrator input power (100% equals 3 HP or 2.3 kW). Both results are plotted against Vibrator RPM, the common horizontal axis in the charts (on this job, full-scale equals 6000-RPM).

Peaks in the upper curve are the resonance peaks of the workpiece. Peaks in the lower curve indicate vibrator speeds that coincide with high-vibrator amplitude. If the amplitude becomes excessive (a peak in power can approach or exceed the overload limit of the Vibrator motor), the overload event triggers the System's motor protection circuitry. The VSR Setup can be modified so as to lower a peak in power by either lowering the unbalance setting or moving the Vibrator onto one of the workpiece's "nodes", which can be made visible by spreading a powder, eg, sand or Oil-Dry® desiccant on the workpiece. The powder will be driven off the high-amplitude regions to the virtually zero amplitude points – the "nodes".

The VSR-8000 System's electronics provides the operator the critical data which is key to refining the VSR Setup, so as to maximize the effectiveness of Treatment, while minimizing Treatment time and "wear & tear" on the vibration equipment.

VSR TREATMENT – 1

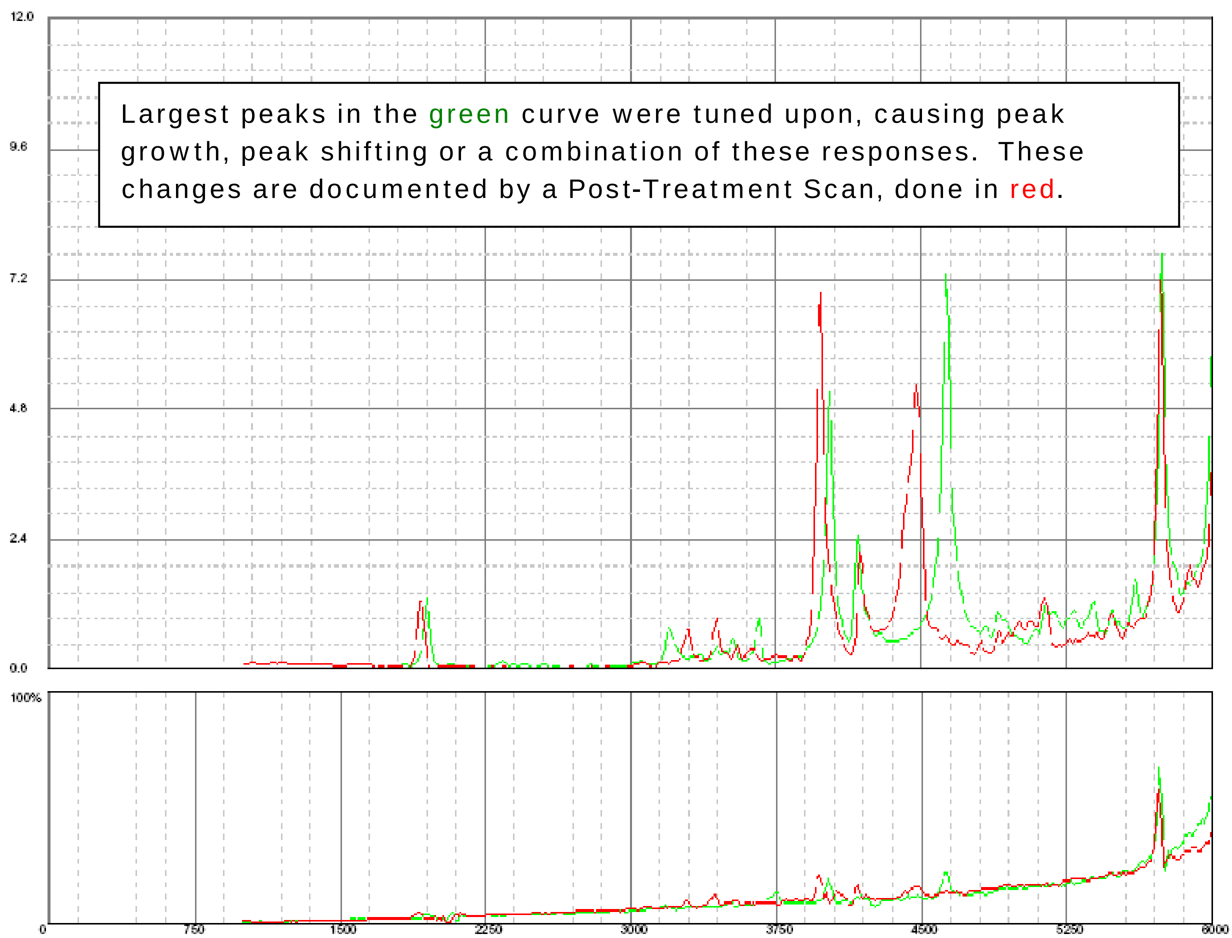
On first Treatment the Vibrator speed was tuned to coincide with each peak in the acceleration curve. This causes maximum workpiece flexure. Independent research has proven that flexure is critical to allowing stress relief to occur: Merely causing mass-oscillation (ie, movement without flexure) of the workpiece will not allow stress relief to occur.

Maximum flexure can only be achieved by resonating a workpiece set up on Isolation Cushions which are positioned so as to minimize damping. Hence the need for the minimum 3 Isolation Cushions (3 points of contact is the minimum needed to determine a geometric plane), and the strategic placement of these Cushions as centrally located beneath the workpiece as possible.

Both peak shifting and peak growth took place during the Treatment – 1. A total of five peaks were tuned upon and held for 15 minutes each; here's how they changed:

PEAK NUMBER	1	2	3	4	5
ORIG PEAK LOCATION(RPM)	1950	4050	4200	4650	5700
FINAL PEAK LOCATION(RPM)	1900	3950	4230	4490	5700
ORIGINAL PEAK HEIGHT (g)	1.2	5	2.4	7.2	7.5
FINAL PEAK HEIGHT (g)	1.3	7	2.3	5.2	7.2

Three peaks grew (usual occurrence), but two peaks reduced: P4 & P5. P4 also underwent a significant shift, and the force output of the vibrator was quickly reduced with a vibrator speed reduction. Vibrator force output is proportional to the square of the RPM, eg, 10 % decrease in speed results in 19% decrease in force output (0.9 X 0.9 = 0.81). Either a reduction in peak height (P4 & P5), or movement of a peak to the right (the shift of P3) is indication of a change in workpiece shape. This change in shape was later confirmed after all four Treatments were performed, but prior to separation of the two workpiece halves.



^ ^ ^ ^ ^

Orig Peak Locations (RPM): 1950 4050 4200 4650 5700

FIGURE 5: TREATMENT-1 POST-TREATMENT SCAN. The Pre-Treatment Scan data (green) is left intact, and the final acceleration and power curves are recorded in red during the post-treatment scan, and superimposed on the graph, for immediate, easy to interpret comparisons.

VSR TREATMENT – 2

The second Treatment was done by increasing the Vibrator unbalance from 20% to 60% (2.4 in-lb unbalance), while decreasing the speed from 6000 RPM to 3750 RPM. This caused resonance peaks that were detected during the Treatment-1 (but which did not have sufficient vibrator force [to low an unbalance setting] to cause stress relieving), to now undergo Treatment.

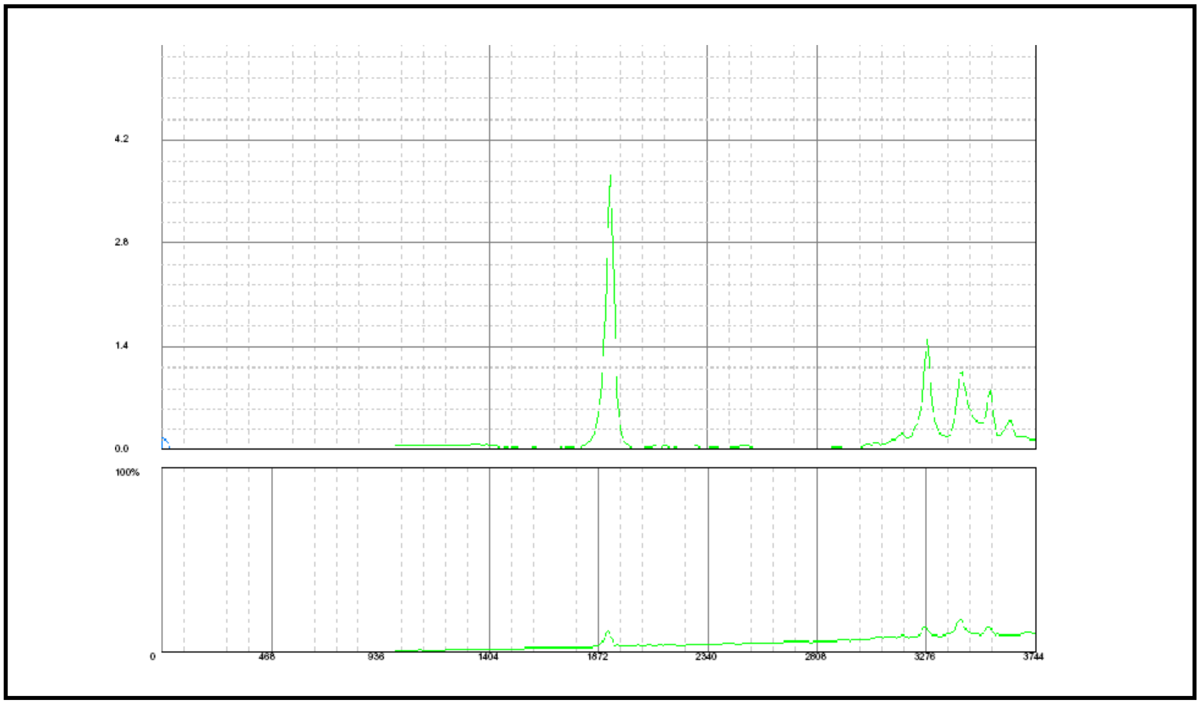
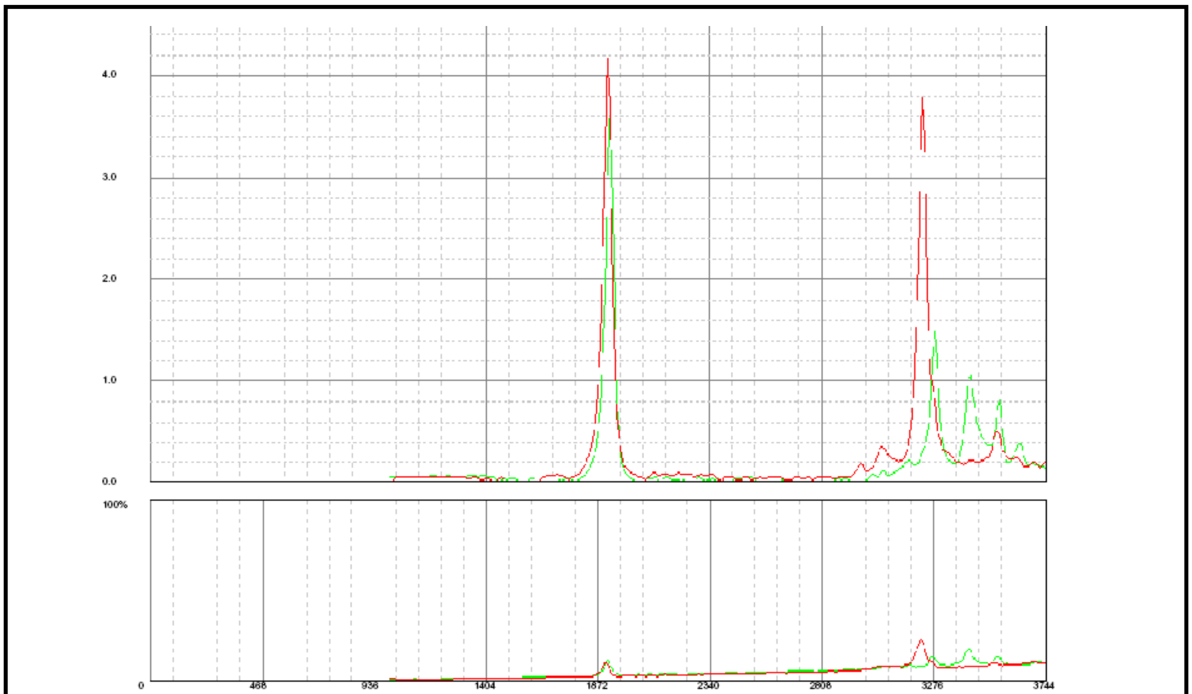


Figure 6: **PRE-TREATMENT SCAN-2. By increasing the unbalance, the small, low-frequency resonance peaks seen in Treatment-1 were increased, eg, the resonance peaks at 1900 RPM increased from 1.3g (seen in Treatment-1) to more than 4g.**



Orig Peak Locations (RPM): ^ 1900 ^ 3275

Figure 7: TREATMENT-2

The result of the Treatment-2 was a 15 % increase in the height of the peak at 1900-RPM, and a 200% increase (along with some shifting) of the peak at 3275-RPM. This further illustrates the importance of sophisticated recording and display instrumentation when performing Vibratory Stress Relief: Data gathered during Treatment-1 should not only aid and document Treatment-1, but also provide insight into the need and methodology for subsequent Treatments.

VSR TECHNOLOGY GROUP experience has proven: Stability of workpiece dimensions only takes place when workpiece resonance patterns are rendered stable through resonant frequency vibration.

RADIAL VSR TREATMENTS

As has been reported in other Treatment Job Reports (eg, VOITH-SIEMENS # 2), ring shaped workpieces exhibit unique behavior during resonance, and this unique behavior must be accounted for to fully treat these types of workpieces. The unique behavior is because they harbor two families of resonances – axial and radial – which are highly independent from one another. A vibrator oriented so that it drives axial excited resonances will not drive radial excited resonances effectively, and vice versa.

Thus, for Treatment-3, the Vibrator was left at 60% unbalance, but reoriented 90°, so that the AOR was now vertical. The Vibrator was also moved approximately 2', so as to be mounted on the other side of the "split-line". This was a precaution (which turned out to be unnecessary) aimed at avoiding marginal transfer of vibration through the plates that span the "split-line" during fabrication. Treatment-3, which was performed with this modified Setup, is shown in Figure 8.

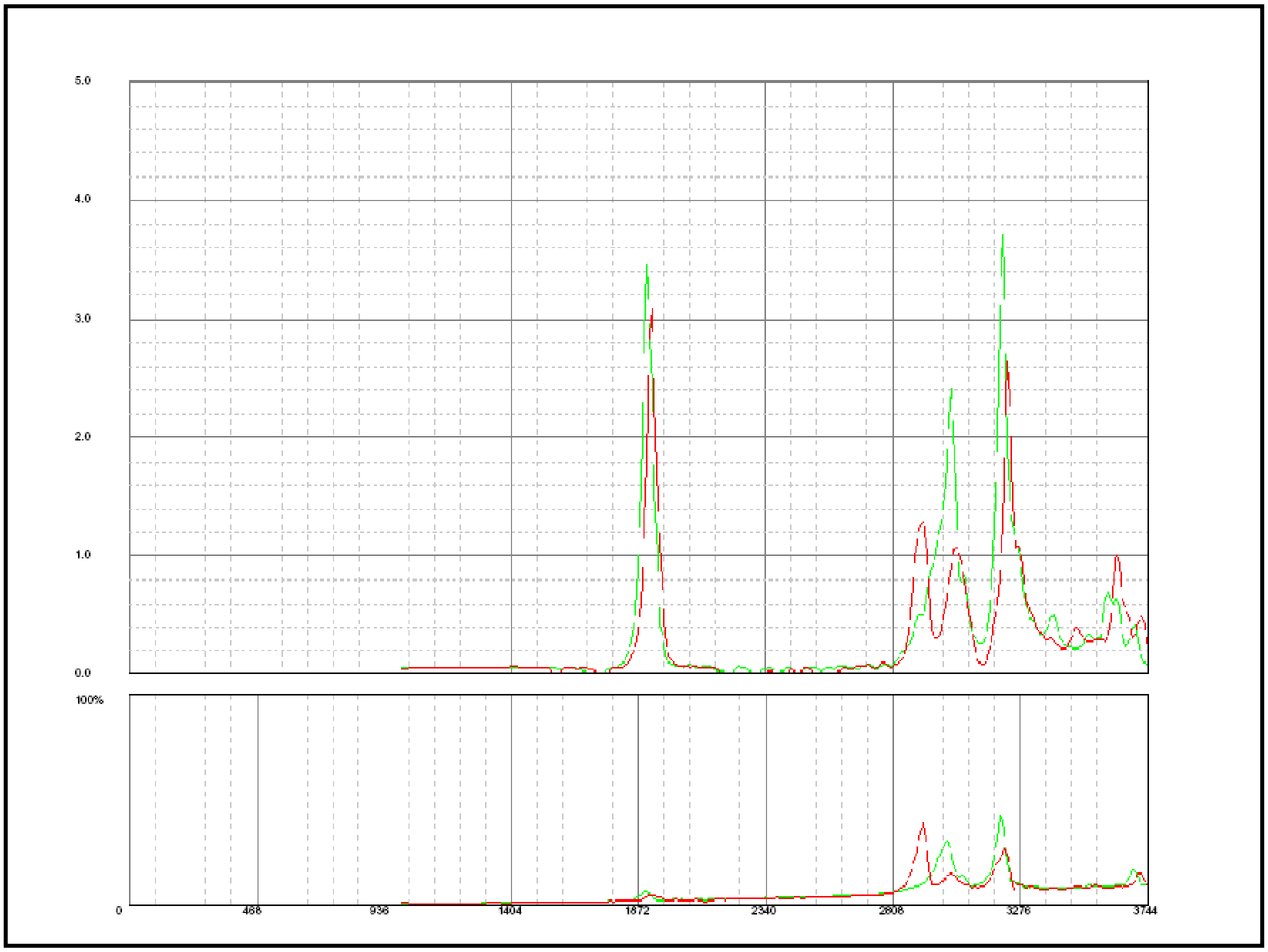


Figure 8: **TREATMENT-3 with radially directed Vibrator set at 60 % unbalance, and mounted on other side of split-line.**

Although some changes took place, notably in the peaks between 2800-RPM – 3300-RPM, these changes were not classic VSR Treatment responses. Little change took place at the 1900-RPM peak.

The fourth and final Treatment was performed using the same Treatment-3 Setup, but with the unbalance setting lowered to 20%, so as to allow higher Vibrator speeds (up to 5600-RPM). Results are shown in Figure 9.

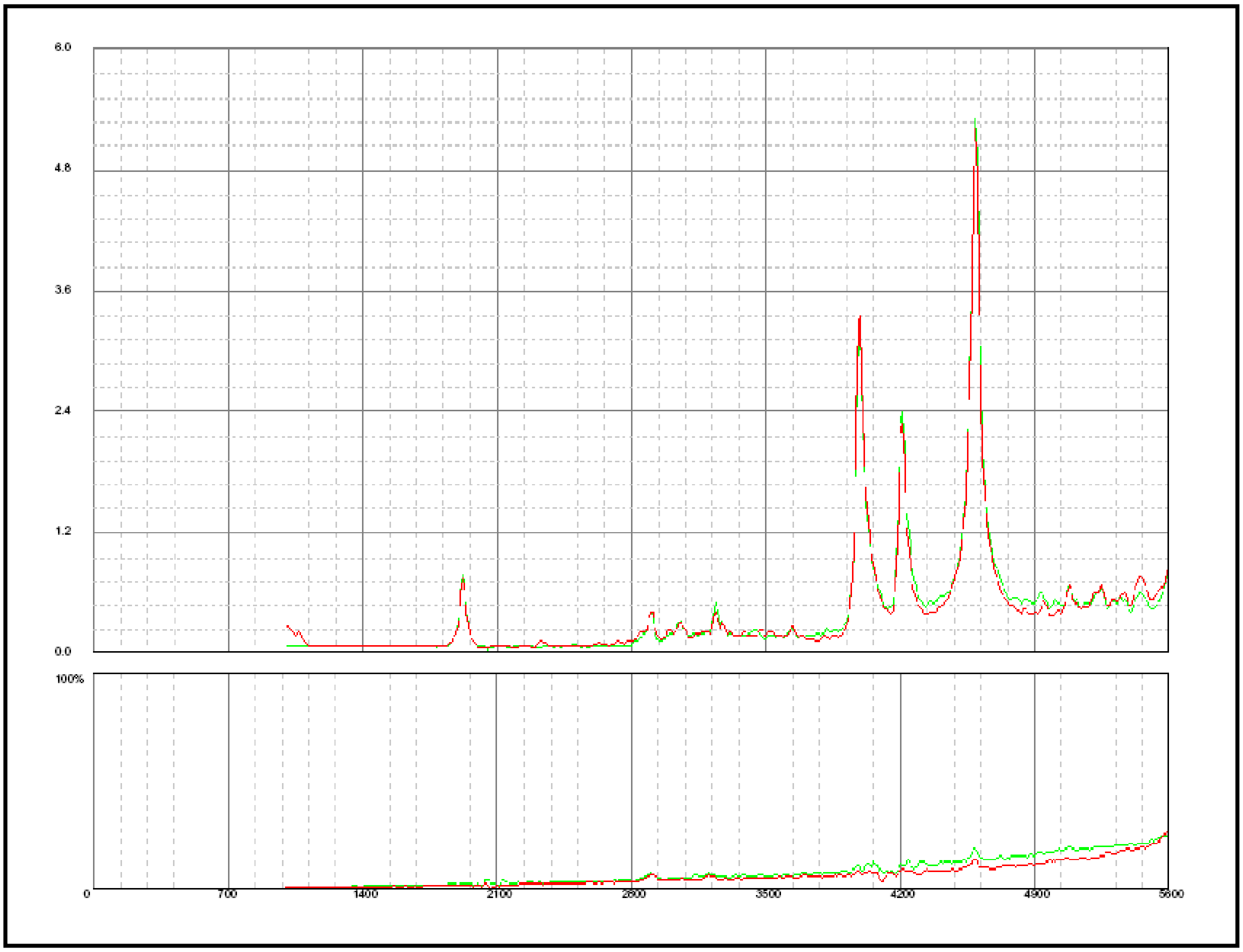


Figure 9: **TREATMENT-4. Vibrator unbalance: 20%. Note the high degree of repeatability between the Pre-Treatment (green) and Post-Treatment (red) Scans. This is proof of a highly stable resonance pattern, and, therefore, a highly stable workpiece.**

RESULTS

The VSR Setup was then knocked-down, and the Fan Housing turned to the upright position. A dimensional inspection revealed that some limited distortion had taken place during the VSR Treatments: Worst case was a 1/2" change in OD of the large flange where the Vibrator had been mounted. However, because sufficient stock had been designed into the flange, this was not a problem: The workpiece was still "inside" drawing tolerances.

The spanning plates were then arc-torch cut off the Fan Housing. Previously this step caused loud impact noises to occur (noises resembling rifle shots). The noises occurred as the arc-torch cut would pass through 80% of the weld holding a spanning plate and the remaining 20% was yanked apart by the twisting and separating Fan Housing halves. After VSR Treatment, only minor noise occurred.

Upon removal of all the spanning plates, the vertical separation between the two halves was 1/8" to 3/16" (worst case). Axial distortion was similar: ≈ 1/8". This reduction represented a five-fold decrease in the distortion, and lead CND to the following conclusions:

1. The VSR Process prevented the unacceptable distortion that usually took place when the halves were separated.

2. The VSR Process will minimize the distortion during transport of these two, nearly mating halves to the machine shop.

3. The VSR Process will minimize distortion during machining.

Figure 10: Fan Housing's upper half was lifted from the lower half during separation.

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.

Figure 11: Arc-torch cut marks were ground smooth.

Figure 12: Fan Housing, reassembled with minimal misalignment, awaiting transport to machine shop.

VSR Technology Group

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