SAME REPAIR AGAIN?
"Fix It For Good" **With Meta-Lax**

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Many metal components experience continual cracking despite numerous attempts to correct the problem. Cracking could occur immediately after welding, shortly after being put into service, as a frequent repair to the same weld area, or simply not lasting as long as the design capability of the component.

SOURCE OF CRACKING IDENTIFIED

A major source that contributes to cracking is residual stress. Residual stress is an internal pressure that is retained following thermal or mechanical straining (1). Thermal stress is caused by a thermal shock (rapid cooling) on the metal such as welding, casting, machining, and hardening. Mechanical stress is caused by forcibly changing the shape of the grains such as cold rolling, bending, and stamping.

Thermal stress leads to three types of problems:

1. Premature Cracking
2. Distortion immediately following machining
3. Delayed Distortion

Mechanical stress, not thermal stress, can be fairly easily calculated and tested. So distortion and fatigue failures tend to be more predictable than for thermal stress and can usually be accounted for in the component's design.

Reducing thermal stress, therefore, would be most beneficial to the performance of the workpiece. That's why stress relieving is very important.

To reduce and eliminate cracking problems the weldment can be relieved of thermal stress by either thermal or mechanical means (2). In the past, the common method of stress relief has been by heat treating. But heat treat stress relief, although effective, has many drawbacks including time, expense, treatment distortion, surface oxidation, changing mechanical properties, and limitations on size and weight.

Other stress relief methods have not been widely used for obvious reasons; natural aging takes too long, cryogenics is too expensive and limited in size, stretch and compression both require simple shaped parts. This leaves vibration. Vibration stress relief does not have any of the above limitations.

Caution: When considering using vibration for stress relief, note that like heat, many different energy levels are possible but only a small range will generate *consistently* effective stress relief results.

The focus of this report will be addressing cracking by using the optimum *SUB-harmonic* vibrations. Sub-harmonic vibrations can be used in two ways - as a stress relief process and during welding as a weld conditioning process.

SUB-HARMONIC VIBRATIONAL TECHNOLOGY

Sub-harmonic vibrational technology is a development of **Bonal Technologies, Inc.**, Southfield, Michigan, from their own planermill machine shop (see Figure 1).

The process, which is frequently called "*Meta-Lax*" (TM), was developed as a replacement to thermal stress relief. **The success criteria for this process was that sub-harmonic treated parts had to meet or exceed the performance of identical parts that were stress relieved using heat.**

The process has two fundamental principles:

1. Sub-harmonic energy must be used for the stress relieving frequency
2. The harmonic curve of a thermally stressed part will shift and stabilize to a new frequency location as the weldment becomes relaxed of thermal stress.

Furthermore, Bonal discovered that this same process can be used during welding to produce a very crack-resistant weld and reduce weld distortion.

WHEN TO APPLY SUB-HARMONIC VIBRATIONS

Fabricators and maintenance shops apply sub-harmonic energy one or more times during manufacturing, including:

1. During welding
2. After fabrication (before rough machining or being put into service if not machined)
3. Between rough and finish machining if very close tolerances are desired
4. On finished machined and even on assembled components before use
5. Periodically during its life if heating and cooling are involved

In addressing weld cracking the *stress relief* treatment will reduce *premature* cracking. Premature cracking is any cracking that occurs at a level that is less than the design capacity of the weldment.

Since there are no negative side affects associated with Sub-harmonic processing, even on finished parts, its application should be considered prior to most anticipated cracking and distortion problems.

The fact that sub-harmonic stress relieving does NOT appreciably change the mechanical properties of the treated workpiece is a very important factor. When a weldment is heat treat stress relieved it is common to have a sacrifice of 10-35% of the strength of the metal. In comparison, using Sub-harmonic stress relief in place of heat is to give those weldments at least a 10-35% strength advantage.

Caution: When Sub-harmonic energy is applied for stress relief expect to achieve only *stress relief* benefits and not *heat* related charges like altering mechanical properties and straightening distorted parts. If softening or straightening are desired then heat <u>must</u> be used.

Caution: Severely mechanically stressed parts do not represent good stress relief applications for this process.

If the metal component has more severe of a cracking problem (e.g. cracking upon cooldown or the usable strength is a fraction of the design strength) then it is recommended to use Sub-harmonic processing *during welding*. This is called "*Sub-harmonic weld conditioning*." Sub-harmonic weld conditioning results in a crack resistant and distortion resistant weld area and will continue throughout the service life of the weldment.

PRINCIPLE #1: SUB-HARMONIC ZONE

Metal components will exhibit a harmonic reaction to induced energy (see Figure 2). The harmonic curve occurs when the excited component cannot dissipate any more energy from the force inducer and responds with an out-of-proportion amplitude movement.

Bonal discovered that at and near the leading edge of the harmonic curve is the optimum frequency for using vibrational energy for stress relief. The harmonic curve clearly establishes the *Sub-harmonic* zone. The Sub-harmonic zone is the leading lowest 1/3 portion of the harmonic curve.

In 1987, Richard Skinner, PE, from Lockheed Missiles and Aerospace, mathematically proved that when using vibrations to achieve stress relief, a slightly lower frequency than the harmonic peak frequency must be used (3).

Caution: The Sub-harmonic processing is in sharp contrast to other vibration techniques which attempt to stress relieve at the "peak." Using the peak as the stress relief energy level may damage the structure and almost always leads to inconsistent results (4).

In stress relieving the workpiece using vibrations, the operator must scan the workpiece to identify the harmonic peak frequency and then set the stress relieving frequency in the sub-harmonic zone. The time for dwell at this frequency will generally vary between 15 to 30 minutes depending on the weight and material of the workpiece.

PRINCIPLE #2: SHIFTING

All metal components have a *natural* harmonic peak. If, however, the part has been subjected to thermal shock (causing residual stress) during manufacturing the harmonic peak will be in an unnatural frequency location. By applying sub-harmonic vibrations the component will neutralize the thermal stress. In doing so, the harmonic peak will shift and stabilize in a new frequency location. This would be its *natural* harmonic frequency.

An analogy would be like having a musical instrument out of tune (thermally stressed). As it comes in tune the true natural note is heard (stress relieved).

Bonal discovered this phenomenon immediately after Principle #1 was applied. Once the harmonic curve settled into a new frequency location then stress relief benefits were realized on a consistent basis.

Professors T.E. Wong and G.C. Johnson at the University of California - Berkeley issued a report in 1987 in which they mathematically demonstrated that the harmonic curve shifting due to residual stress can be used to verify relief of stresses (5).

As the harmonic curve shifts, the operator will take scans periodically. After each shift the operator will reset the stress relieving frequency in the new Sub-harmonic zone and dwell at that new frequency for 5 to 10 additional minutes. Eventually there will be no more shifting. One scan will repeat the previous scan. When this occurs, stress relief is complete for that force inducer location. If the weldment is large (greater than 15-feet) one or more additional force inducer placements will be needed to assure overall stress relief throughout the entire weldment.

SUB-HARMONIC WELD CONDITIONING

When the Sub-harmonic stress relief process is applied *during welding* (hence *sub-harmonic weld conditioning*) generally a weld grain refinement results. This translates into several benefits:

1. Less weld cracking
2. Longer fatigue life
3. Less weld distortion
4. Less porosity

Other observations of Sub-harmonic weld conditioning include deeper weld penetration, less undercutting and porosity, smoother weld bead, easier control of the weld puddle in all positions, and less spatter.

The U.S. Department of Energy sponsored a study in 1989 investigating Sub-harmonic processing in comparison to heat treat stress relief and control specimens. Sub-harmonic processing was applied in both ways - as a stress relief and during welding as a weld conditioning process. The report concluded "there is evidence that the Meta-Lax [Sub-harmonic] system is performing comparable to the thermal stress relief process on A-36 carbon steel (6)." See summary table on the following page as published in DOE's own Tech Brief about their findings (7).

Generally when metal is welded, the weld area and heat affected zone tend to be susceptible to cracking. Yet when Sub-harmonic weld conditioning is added to the welding procedure the fatigue life of the entire weldment is greatly extended. This is due to three reasons:

1. Finer weld grain. This tends to make the weld metal more crack resistant than non-treated weld metal (see Figures 3 and 4).
2. Less residual stress in the heat affected zone. The rate of solidification is slowed down allowing the weld metal to solidify more evenly from the root to the face. This translates into less distortion which means less residual stress in the HAZ. Therefore the HAZ will be crack resistant compared to a non-weld-conditioned HAZ.
3. Stress relief of base material. The base material is stress relieved while the welding is going on. This enables the base material to resist premature cracking.

In applying Sub-harmonic vibrational energy during welding, three steps are recommended:

1. Pre-weld stress relief for about 1/2-2/3 the time it would normally take for a full stress relief treatment.
2. Weld Condition - reset frequency to foot of harmonic curve until welding is complete
3. Post-weld cooldown until the last area welded is less than 200^{o} F.

Table 1: Data Summary from DE-FG01-89CE15412 Report

A-36 Low Carbon Steel After 30 Days Restraint	**As Welded**	**Meta-Lax During Welding**	**Meta-Lax After Welding**	**Thermal Stress Relief**
Tensile Strength (psi)	77,250	76,450	76,750	66,750
Charpy-Weld (ft-lbs)	36.3	37.2	31.7	21.5
Charpy-HAZ (ft-lbs)	6.4	11.2	12	14.1

FIELD RESULTS

National Steel, Great Lakes Steel Division, historically has had cracking problems with their front-end loader buckets (see Figure 5). The abrasion resistant T-1 edges which are welded to low carbon steel buckets would last less than two months in service before severe cracking would develop. Despite using a 450^{o} - 500^{o} F preheat, a detailed cleaning approach, and a welding engineer's recommended weld sequence severe cracking persisted.

In 1991 Great Lakes Steel began using Sub-harmonic stress relief *during* every weld repair of the loader buckets. According to Marian Pittman, Weld Shop Foreman, "We hardly see anymore cracking in the weld area now. The edges actually wear out before breaking off. And they're lasting over 10 months in service." They have been able to increase the size of the edge from 5-inches to 8-inches. This allows the loader buckets to exceed 14 months in service without coming in for a new edge.

Mr. Pittman also observed another change from using the Sub-harmonic weld conditioning process. "We are now using 125^{o} - 200^{o} F preheat. This is easily done with a rosebud torch just before welding. We also see less distortion following welding."

Great lakes Steel doesn't use Sub-harmonic weld conditioning on everything. Several weldments receive Sub-harmonic stress relief after welding. The "vessel ring," for example, is a approximately 12-foot diameter welded ring which is mounted at the lip of a furnace and is used to protect castings from spillage (see Figure 6). It is stress relieved to reduce premature cracking. Mr. Pittman noted that "In the past, these vessel rings would always curl due to extreme heat. We had to burn them out when we wanted to replace them. Now after we started Meta-Lax stress relieving them the vessel rings stay flat at the higher temperatures and remain flat even up to the time they need replacing."

Build-A-Mold, Ltd., Oldcastle, Ontario, Canada, was experiencing severe cracking upon weld cooldown in manufacturing a 10,000 lb. platen for a plastic injection mold press (see Figure 7). Horst Schmidt decided to use Meta-Lax weld conditioning. He recalls, "We had welds without cracking within the first 15 minutes! By applying Sub-harmonic vibrations to the platen during welding the welder would weld anywhere he wanted. We could actually see improvement in the way the weld flowed, even in tight areas." Mr. Schmidt sums up his experience with Meta-Lax by stating "We were very successful in achieving weld quality improvement with Meta-Lax."

CONCLUSION

In the past, stress relieving processes like natural aging and heat treating were used to effectively stress relieve metal welded components. Now Meta-Lax Sub-harmonic vibrational energy has proven to be fast, economical, and as effective as the earlier processes. In addition to stress relief benefits, the Sub-harmonic process can be used during welding to produce a very crack resistant and distortion resistant weld. The Sub-harmonic process has been verified in a laboratory, mathematically by professional engineers, and in field applications in facilities like National Steel and Build-A-Mold.

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