SUCCESSFUL STRESS RELIEF OF MOLDS USING SUB-HARMONIC ENERGY

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Beauty is only skin deep applies to molds too! The quality of the mold lies mostly beneath the surface. In fact, quality, which reflects itself in performance, can vary greatly even between two supposedly identically prepared molds. Quality will affect machine stability, long-term shape stabilization, and the mold's resistancy to cracking in service.

Figure 1. Minco Tool and Mold, Dayton, OH, has an 'on time every time' delivery policy. Sub-harmonic stress relieving plays an important part of this commitment in limiting stress relief to two hours. In doing so, they also realized elimination of most costs associated with heat treat stress relief and yet they maintain their high standard of quality.

MAJOR SOURCE OF INCONSISTENCY IDENTIFIED

Mold quality can be affected by several factors - chemical composition, heat treatment, speeds and feeds of cuts, sharpness of cutters, and such. Perhaps the most significant factor that affects the consistency of mold performance is *residual stress*.

Residual stress is an internal pressure that is retained following thermal or mechanical straining (1). *Thermal stress* is caused by a sharp temperature drop on a metal part such as welding, casting, hot rolling, machining, grinding, EDM machining, and hardening. The sharper the temperature drop, the more intense the pressure will be. *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. distortion immediately following machining or grinding
2. delayed distortion
3. premature cracking

Mechanical stress can easily be calculated. Accurate distortion and fatigue limits from mechanically stressed components can be accommodated for in the component's design to set and predict reasonable operating capacity. Not so with thermally stressed components. Thermal stress is extremely difficult to calculate and is not widely understood by most engineers.

Thermal stress can vary in strength from a negligible amount to an amount that is equal to the material's yield strength. Therefore reducing *thermal stress* becomes the key to achieving and maintaining consistently high quality in molds.

Figure 2. Build-A-Mold, Ontario, Canada, has used sub-harmonic vibrations for stress relief since 1986. They have noticed that their production is smoother and their customers have noticed the service life of their molds have improved, sometimes up to double.

THREE OPTIONS IN DEALING WITH THERMAL STRESS

1. *Ignore it* and suffer the consequences. Consequences include such things as allowing more stock to remove, taking more cuts across surfaces, higher scrap rate, more frequent and extensive repairs, and early replacement of the mold. This approach is risky since it could lead to more machining time, extra costs, wasted raw materials, and dissatisfied customers.

2. *Minimize any thermal shock* on the mold block, if possible. Examine every manufacturing step along the way. Wherever a sharp temperature drop occurs insist on a slower cooling rate unless the cooling rate is necessary for mechanical properties enhancement. For example, if a billet of mold steel is set on the ground to cool off, request that it be separated from the ground even slightly. Or better yet, have it wrapped in an insulated blanket during cooldown.

3. *Stress relieve* the mold block by using one of several different methods. Thermal stress can be reduced using thermal or mechanical means (2). In the past, the common method of stress relief has been by using heat. 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 very limited in size. Stretch and compression require simple shaped parts. And finally, vibration, which, although it has none of these limitations, has witnessed industry's reception varying between being very receptive to being very skeptical and resistant.

CAUTION: Just as heat has many different energy levels to accomplish certain goals, vibrational energy can be varied with a dramatic impact on the effectiveness and consistency of the process.

THE SUB-HARMONIC ALTERNATIVE

The potential benefits of time and cost savings and quality improvement that vibration stress relief could provide to the mold industry are enormous but only if the process is successful on a consistent basis (see Figures 1 and 2). One vibration stress relief process that has experienced consistently successful results in the metalworking industry uses what is called *sub-harmonic* technology.

Sub-harmonic vibration technology was developed by Bonal Technologies in its own planermill machine shop after first experiencing inconsistent results when using the former *resonant* vibration approach. The developers of this process, which is frequently referred to as *Meta-Lax* (TM), required parts treated by vibration had to meet or exceed the performance of parts that were heat treat stress relieved. In discovering the key principles behind using vibrational energy to generate successful stress relief results, the former theories of using vibrations had to be discarded and an advanced procedure developed.

The sub-harmonic vibration stress relief process has two fundamental principles:
1. <u>Sub</u>-harmonic energy must be used for the stress relief dwell frequency; and
2. The harmonic curve of a thermally stressed metal part <u>will shift and stabilize</u> to a new frequency location as the workpiece becomes relieved of thermal stress.

PRINCIPLE #1 - SUB-HARMONIC ENERGY

Metal components exhibit a harmonic reaction to induced energy (Figure 3). The harmonic curve occurs when the vibrated component cannot dissipate any more energy from the force inducer and responds with an out-of-portion amplitude movement. *At and near* the leading edge of the harmonic curve (i.e. *sub-harmonic* zone) is the optimum frequency for using vibrational energy for stress relief. The significance of finding the harmonic curve clearly establishes where the sub-harmonic zone is. The sub-harmonic zone is defined as the leading lowest 1/3 portion of the harmonic curve for low strength metals and 1/3 to 1/2 for high strength and exotic metals.

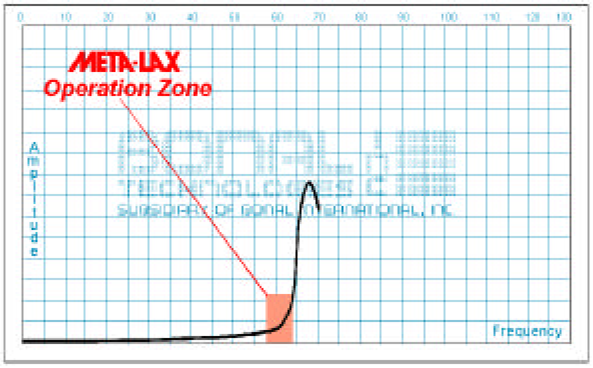

Figure 3. The optimum zone for stress relieving using vibrations is in the sub-harmonic zone.

In 1987, Richard Skinner, a professional engineer at 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). Mr. Skinner verified this theory on eight different metals.

CAUTION: Former vibration methods operated AT the highest amplitude peak (resonance) that the workpiece experienced. This resonant approach lead to inconsistent results (4) and if maintained for an extended period of time could damage the workpiece (5).

Following a scan of the mold block, the stress relief dwell frequency of vibration is set at the appropriate sub-harmonic level and maintained at this level for 15 to 60 minutes depending on the metal and weight of the workpiece.

PRINCIPLE #2 - SHIFTING AND STABILIZING

All metal components have a *natural* harmonic peak. If the part had been subjected to a thermal shock (causing thermal stress) during manufacturing, the harmonic peak would be in an unnatural frequency location. As the workpiece becomes stress relieved by applying sub-harmonic vibrations, the harmonic peak will shift and eventually stabilize in a new frequency location. The stabilized frequency would be the *natural* harmonic frequency (see Figure 4).

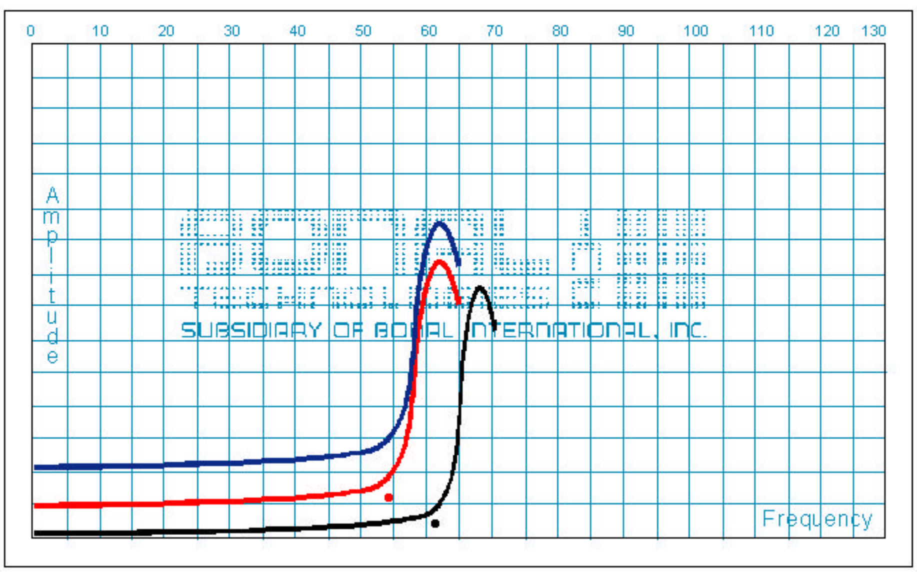

Figure 4. The harmonic curve of a thermally stressed part will be out of phase from its natural location. By applying sub-harmonic vibrations, the curve shifts and stabilizes into its natural frequency, indicating that stress relief is complete.

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

Professors T.E. Wong and G.C. Johnson of the University of California - Berkeley issued a report in 1987 in which they mathematically demonstrated that the harmonic curve will shift due to residual stress, and that this shifting can be used to verify the relief of stresses (6).

Beyond the initial treatment of the mold block following the first scan, the workpiece should be monitored periodically (every 5 to 15 minutes) and the sub-harmonic frequency readjusted every time the harmonic curve shifts. Once the harmonic curve stabilizes in a new frequency location, then stress relief is complete.

SIMILARITIES BETWEEN SUB-HARMONIC AND HEAT STRESS RELIEF

1. Both processes require that the correct procedure must be followed to find and maintain the optimum zone for stress relief to achieve successful results. Operating outside the optimum guidelines may result in achieving no stress relief benefits or, worse case scenario, could damage the part.

2. Both processes rely on *internal accelerated motion* to accomplish stress relief. In fact, all stress relieving processes rely on this. Internal accelerated motion seems to be the only common denominator between all stress relieving processes.

3. Both processes require a *dwell* period.

4. Both processes achieve *stress relief* benefits consistently.

5. Both processes have been originally verified by industry as successful through field performance comparisons.

6. Both processes have been tested and are considered as *"comparable"* according to a U.S. Department of Energy sponsored test (see Chart 1).

Chart 1. Data Summary from DE-FG01-89CE15412 Report

A-36 LOW CARBON STEEL AFTER 30 DAYS RESTRAINT	AS WELDED	SUB-HARMONIC DURING WELDING	SUB-HARMONIC 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

DIFFERENCES BETWEEN SUB-HARMONIC AND HEAT STRESS RELIEF

1. Expense. The *expense* of sub-harmonic processing typically ranges between 5 to 15% of the costs associated with heat treat stress relieving.

2. Time. The *time* that it takes for sub-harmonic processing is typically less than 5% of what the heat treat stress relief would require (30 to 60 minutes for sub-harmonic stress relief vs. three to five days for off-site heat treat services).

3. Side effects. Sub-harmonic processing does NOT produce heat treat *side effects* such as treatment distortion, surface oxidation or scaling, or changing mechanical properties including hardness and softness. CAUTION: If any of these heat treat side effects are desired from the stress relief process, then heat <u>must</u> be used.

4. Secondary steps. Sub-harmonic processing eliminates the need for many *secondary steps* associated with heat treat stress relieving such as trucking, handling, cleaning, re-machining, inspections, and rescheduling.

5. Quality Assurance and Convenience. Sub-harmonic processing can be used virtually any time between other manufacturing steps. This allows stress relief to be applied on near-net finished, semi-finished, finished, and even assembled molds and dies for quality improvement and assurance (see Figure 5).

6. Certification capability. Due to the certification capability of the process, sub-harmonic processing can be used for *thermal* stress relief assurance. For example, checking incoming molds to verify stress relief had previously taken place.

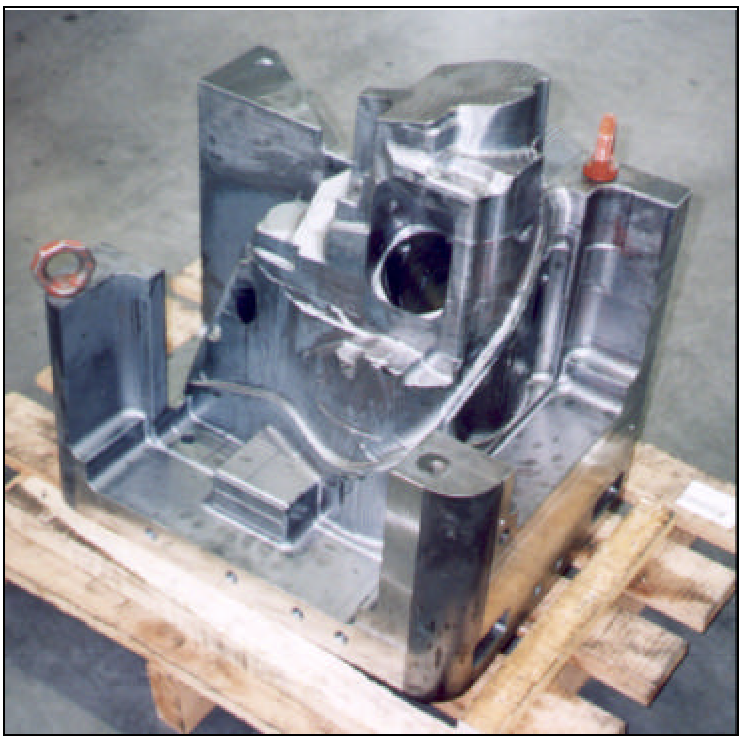

Figure 5. Beiter Moldmaking, Germany, likes the quality improvement from using sub-harmonic stress relief on their specialty automotive headlight mirror-finished molds. Without this process hardening cracks frequently occurred in the delicate areas of the mold. Since they started applying sub-harmonic energy three years ago, they have seen no cracks.

WHEN TO USE SUB-HARMONIC VIBRATIONS

It is recommended to use sub-harmonic vibrations in advance of any manufacturing step where distortion and/or cracking is likely to cause rework or scrap. (Standard practices are bolded).

Incoming mold or die block. Most mold blocks are already stress relieved as received from the steel supplier. This is done either by slow cooling the mold block or by stress relieving the mold block once it has been sawed from the billet. Because of this most mold manufacturers do not apply any additional stress relief at this time. However, if severe distortion is expected then sub-harmonic stress relief should be added before rough milling.

Between rough and finish milling (or semi-finish milling). This is the usual time for applying sub-harmonic vibrations by mold makers. For most mold blocks stress relieving at this time is sufficient to achieve the necessary distortion control and maintain quality throughout the service life of the mold.

Between semi-finish and finish milling. Frequently the semi-finish milling step can be eliminated if the semi-finish pass was necessary to accommodate for the distortion that would have occurred from heat treat stress relieving. By taking advantage of the no treatment distortion from the sub-harmonic stress relief process, a closer net finish can be milled from roughing. However, if very close tolerances are desired and a semi-finish pass is necessary, then adding a sub-harmonic treatment at this time will greatly reduce the distortion of the finish pass and polishing.

Before rough EDM - wire or sinker. Dies that require EDM machining have typically been ground after stress relieving. Even marginal thermal stress in these die blocks could cause distortion or cracking of the block, or pinching of the wire. To apply sub-harmonic stress relief at this time would minimize if not eliminate these problems (see Figure 6).

Figure 6. Hydro-Cam and Engineering, Troy, MI, eliminated a 56% scrap rate on a unique design for carbide preform dies. Applying the sub-harmonic vibration treatment immediately before wire EDM was the key. It's the law now.   Sub-harmonic processing saves their customers a substantial amount of money.

Before shipping to customer. As a finished mold or die apply sub-harmonic stress relief for quality assurance for the customer.

During welding. For repairing and rebuilding of molds apply sub-harmonic vibrations during welding (weld conditioning). This generally produces a finer weld grain structure and allows the welder to weld using less amps (see Figures 7 and 8). Ultimately, sub-harmonic weld conditioning results in less distortion from welding and less susceptibility to cracking (see Figure 9).

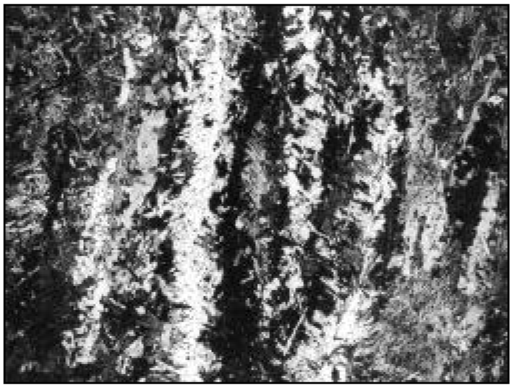

Figure 7. Regular weld metal photomicrograph, shows columnar structure patterns. (1020 HRS, 70,000 psi rod).

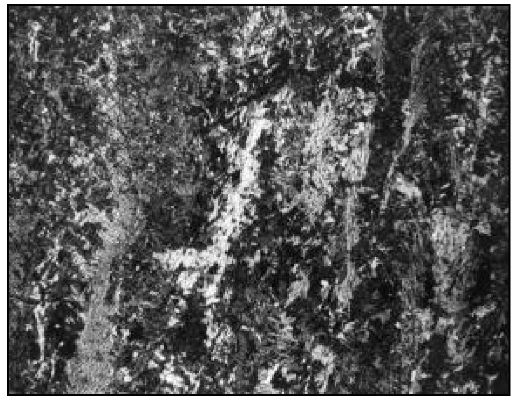

Figure 8. Sub-Harmonic vibrations applied during welding produced grain refinement which is almost always metallurgically desirable for crack resistancy.

Figure 9. Modern Tooling Systems, Toledo, OH, impressed their customer when they put over 80 hours of welding on this 25,000 lb. P20 jet ski mold without cracking. The key was sub-harmonic stress relief during welding. Without sub-harmonic energy they had cracking within 15 seconds. The extensive engineering change turned out to be no big deal.

SUMMARY:

Stress relief is important to molds and dies to assure consistent quality of performance as evidenced by machine distortion control, long-term shape stabilization, and reducing premature cracking in service. The sub-harmonic vibration process has been verified academically as well as proven in field applications as an effective stress relief alternative to other methods including the heat treat stress relief process. This process is an advancement over former vibration stress relief techniques. In addition, the sub-harmonic process can be used during welding to reduce distortion from welding and cracking.

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