High-Speed High-Precision Stress Relieving

By Mario Grenier
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In late 1980, Pyro developed and introduced a new method of stress relieving to the spring industry. The Pyro process was approved by the automotive industry for the treatment of valve springs in the mid '90s. As of now, about every type of spring being manufactured has been treated with this process somewhere in the world.

Advances in high-speed stress relief in the past couple of years are in two main areas:

1. Advances in Pyrograph simulation software.

2. Advances in equipment, in terms of size, ranging from very large to very small.

Before talking about what's new, let me go over some basics about the soak-time question. It is very important to thoroughly understand the reasons that have governed stress relief before one attempts to make any lasting changes to them.

The Soak Time Illusion

After we go through the following explanations, you will see why I say, "the soak time illusion."

Figure 1, below, shows standard stress relief tables used in the industry, which you're all very familiar with. Figure 2, below, illustrates the heat transfer in a loaded batch oven as a function of spring position in the load. As you can see, the heat transfer rate (the speed at which the temperature rises in the wire) is a function of the spring's position in the basket.

MATERIAL	SPECIFICATIONS	TEMPERATURE DEGRE F	TIME MINUTES
Music Wire	ASTM A228	450	30
Music Wire tin coated	ASTM A228	300	30
Music Wire cadmium-zinc coated	ASTM A228	400	30
Music Wire	ASM 5112	540	60
O.T.M.B.	ASTM A229	450	30
H.D.M.B. CLASS I OR II	ASTM A227	450	30
High tensile Hard Draw or iii	ASTM A679	450	30
Galvanized M.B. class i or ii	ASTM A674	450	30
Chrome-Silicon	SAE J157 OR ASTM A401	700	60
Chrome-Silicon (Lifens)	SAE J157	725	60
Chrome-Vavadium	ASTM A 231	700	60
Stainless Steel 301	*	650	30
Stainless Steel 302	AMS 5688	650	30
Stainless Steel 304	ASTM A313	650	30
Stainless Steel 316	ASTM A313	600	60

Figure 1: Standard stress-relief table.

Thus, springs lying against the inlet duct will gain heat much more rapidly than the ones lying in the center of the mass. The standard asks for one hour at 700ºF. The springs against the duct will get the recommended heat dose, or maybe close to it, but the ones in the center…no one knows how long they will have been at the recommended temperature. Maybe they have just barely made it there by the time the hour is over. Consequently, the one hour is not a fixed, proven time that guarantees stress relief for each and every spring. Instead, it is a general guideline for placing springs in the oven long enough so that they all reach the stress relief temperature that you find in the table.

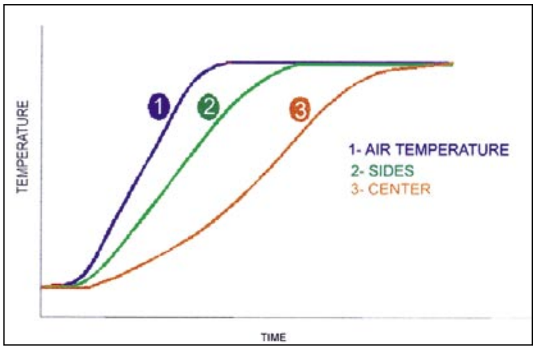

Figure 2: Heat-transfer uniformity.

Ovens are pieces of equipment designed to transfer heat (energy) to a mass of springs. Nothing in the standards that regulate oven design is said to measure and compare the capacity of ovens to transfer heat. Instead, ovens are calibrated against temperature at set point and temperature within a working volume only. There is no mention of heat-transfer ability in the standards. The long soak time in the Figure 1 table is meant to make up for this lack of standardization. The standards are purposely conservative to allow for the less efficient ovens. In addition, they allow for the fact that many springmakers use general-purpose ovens, which have applications in a variety of industries. General-purpose ovens are advertised by their manufacturers as good for curing, tempering, normalizing and, finally, stress relieving. No wonder why the standard makers are cautious.

REPRINTED FROM SPRINGS, OCTOBER 2002

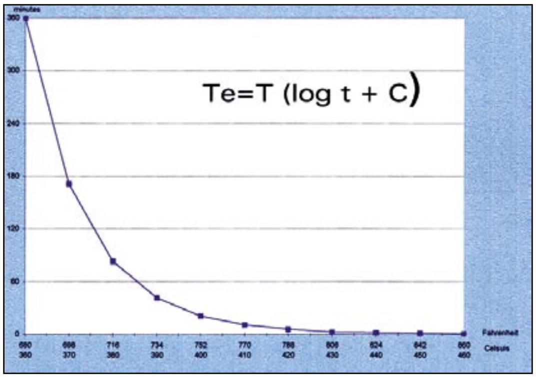

Figure 3: Equal stress-relief function, derived by Larsen Miller (1948).

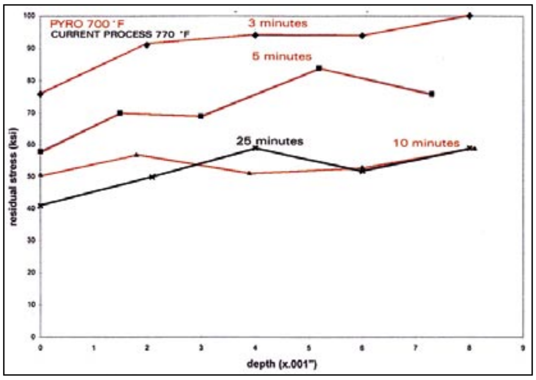

Figure 4: Pyro residual-stress-relief experiment.

Larsen Miller (1948) derived an equal stress-relief function (Figure 3, above). Stress relief is, therefore, not a fixed recipe of one time, one temperature, as stated in the table. It involves a whole realm of possibilities, and if you have the proper tool and the right oven, you can stress relieve wire rapidly, as demonstrated by the X-ray diffraction illustrations in Figure 4 and Figure 5, above.

As can be seen, 5 min. at 800°F is equivalent to 10 min. at 770ºF in a Pyro. This illustrates the Larsen Miller effect. Secondly, 10 min. at 770ºF in a Pyro is equivalent to 25 min. at the same temperature in a regular oven.

In other words, to be stress relieved, a wire just needs to be heated to the core and not for very long. Now how do you go about heating springs to the core for just the exact time each and every time? You need very consistent ovens and a method for using them. We have developed over the years, and significantly over the past three years, a computer-assisted tool called the "Pyrograph."

Science on the Shop Floor

"Prove to me that the wire is heated right through the core!" That's the remark made several years ago by a springmaker that triggered the development of Pyrograph software.

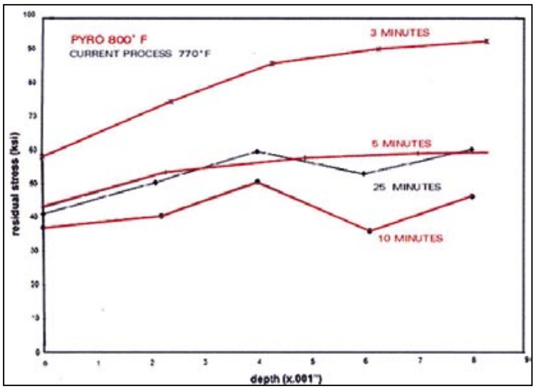

Figure 5: Pyro residual-stress-relief experiment.

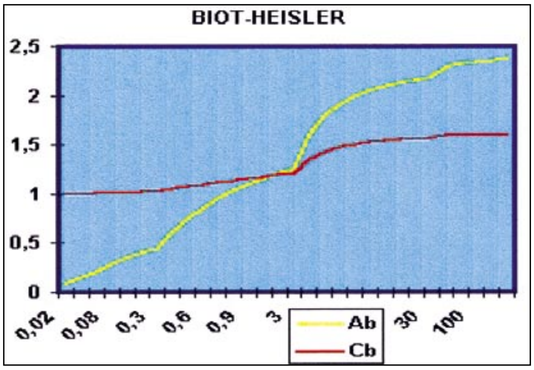

Figure 6: Biot Heisler function.

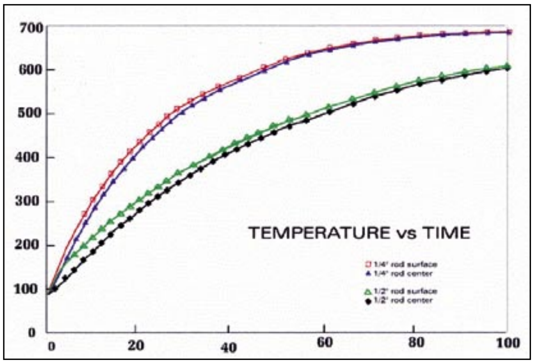

Figure 7: Temperature gain on the surface and through the core of a 0.250″ and a 0.5″ wire placed in a 700°F Pyro oven.

The Pyrograph is a piece of software based on Heisler (1948) unsteady-state heat-transfer equations for infinite cylinders. Figure 7, left, shows the temperature gain on the surface and through the core of a 0.250″ and a 0.5″ wire placed in a 700ºF oven. For one thing, it settled the surface/core temperature issue.

As shown in Figure 7, the surface and core temperatures on a 0.250″ wire soon meet one another and, after a few minutes, overlap one another. We gradually added features to the Pyrograph and soon found out that it could become a powerful simulation tool, so the springmaker

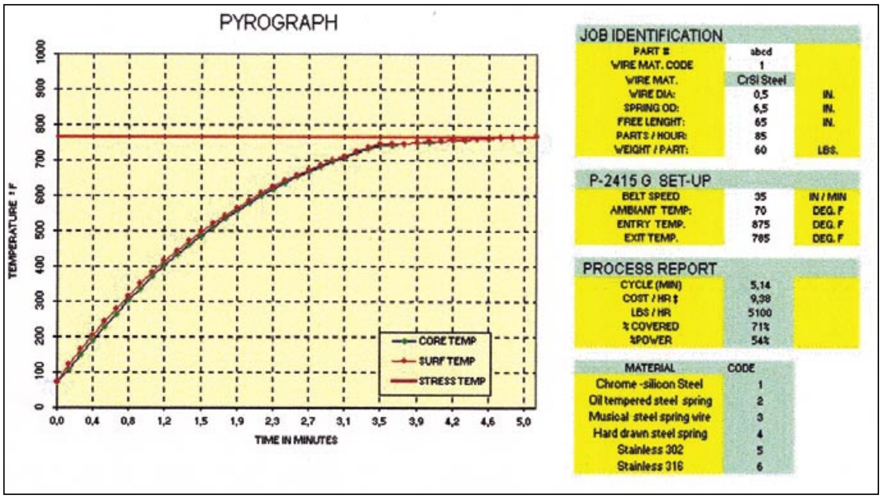

Figure 8: Pyrograph, proper setup.

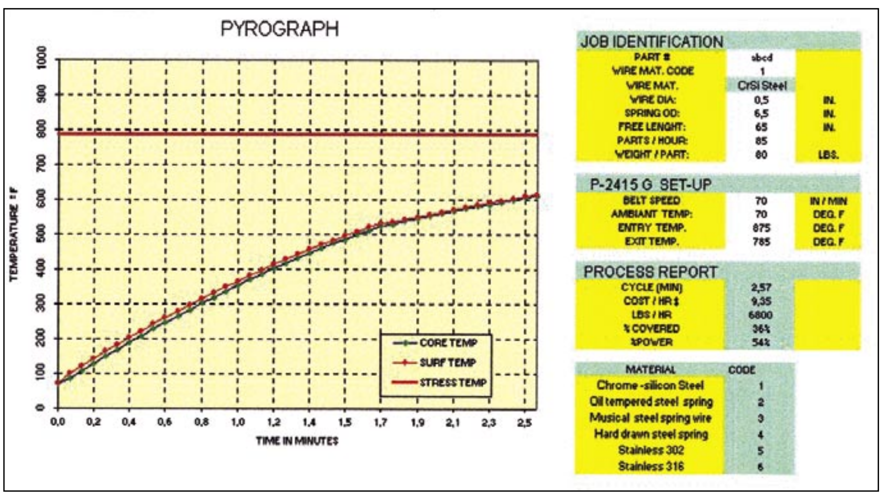

Figure 9: Pyrograph, improper setup.

could see beforehand what would happen in the oven. Figure 8, right, shows an actual Pyrograph display of a proper setup.

The user enters the spring characteristics in the top right section of the screen. These include alloy, wire size, O.D, free length, parts/hr. and weight.

The midsection is where users set the oven parameters. These include the conveyor speed, set in inches of belt travel per minute, and the temperature in each zone of the oven.

The bottom section gives users a process report, including cycle time, cost, belt-occupation ratio and percentage power usage. Figure 9, right, gives an example of an improper setup. As you can see, the wire temperature doesn't reach the target stress-relief temperature.

New features that we have recently integrated into the software include automatic stress-relief temperature selection according to alloy type. We have also integrated Larsen Miller, and this is the greatest improvement. This feature sets the stress-relief temperature automatically as a function of the cycle time. We have also integrated a high-temperature "bumper" to prevent users from going above a certain temperature and negatively affecting the wire hardness.

The Pyrograph enables users to visualize beforehand what is going on and to be confident that each spring is heated to the core consistently.

Left: Figure 10, Small electric Pyro.

Below: Figure 11, Large, gas-fired Pyro.

Equipment

Evolution of stress relief equipment

Batch ovens. Springs were originally stress relieved in batch ovens, and that is where the standards were established, as can be seen from the preceding discussion.

In-line ovens. Then came the in-line ovens. The first in-lines (and there are a lot of these in operation in modern spring shops), were more or less lengthened batch ovens with two doors, connected by a conveyor to transport the springs. Very often, springs are put in baskets on the belt and will stay in for as long as they would in a batch except that they are moving, thus requiring less handling.

Next came the portable, at-the-coiler in-line type ovens. A great innovation, these offer improved product quality and less handling. They are primarily used on small wire and at shortened cycle times, in some instances.

Pyro ovens. Pyro is a line of ovens designed for high-precision stress relieving of large wire at high speeds. Refer to the 1999 SMI Technical Symposium Proceedings for the history of their development. The speed is a means to reach precision, the only goal being precision and consistency.

Pyro comes in three classes of machines, with the top of the line being high-capacity gas-fired models (Figure 10 and Figure 11, page 70). Here are the main features of these machines:

• Precise control of temperature. The ovens include top-of-the-line temperature controllers; and very fast power switching through SSR devices for electric models or fast modulating motors for the gas-fired models. The objective is to maintain set-point accuracy within a few degrees under varying loading conditions.

• Sufficient reserve power for quick recovery at startup of a load.

• Precise control of time. The Pyro comes (equipped as standard for E and G series, optional on the HE) with a digital closed-loop speed controller. Calibrated in inches of belt travel per minute, the closed loop acts like a cruise control on a car. It maintains accurate cycle time regardless of the variations introduced by friction, load and voltage. This is a very important feature since, on a 4 min. trip, a few seconds make a difference. This system is accurate to within 0.4 sec on 4 min. cycle time.

• Heat transfer uniformity. A high-precision oven needs to be uniform not only temperature-wise but also heat-transfer wise. The Pyro uses convection as the primary source of heat transfer and radiation as secondary on electric models. The turbines, their number and position, the shape of the chambers, and the conveyor are all designed to maximize the air velocity at the part in a uniform manner all along the spring path. This is what is meant by "heat-transfer uniformity."

• Pyro saves floor space. The ovens can be as small as 10% the size of regular ovens. Because of the reduced size, they are also more energy-efficient.

• Capacity. We now have Pyro machines that process 0.625″ CrSi wire in 6 min. total cycle at rates of 20,000 lbs/hr.

Areas of development in years to come

• Very large capacity gas-fired Pyro ovens.

• Very small box-type high-speed tryout ovens for setup purposes.

Mario Grenier is president of Pyromaître Inc. in St-Nicolas, Quebec, Canada. In 1984, with a small team, Grenier developed a variety of industrial ovens and furnaces. His first encounter with the spring industry occurred in 1986. The development of the high-speed stress-relief process started in 1989 and continues to grow and advance. Readers may contact Grenier by phone at (418) 831-2576 or e-mail at pryo@pyromaitre.com. ❖