



VSR REPORT

INGERSOLL MILLING MACHINE is renowned not only for its ability to produce large milling machines, but also for the exceptional accuracy of the equipment produced. To date, INGERSOLL has produced milling machines capable of machining parts over 100 feet in length. Stress relieving their machines' components can be a challenge.

In November 2002, the VSR Process was used to stabilize a 59' long milling machine gantry. Stress relieving the Workpiece both before and after rough machining (total time < 4-hours) resulted in a dimensional accuracy of 0.0036" over the entire length, and only 0.0018" in the critical center portion of the component where spindle travel occurs. While awaiting final assembly, the dimensional stability of the gantry was periodically checked over a three-week period. As should be expected when using the vibratory stress relief method, dimensions remained accurate to 0.0008".

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In November, 2002, the VSR Technology Group of AIRMATIC INC. was chosen by INGERSOLL MILLING MACHINE to stabilize the dimensions of a Top Beam (a 59 ft gantry component). VSR's Vibratory Stress Relief process was utilized both before and after rough machining, so as to address two concerns about such a long part:

1. Welding stresses that could interfere with the rough machining results. If not effectively stress relieved before rough machining, long Workpieces regularly distort more than the remaining stock allowed for final machining.
2. Machining stresses, or stresses brought to the surface during rough machining, either of which can interfere with the accuracy of the final machined Workpiece.

The Top Beam Workpiece exhibited straightness of 0.004" over its full length after final machining. The dimensional stability was closely monitored for several weeks after machining; it held at 0.0008" over the full length.

More than 2,400 Lbs of material was machined away from the Workpiece to get it in its final form. Obviously, such dimensional accuracy and stability in such a Workpiece does not occur in such a part by accident; it can only be accomplished with suitable fabrication and machining methods – *and a highly effective stress relief process.*

The VSR Process was engineered to be *highly effective*. The key to its effectiveness is that its vibration treatment causes a permanent change in the Workpiece's acoustic spectrum. Such permanent changes take place if, and only if, the part undergoes plastic deformation, which occurs by combining the potential energy of the stresses, with the kinetic energy generated by the VSR Vibrator.

The form of vibration found to be most effective in generating kinetic energy is *resonance*. It is this resonant vibration that is able to multiply the force output of the vibrator to levels that can cause stress relief activity, i.e., plastic deformation. The plastic flow is absolutely required to depopulate and moderate the potential energy levels (locked inside highly stressed areas), that threaten the dimensional integrity of a precision component.

The VSR Process' resonant vibration is not only the most effective means of providing the force required to stress relieve, it is also key to the method which enables the VSR Process to be both monitored and documented.

One result of effective stress relief is a change in the rigidity of the Workpiece. If high levels of residual stress were present before a stress relief treatment, VSR Treatment will cause the Workpiece to become more compliant or limber. This "Inflated-k" effect can be observed when undertaking a cold straightening operation. Workpieces that contain high levels of stress require more force to straighten.

Those that have less stress, due perhaps to having been stress relieved, will be straightened more easily. This difference in rigidity not only manifests itself during straightening, but also in how it changes the resonance pattern of the Workpiece, which is typically in two ways: (1) higher amplitudes at the resonant peak(s); (2) lower resonance frequencies.

By resonating the Workpiece and monitoring the resonance condition, effective stress relieving can be both detected (which verifies correct set-up), and monitored in real-time. This provides the answer to the critical question, "*How long do you vibrate?*"; answer: "*Vibrate the Workpiece as long as the resonance is changing, because the changes in resonance are evidence of stress relieving.*"

The changes in resonance pattern do not go on forever; eventually the changes become slower and more subtle. The result is a stable resonance pattern. It should be noted that two forms of stability are closely associated (in fact, they track or mirror each other): the stability of the Workpieces resonance pattern, and its dimensional stability. The VSR Process has demonstrated innumerable times, that each time a Workpiece undergoes the resonance pattern change (resulting in stability), that both forms of stability (dimensional and resonance pattern), go hand-in-hand.

VSR SET-UP

A correct set-up for VSR Treatment involves allowing the Workpiece to resonate fully. Resonance of large metal structures come in two basic forms: bend and torsional (twisting). Isolation of the Workpiece - using strategically placed rubber cushions - will enable both forms of resonance to occur. The cushions must be positioned away from the corners or ends of the Workpiece so as to not dampen the resonance effect.

For this Workpiece, proper cushion placement was at 4 points, 1/3rd in from each end, along both sides (*See page 5, Photo 1*).

The vibrator was located above one of the cushions, and oriented so that its axis of rotation was parallel to the length of the Workpiece (*See page 6, Photo 4*). The vibrator's output is principally radial, and the workplace is least likely to resonate lengthwise. The vibrator's unbalance (adjustable over a 20:1 range) was set to minimum, to determine the responsiveness of the Workpiece. The unbalance was later increased to 20% of maximum, which allowed the Workpiece to display two significant resonance peaks, both several G's tall. Whether this was sufficient to cause the classic changes in resonance patterns common to the VSR Process is not known until dwell-time upon the resonance peak is done.

An accelerometer (a sensor device whose output is proportional to acceleration), was placed at the end of the Workpiece, and oriented for maximum sensitivity to motion – perpendicular to the Top Beam's length, and horizontal in direction (*See page 6, Photo 3*). Acceleration, rather than deflection or velocity, is used since levels of force cause the VSR Process to work, and acceleration is proportional to force ($F = ma$).

FIRST SCAN

The VSR System utilizes an automatic scanner, and an XY-plotter. The system generates high resolution charts which accurately display both the vibrator speeds (X) where resonance occurs, and the height of the resonance peak (Y) in G's. The first scan is done in green ink (See Chart on page 9).

VSR TREATMENT

Using the data from the first scan, the vibrator was initially tuned to the peak with the greatest height, which was slightly more than 10 G's. Maintaining dwell-time upon the peak required frequent reduction of the vibrator's speed, initially at the rate of 3 times-a-minute. After 5-minutes the need to re-tune vibrator speed decreased to once every 3-minutes. This trend continued, taking 30-minutes to fully stabilize. At the same time, the peak was growing (it is not unusual for peaks to grow *and* shift), increasing to slightly more than 12 G's.

After the first peak was treated, the shorter (lower) frequency peak was addressed. It had already shifted significantly as a result of treatment of the first peak. Twenty minutes of dwell-time upon this peak resulted in further growth of about 15%, during which time the plotter's pen dropped several times, as it traced the progress of the peak throughout the time that it grew and stabilized. (Note the green "Progress" dots above peak on the Chart shown on page 7).

POST TREATMENT SCAN

At this point the operator changed the green pen to a red pen, and a new resonance pattern scan was recorded. Although it was similar, it had changed due to the stress relief.

The Workpiece was then rough machined over the course of the next 24-hours.

SECOND TREATMENT

A second Treatment was done to the Workpiece after rough machining. The set-up and treatment procedure were identical to the first, except for a reduction of the vibrator unbalance to 15% of maximum, because a Workpiece is generally more responsive to vibration, after stock is removed during rough machining (*See Chart on page 8*).

FINAL MACHINING

After completion of the final machining, the part moved only slightly (0.0036") when released. The result was almost identical to the Total-Indicated-Runout displayed during INGERSOLL's laser scan testing over the course of the next several weeks. There were no further changes in shape after the final machining (other than the expected response to temperature variations) (*See Dimensional Charts pages 9 & 10*).

CONCLUSION

Results such as these confirm the effectiveness of the VSR Process. Moreover, since two VSR Treatments on such a Workpiece cost considerably less money than one thermal treatment (just transport to the nearest furnace capable of holding the 59' Top Beam would have been several thousand dollars), and took a fraction of the time that a furnace would have required – the total savings were significant. The benefits provided by the VSR Process are undeniable.

1. Improved stability, and predictability of parts during each machining cycle.
2. Reduced handling of Workpiece; VSR Treatment takes place *on the shop floor*.
3. Decreased time required to stress relieve a Workpiece; typical treatment time is 2-hours, including set-up and knock-down.
4. Documentation of the effectiveness of the stress relief. The VSR treatment chart shows the actual response of the part, *not just* the conditions it was subjected to (which is the method provided by thermal treatment's "temperature vs. time" chart, which is not a guarantee of stability).
5. Elimination of sandblasting to remove furnace scale.

While priority of the benefits will change with the Workpieces treated, the conclusion is undeniable - manufacturers of large, precision metal components should include VSR Technology's Vibratory Stress Relieve Process.

Photos & Charts

Page 5	Photo of Top Beam, showing overall view.
Page 6	Photos of Vibrator, Accelerometer, and Cushion.
Page 7	VSR Treatment Chart, 1 st Treatment, As Welded.
Page 8	VSR Treatment Chart, 2 nd Treatment, After Rough Machining.
Page 9	Lower Way Dimensional Chart, courtesy INGERSOLL MILLING MACHINE.
Page 10	Upper Way Dimensional Chart, courtesy INGERSOLL MILLING MACHINE.
Page 11	Photo of Top Beam set on columns.

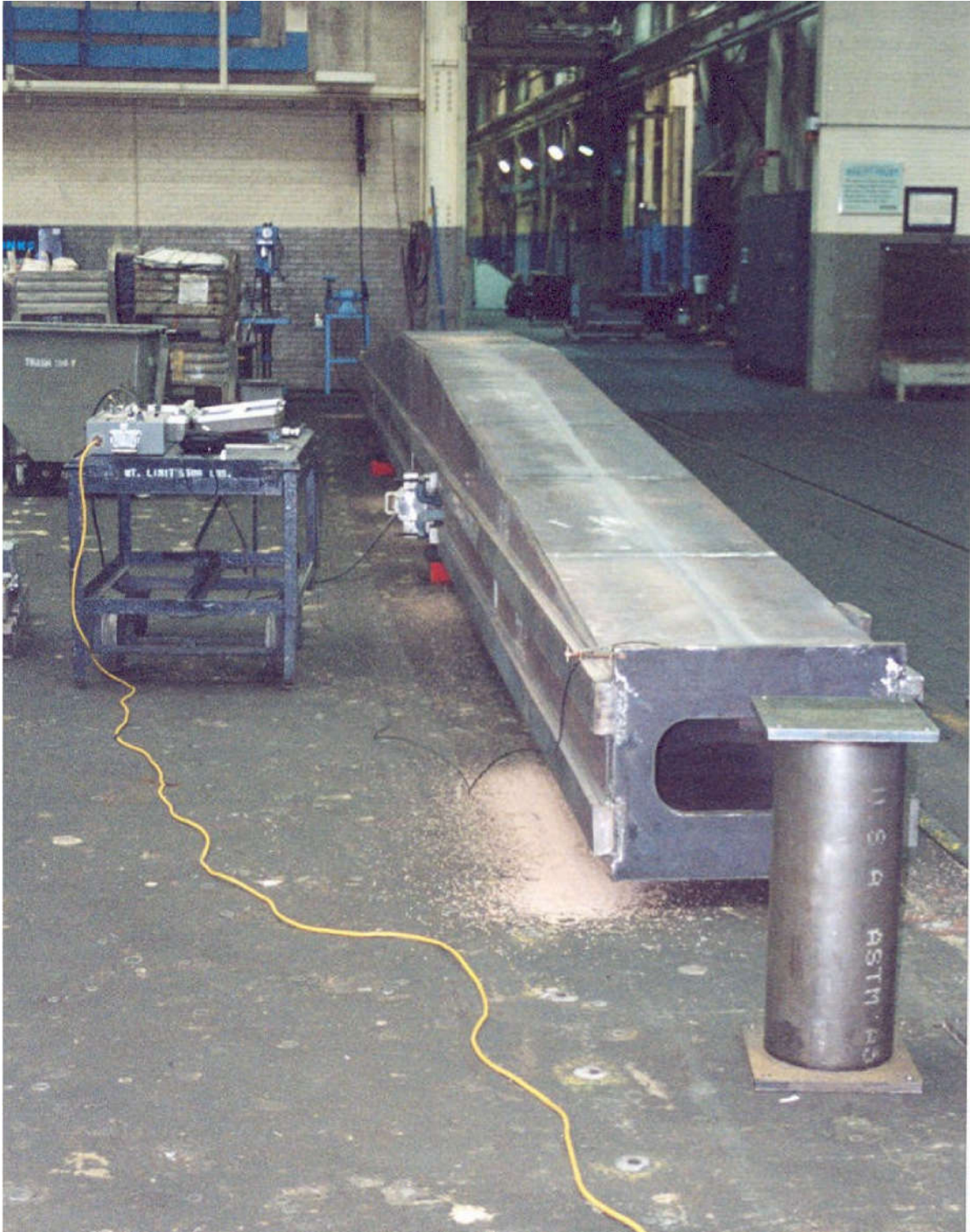


Photo 1: VSR Setup shows 18 m long gantry setup for stress relief treatment. Note the isolation cushions (orange), which are located ~ 30% of the length from each end, matching two on the other side. Sensor is on left near corner, oriented to best detect sideways amplitudes.



Photo #2

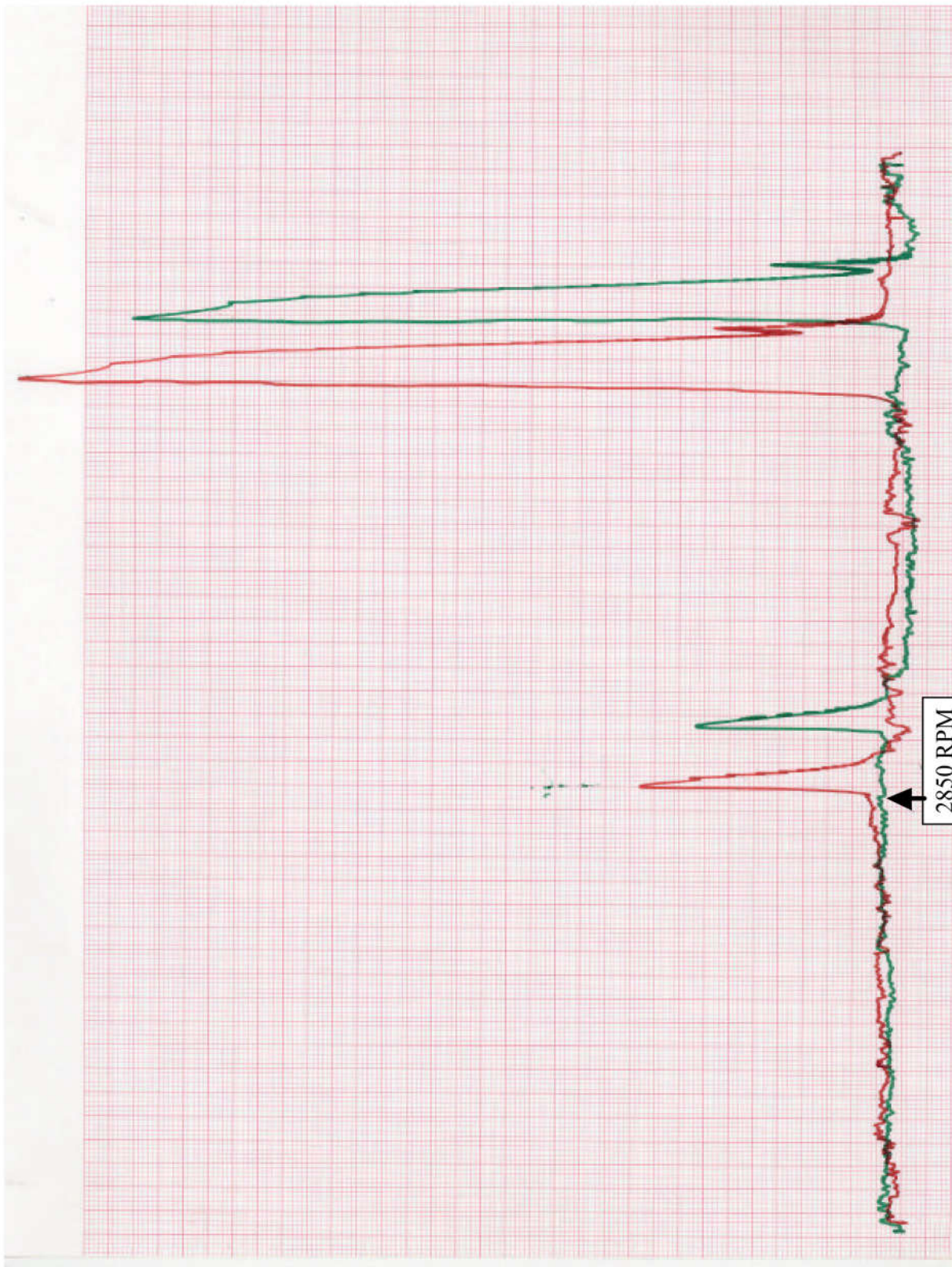


Photo #3

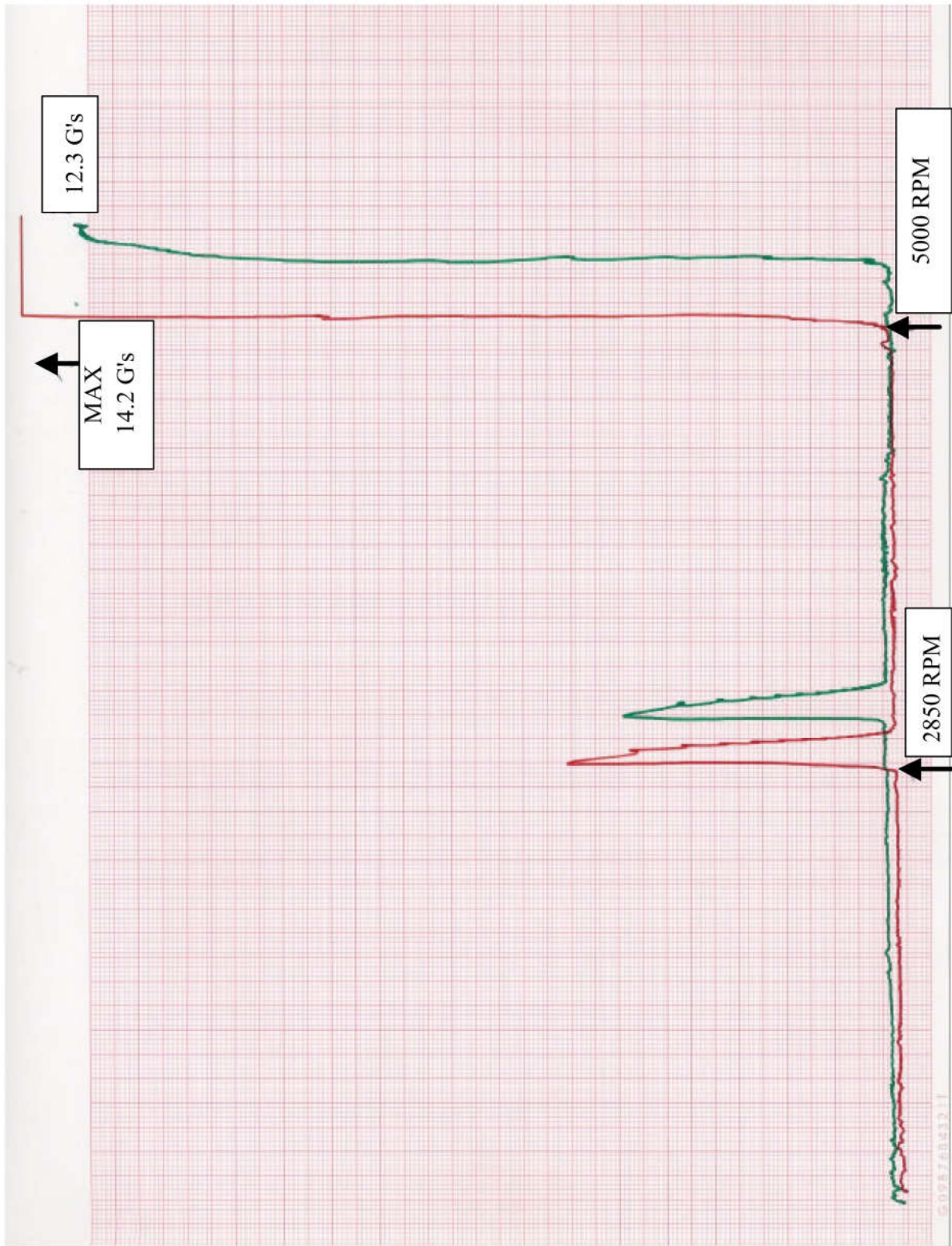


Photo #4

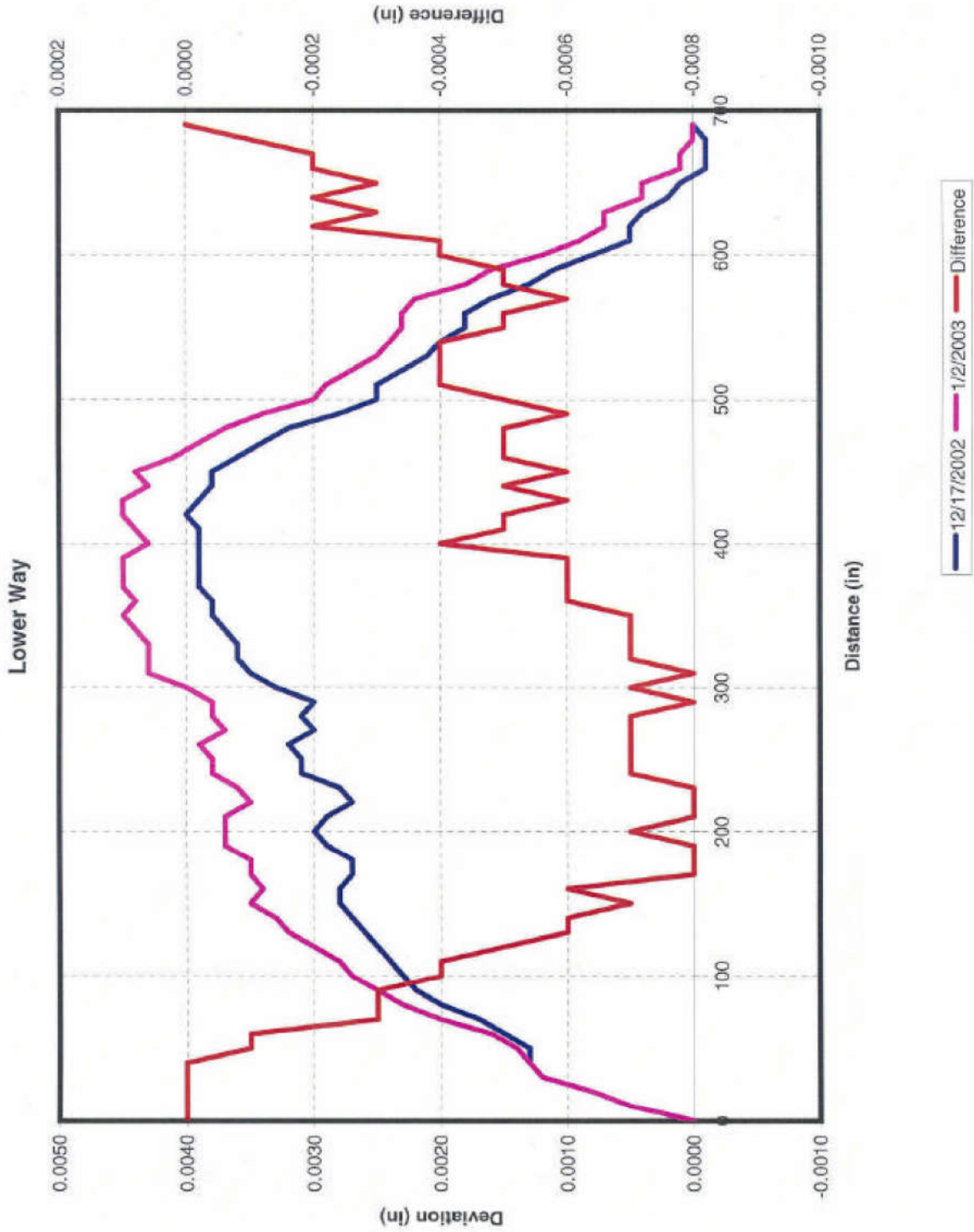
Photo 2 shows stack of cushions, used to gain full clearance of workpiece from floor. Photo 3 shows closeup of accelerometer (acceleration sensor), while Photo 3 shows the vibrator. Note vibrator orientation aligned with workpiece length.



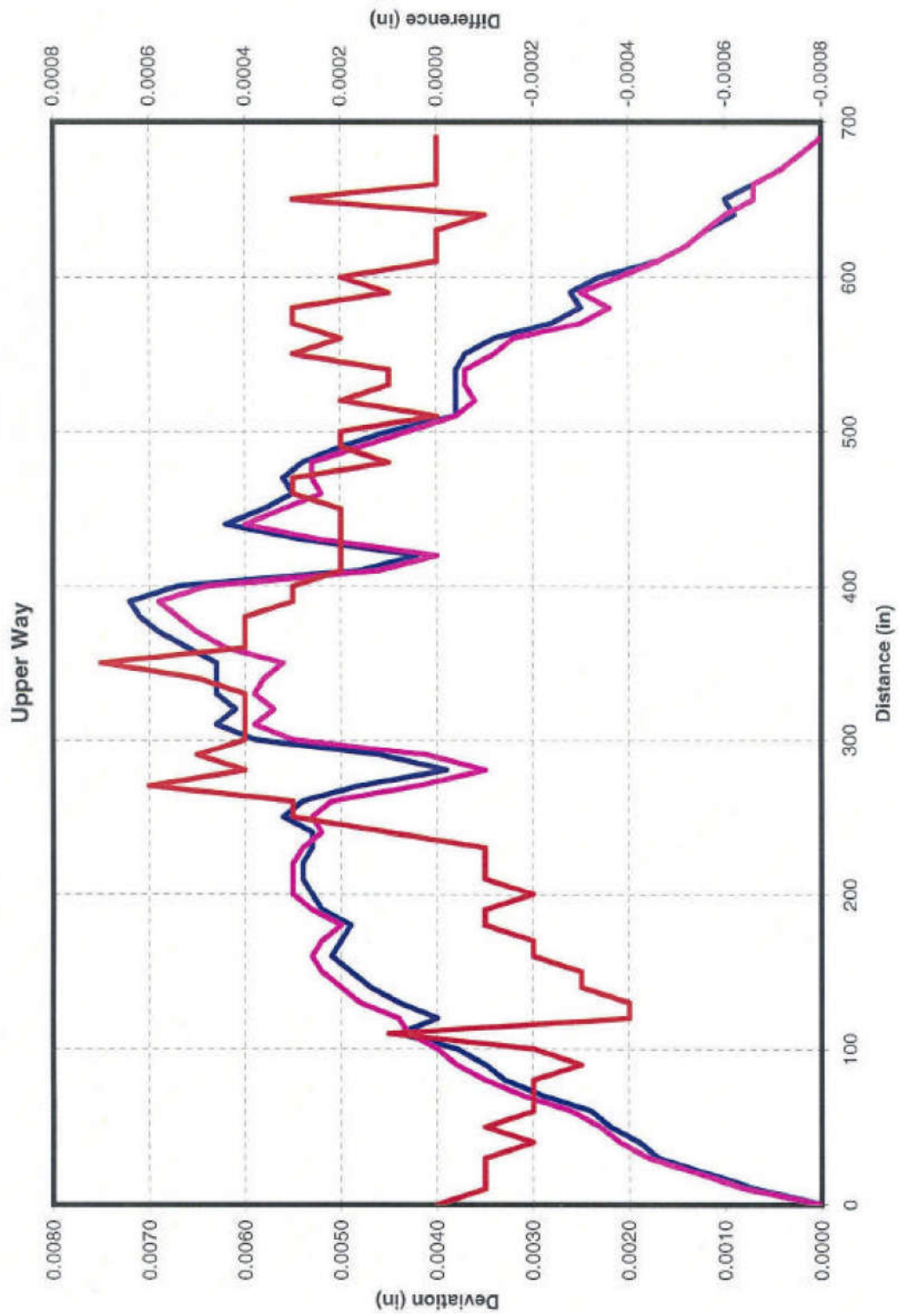
VSR Treatment of gantry as-welded. Top of acc scale ~ 12 g's. Green = B4, red after VSR Treatment.



VSR Treatment after rough machining shows additional response. Top of acc scale ~ 12.5 g's.



Dimensional inspection report of lower way of gantry from Ingersoll shows an envelope of 0.004 inch of total run-out over 700 inches, with variations over a 2 week time period of 0.0008 inch.



Inspection report of upper way of gantry from Ingersoll shows an envelope of 0.008 inch over a 700 inch length, while variations over a two week period were less than 0.0002 inch.



During the four months of production and assembly of the machine, and again after attachment to the 40' tall columns, the Top Beam was monitored. It consistently exhibited its excellent dimensional accuracy of 0.004" TIR. Using the VSR Process enabled INGERSOLL to avoid the time and expense – and compromise of quality – that would have occurred if:

1. the Top Beam had been shipped several hundred miles to a furnace of sufficient size for the Workpiece, *or...*
2. a temporary furnace had to be built around the Top Beam, *or...*
3. the Top Beam had been thermally stress relieved in two, or three sections, which would have required bricking around the portion(s) that extend beyond the furnace, *or...*
4. the Top Beam had been designed as two pieces (*i.e.*, a bolted assembly), which would have been not only more complex and expensive, but also would not have allowed the long term accuracy and life expectancy that INGERSOLL requires of its products.

The VSR Process was a key component in helping INGERSOLL achieve its project goals.