



VSR REPORT

**TUFTCO
Chattanooga, TN
February 26, 2016**

MACHINING RESULTS UPDATE:

MOVEMENT UPON RELEASE FROM ALL MACHINING SETUPS SHOWED AT LEAST A THREE FOLD / AS MUCH AS TEN FOLD IMPROVEMENT IN ACHIEVED MACHINING ACCURACY, COMPARED TO NON-VIBRATED WORKPIECES. IMPROVEMENT IN SURFACE FINISH WAS ALSO ACHIEVED, A DIRECT RESULT OF EFFECTIVE STRESS RELIEF. (CUSTOMER'S DIMENSIONAL RESULTS APPEAR ON LAST PAGE.)

Tuftco is a manufacturer of high-quality carpet and rug making systems including equipment that can make custom image carpets, using digital imaging technology.

In the second round of parts stress relieved with VSR Technology, a rail frame that was similar, but slightly shorter than one treated earlier, along with a "head-structure" weldment, were stress relieved. Tuftco choose to have additional workpieces VSR Processed after the machining results from the first frame indicated that accuracies of better than 0.010" over a 20 foot distance were achieved.

Refinements in the VSR Setup compared with the earlier work included tooling that allowed ideal orientation of the vibrator, which is achieved when the workpiece length is aligned with the vibrator's Axis of Rotation (AOR). VSR Charts showed both resonance peak growth AND shifting taking place during stress relief, changes that only tuning directly upon resonant peaks are able to fully resolve.

Report prepared by:
Bruce Klauba
Advanced VSR / Technical Director

Tuftco is a manufacturer of high-quality carpet and rug making systems including equipment that can make custom image carpets, using digital imaging technology.

In the second round of parts stress relieved with VSR Technology, a rail frame that was similar, but slightly shorter than one treated earlier, along with a “head-structure” weldment, were stress relieved.

Refinements in the VSR Setup included tooling that allowed ideal orientation of the vibrator, which is achieved when the workpiece length is aligned with the vibrator's Axis of Rotation (AOR).

VSR SETUP

The VSR Process uses resonant vibration to cause sufficient flexure of the work-piece, so to combine the dynamic load from resonant vibration with residual stresses trapped in the material, resulting in plastic flow. Several independent research works, including those of Hahn¹, Shankar², and Yang, Jung and Yancey³, have proven that resonance frequency vibration is the most effective form of vibration to relieve stress.

Figure 1: Frame setup for VSR Treatment. Three isolation cushions are positioned around the center of the frame, separated by ~ 5 feet, with the vibrator near the far cushion. This cushion arrangement minimizes damping, and thus maximizes workpiece resonances. An accelerometer is mounted on the far left corner, and oriented to be most sensitive to vertical amplitudes. Note that the vibrator's AOR (Axis of Rotation) is aligned with the workpiece length, which allows both vertical and horizontal amplitudes to be generated.



¹ Dr. William Hahn, [Vibratory Residual Stress Relief and Modifications in Materials to Conserve Resources and Prevent Pollution](#)

² Dr. S. Shankar, [Vibratory Stress Relief of Mild Steel Weldments](#)

³ Drs. Y. P. Yang, G. Jung, and R. Yancey, [Finite Element Modeling Of Vibration Stress Relief After Welding](#)

To maximize resonant response, and hence, flexure, placement of urethane isolation cushions was made far from the corners or ends of the workpiece, in a tight triangular, centered array (see Fig. 1), 3 being the minimum number that determines a plane.



Figure 2: VSR Tooling consisted of two plates, each with a 4 bolt pattern for the threaded rod, plus 2 mounting holes for the vibrator. Accelerometer is on right.



Figure 3: Advanced VSR Model 7.5 Console features a 15" touchscreen PC, 5 HP Allen-Bradley VFD motor drive (with external heat-sink), installed in a NEMA 4 rated enclosure. Flip up / down lid holds a keyboard when open, and covers all controls when closed. Front panel includes a quarter-turn disconnect switch, plus jacks for the accelerometer and vibrator, plus two USB's.

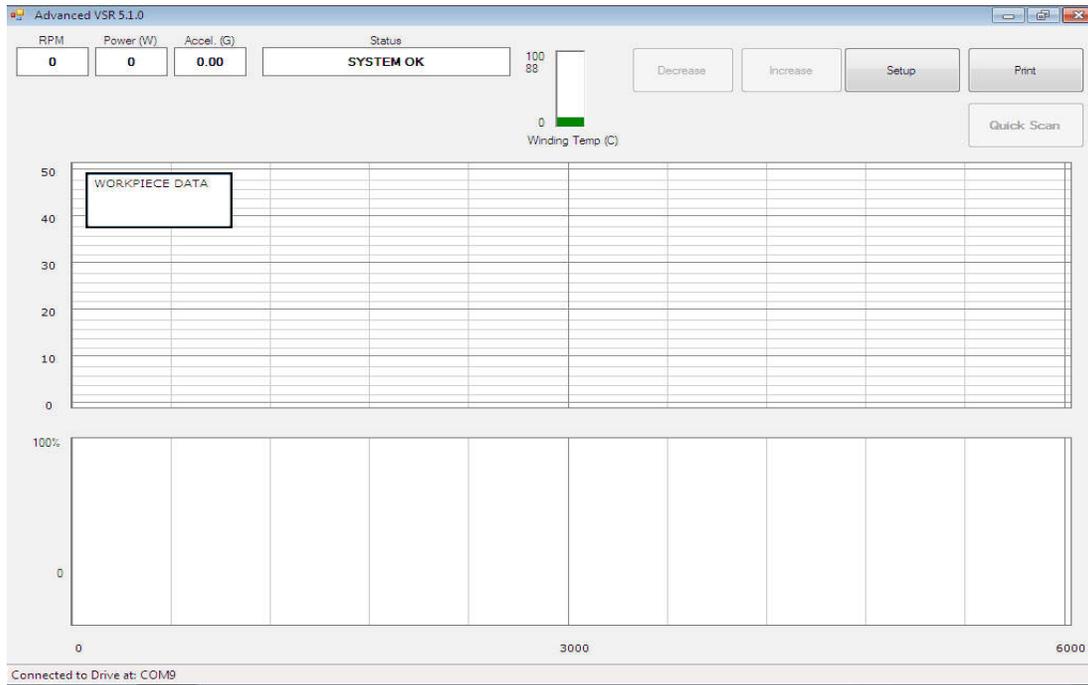


Figure 4: VSR OS Main Screen displays all the key parameters used in the VSR Process (Workpiece Acceleration, Vibrator RPM and Power Input), both graphically and digitally, along with motor winding temperature, with choice of F or C temperature scales. SETUP button opens window that allows operator to chose start speed, end speed, scan rate, and acceleration scale. Scales for both RPM and acceleration can be changed after a scan is made, without any loss of data integrity. PRINT button opens a high-resolution PDF maker that generates an image of the charts displayed, along with the document tagging window (upper-left of acceleration curve). The following pages contain these saved high-resolution charts that were generated with this PDF maker.

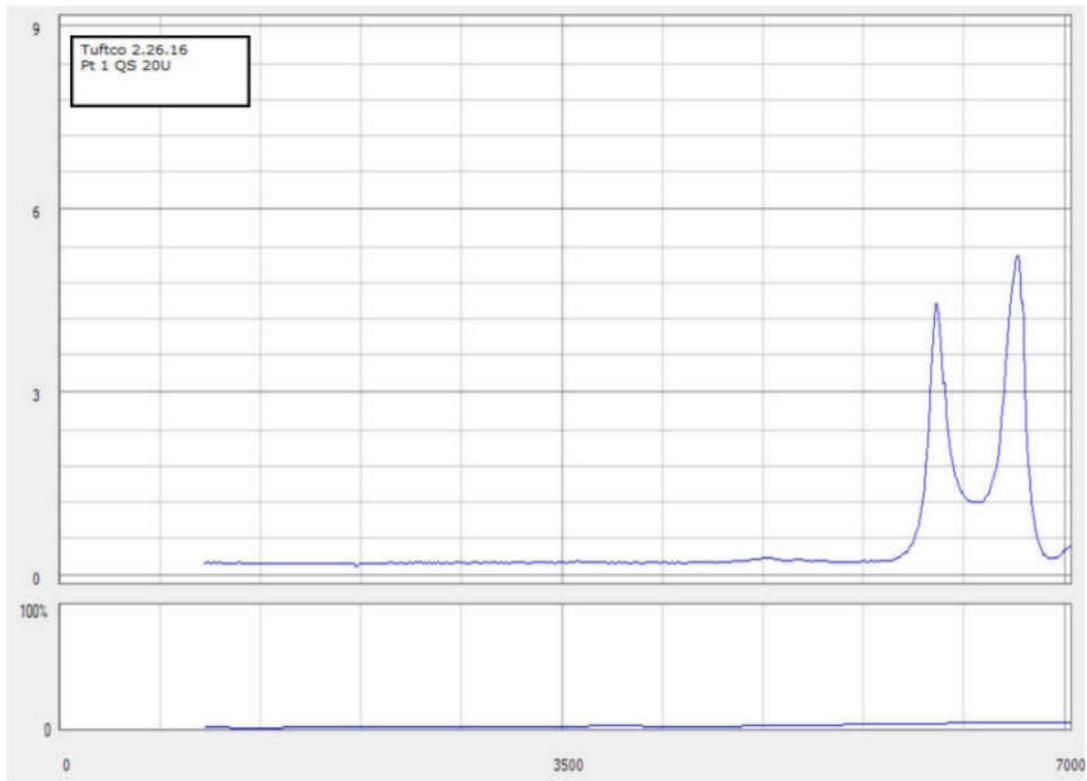


Figure 5: Quick Scan of frame, produced by employing PRINT function: A Quick Scan (QS) of the work-piece is done for calibration purposes. QS's use a scan rate of 50 RPM / second, and take less than two minutes to produce. Plots are done in blue.

VSR Treatment Charts, which include QS's, Pre- & Post-Treatment Scans, consist of two plots:

- An upper plot of work-piece acceleration and a lower plot of vibrator input power, both of these plotted on a vertical axis vs. a common horizontal axis of vibrator RPM. Upper plot has adjustable scale; lower is fixed with full-scale = 1.2 kW
- Peaks in the upper plot are resonances of the work-piece.
- Peaks in the lower plot are resonances that cause increased, perhaps excessive, vibrator input power. Excessive power is addressed by either lowering the vibrator unbalance, repositioning the vibrator, or a combination of both actions.

Full-scale for acceleration for this chart = 9 g's For RPM 7000 Unbalance = 20 %

Re-scaling of acceleration or RPM can be done without compromise of vibration data integrity.

VSR TREATMENT

Stress relief is done by tuning the vibrator upon peaks in the acceleration curve. If stress relief occurs, the peaks will grow and/or shift, and keep shifting until the treatment is completed. When the vibration data is stable, a Post-Treatment Scan is performed. The vibrator's speed can be adjusted in increments of 6 RPM.

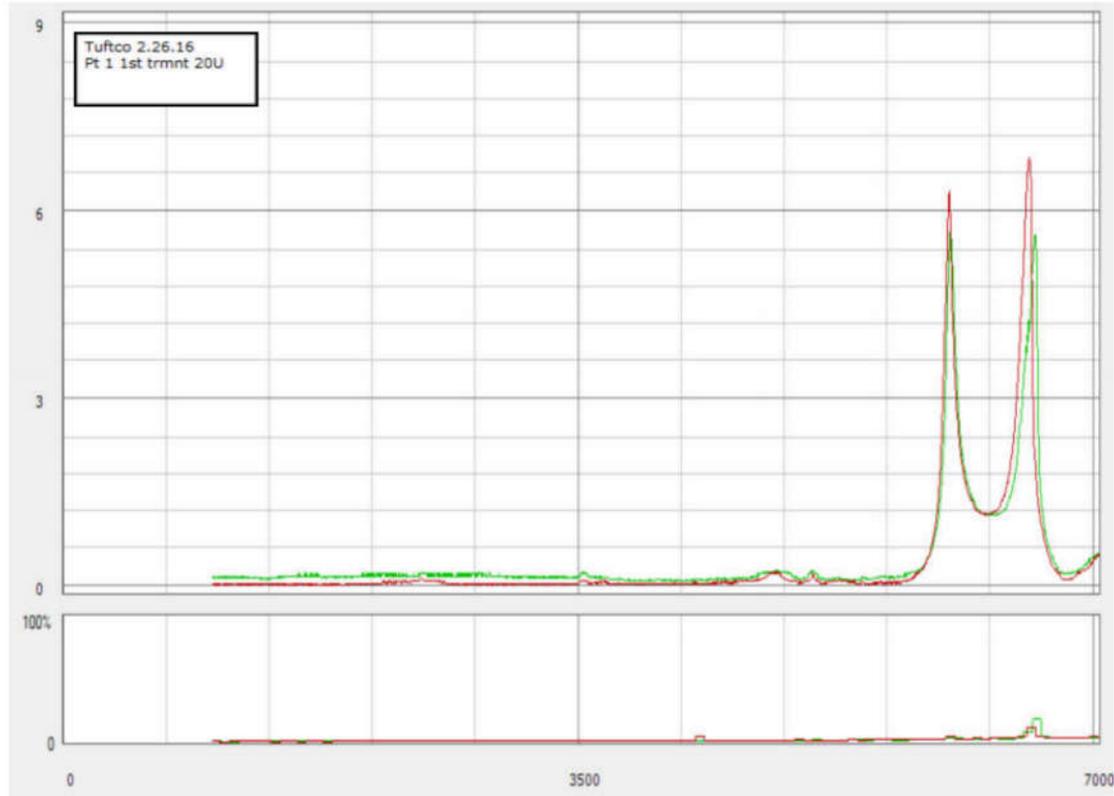


Figure 6: First of two VSR Treatments of Part 1, this one concentrating on high-frequency resonances on the 6 – 7 KRPM range. Green (since the part is “green”, like a green casting) is the Pre-Scan / baseline used to perform treatment, by tuning upon the peaks. As the peaks grew, with some shifting taking place also of the right-most peak, stress relieving occurred. After growth and shifting were completed, the red, Post-Treatment Scan was done.

A peak in the power curve coincide with one of the resonance peaks, but is modest, indicating a good setup has been achieved.

Full-scale for acceleration for this chart = 9 g's For RPM 7000 Unbalance = 20 %

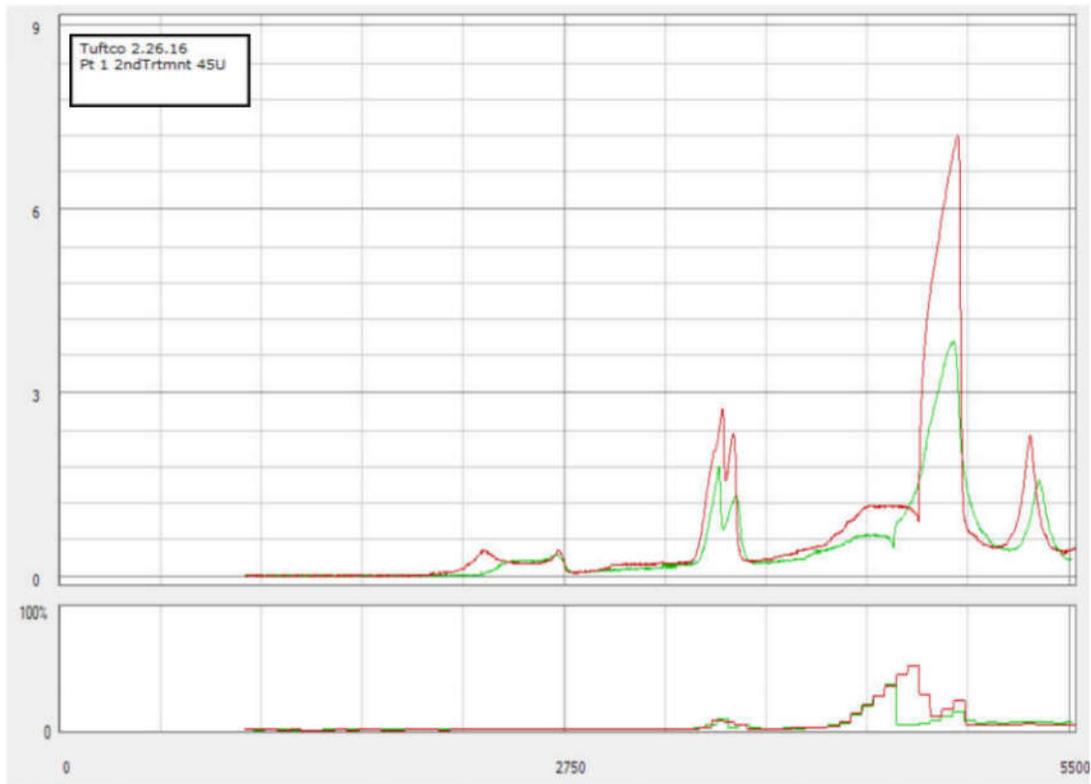


Figure 7: Second VSR Treatment used 45 % unbalance, more than twice that of the 1st treatment, this setting bringing out resonances that were too short to use previously. Again, green is the Pre-Scan data, whose peaks grew with some shifting occurring, the changes documented with the red, Post-Scan.

Peaks in the power curve coincide with the resonance peaks, and note that the power peak also grew in a similar way as the resonance peak. Although sizable, this peak did not cause excessive heating of the vibrator motor. (Large peaks in the power curve are the “red-flag” / warning to the operator to watch the motor winding temperature displayed on the VSR OS Main Screen's thermometer; see Fig. 4.)

Full-scale for acceleration for this chart = 9 g's For RPM 5500 Unbalance = 45 %



Figure 8: Workpiece # 2 / head structure was setup in a manner similar to # 1. An adapter plate was used to secure the vibrator using the bolt pattern in the cross-brace. Two treatments were performed, again a high-frequency range, with modest unbalance setting, and a low-frequency range treatment, with higher unbalance setting. This approach assures that all the available modes of vibration, and hence, flexure patterns, are treated.



Figure 9 shows back of head structure, with single cushion at the center. Again, this arrangement of 3 cushions positioned far from the corners of the workpiece allows the flexure to occur that is critical to achieving effective stress relief.

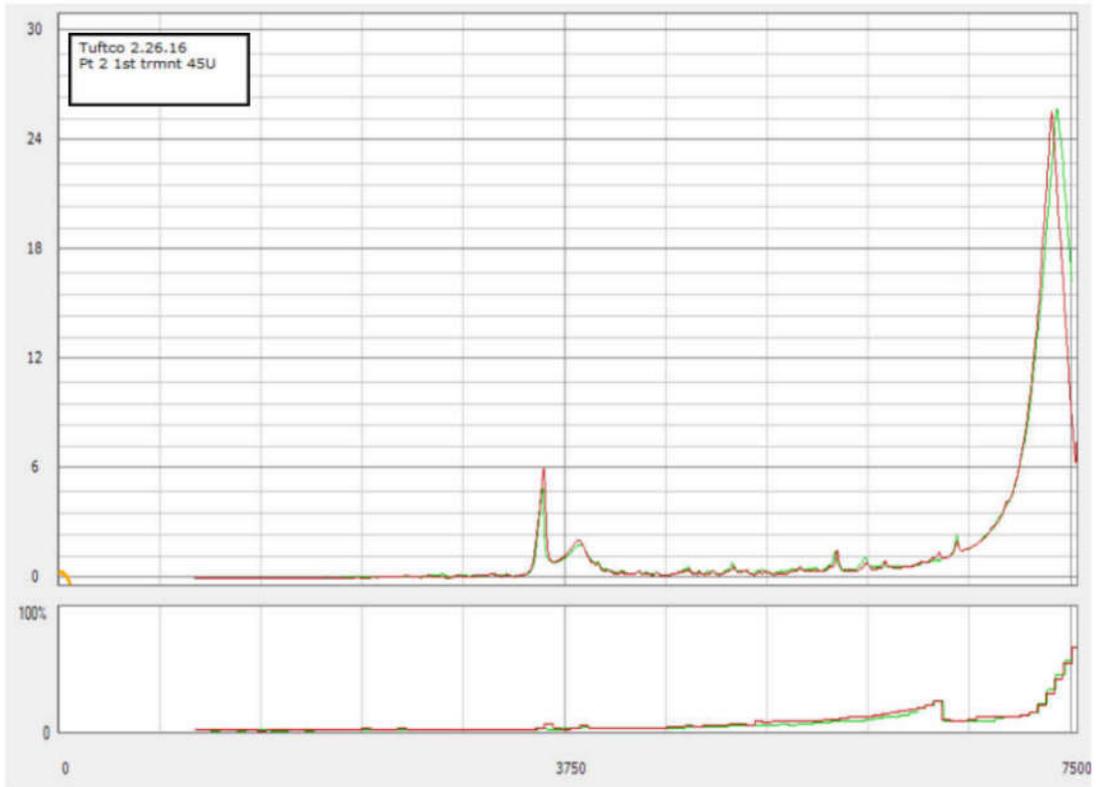


Figure 10: First VSR Treatment of Part # 2 was done at 45 % unbalance, with a top speed of 7500 RPM, which was sufficient to display a large (above 25 g's) peak near the end of the speed range. VSR Response was only shifting, and this modest.

Full-scale for acceleration for this chart = 9 g's For RPM 7500 Unbalance = 45 %

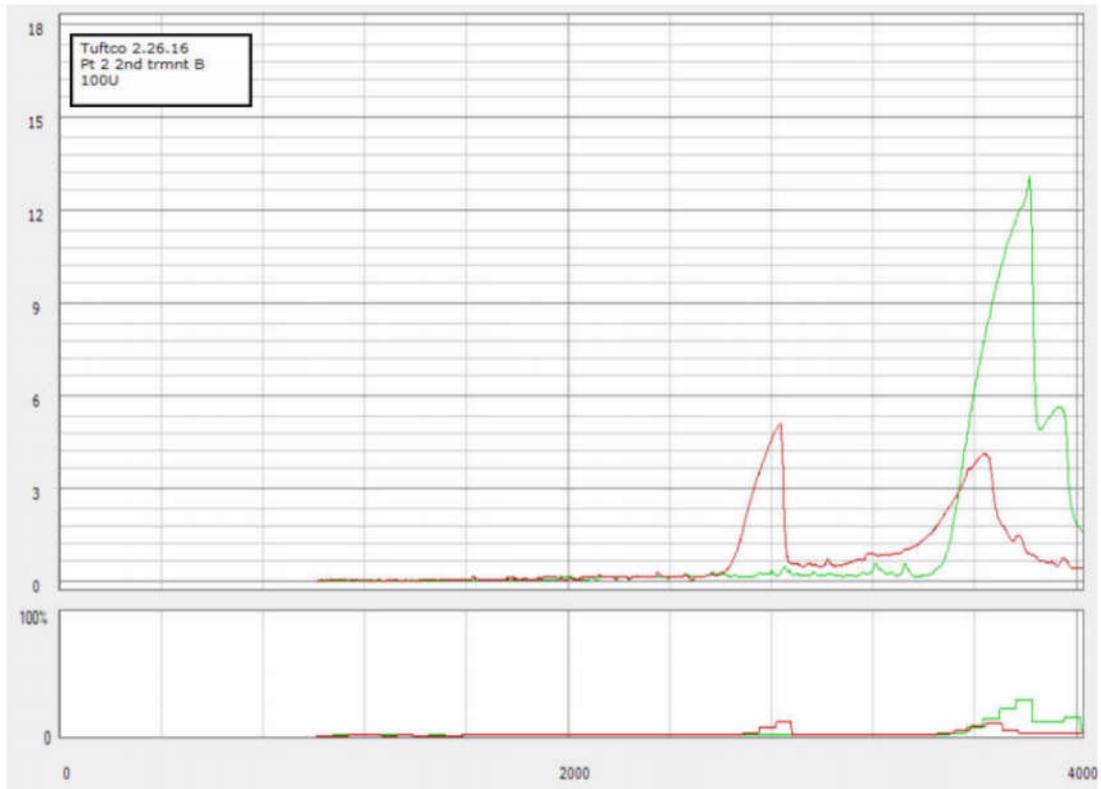


Figure 11: Second VSR Treatment of Part # 2 showed a somewhat unusual, very large shift of the resonances. Initially these resonances overlapped in position, but treatment caused them to both shift, the left-most one shifting ~ 900 RPM.

Full-scale for acceleration for this chart = 18 g's For RPM 4000 Unbalance = 100 %

CONCLUSION

Based upon the clear changes in resonance patterns, which included both resonance peak growth AND shifting, that took place during treatments of both parts, these structures should display good dimensional stability during subsequent machining, assembly and use.

UPDATE:

The machining results from the manufacturer of both workpieces is outlined on the following page. The marked improvement in dimensional accuracy / reduction in movement upon release was large enough to not only meet dimensional tolerances, but potentially could reduce the number of machining setups and machine time required.

Quoted directly from customer:

The results on the bedplate and head structure were positive.

Part A – 168" iTron Bedplate

Operation 1

Front rail moved .003" after machining

Rear rail moved .010" after machining

Operation 2

Front rail moved .001" after machining

Rear rail moved .008" after machining

Operation 3

Front rail held position after machining

Rear rail moved .006" after machining.

An untreated bedplate typically moves .030" to .060" after each operation. This improvement will allow us to make more aggressive passes for each operation. If we couple some work holding improvements and also slight changes to the VSR operation, we likely will see further improvement on the rear rail as well.

Part B – 165 Standard Head Weldment

Operation 1 and 2

Bottom of the head surface was within .003" flatness after first operation on that surface and full machining of the sides. Previously untreated heads would need .030" of cleanup.

The sides of the head were straight within .005". Previously, straightness was within .020".

This improvement will possibly allow us to reduce the number of setups from 3 to 2. We may be able to eliminate the finish pass on the bottom of the head that required the third setup. Additionally, we should be able to make more aggressive cuts when we get our more powerful milling center.