INTRODUCTION

My company got involved in the manufacture of stress relief batch ovens 12 years ago. Ten years ago this same first customer ask us to design an in line oven capable of stress releasing with 0 defect high precision ,250''CrSi torsion springs at a rate of 800 lb./hr. Joint effort with this customer produced the Pyro High Speed process I will talk about today. I will first say a few words about stress and what is stress releasing. I will then shortly review stress relief practice in the industry and explain how in my view it is equipment dependant and thus limited. I will then talk about the Pyro high speed process, present comparative studies and talk about the benefits for the spring maker.

STRESS AND STRESS RELEASING: (Recrystallization)

What is stress?

Stress is caused by compressive and stretching forces trapped in the metallic crystal network as a result of mechanical deformation or bending (see Figures 1& 2, page 126).

How is stress released?

In order to release theses forces, you need to apply a precise amount of energy to the crystal structure in order to recrystallize it. This process of recrystallization or stress releasing can be done in a powerful and quick way, or in a less powerful slower manner.

Mario Grenier received a masters degree in Psychology and attended McGill University to work on tactile perception of speech. He received a .M.Sc.A degree. Grenier began work as a clinical audiologist in a school for the hearing impaired. He became interested in kilns and began to create his own. In 1981 he started Pyromaitre, a part-time interest to explore more complex versions of his hobby. In 1984, it became a full-time concern, quitting his job and building industrial ovens and furnaces. In 1986 Grenier first encountered the spring industry, and by 1989 he had developed the high-speed stress relief process. He has continued to hone and refine this system.

Larsen MillerEqual Stress Releasing Curves

Larsen,. Miller. (1948) has derived the mathematical function in Figure 3. that describes this physical law. The time temperature curve you see represents equal stress relief. This means that stress releasing is not a fixed recipe of one time temperature combination like you see in most spring shops today, but a whole series of different combinations.

STRESS RELIEF PRACTICE IN THE INDUSTRY

Stress relief tables

Figure 4 is an example of a stress relief table, you are all very familiar with. Larsen Miller came up with their equation in 1945, so why hasn't it influenced the spring industry while it has been used in other industries. Michael Limb the conference chairman told me that it was used in England but not for springs. My explanation is that this situation is caused by equipment limitations and incomplete oven standardization.

Ovens are the Limiting Factor

First of all, of all the machinery used in the spring making process, ovens are about the only piece of equipment to my knowledge that is not custom designed for the process. Ovens used whether they are batch or in line are general purpose industrial heating work horses seen in other industries and advertized by their manufacturers has good for heating, curing, drying, aging, etc... and finally stress releasing.

Second and in my mind most important is that batch or in line ovens are only standardized by means of temperature accuracy around a set point and temperature uniformity in a work volume. The only function of a stress relief oven is to transfer thermal energy to a mass of springs and nothing in the standard is said to measure and compare the heat transfer efficiency of ovens. Although the air temperature profile of a batch oven is within limits, the capacity of this same oven to transfer energy to a spring varies as a function of spring position within work volume. The following Figure illustrates this phenomenon. For instance heat transfer uniformity in a loaded batch oven is nothing but uniform. Springs laying right against the inlet ducts will get heated much faster than the springs laying in the center of the basket. Great variations will also occur between oven brands. This is why, soak time is needed. Soak time is needed to make sure every spring reach the target temperature, not to insure that every spring stays at temperature for a predetermined amount of time. The same apply to in line ovens especially the long wide belt types where springs are piled up thick. The stress relief tables have been built to cover the worst scenarios and here is the reason for the long cycle times.

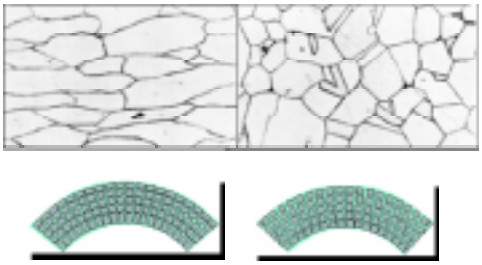

Fig. 1 and Fig. 2: Stress is caused by compressive and stretching forces trapped in the metallic crystal network as a result of mechanical deformation or bending.

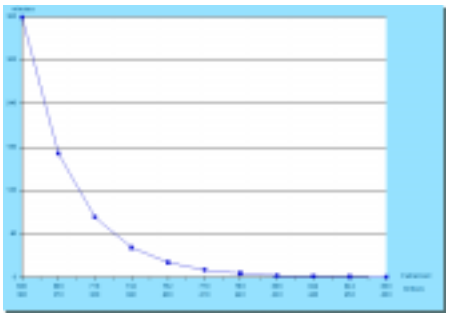

Fig. 3. Larsen,. Miller.(1948) has derived the following mathematical function.

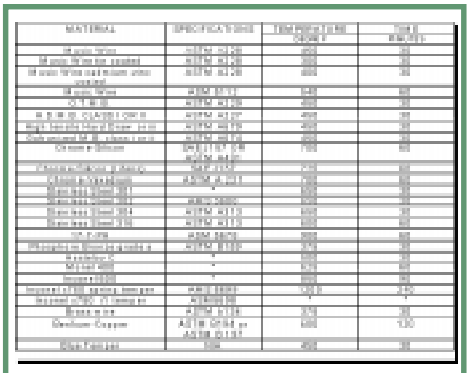

Fig. 4. An example of a stress relief table, you are all very familiar with. Larsen Miller came up with their equation in 1945, so why hasn't it influenced the spring industry while it has been used in other industries.

The Effects of Improper Stress Relieving

Stress relief has you know has great impact on the finished spring parts. Positions, OD, loads can vary greatly and cause costly inspections reprocessing and rejects not to mention the worst of all, spring failures in the field. Spring makers invest big dollar in sophisticated specialized CNC forming and grinding equipment to insure top consistency and then put their investment at risk in ovens that are to often every thing but "hot ".

Stress Relief, a Weak Link

I have discovered during my 12 years involvement in this field that stress releasing is an understated misunderstood to often overlooked very important spring making process that needs to be upgraded for the benefit of the industry and your customers.

PYRO HIGH SPEED STRESS RELIEF PROCESS

History of a Quest for Quality

When we delivered that very first in line oven on that high precision torsion spring job mentioned in introduction, initial reject rate was 30%. Pretty far from the zero defect goal and pretty frightening. I even had brief thoughts that this task might be impossible. The goal was clear and I knew the direction. Every modification made in that direction reduced the reject rate. My team and I with the help of the customer first learned

to crawl, then walk to finally be able to run and succeed. One day my customer calls me to say that he had experimented with short cycle times at elevated temperatures and that this yielded much better consistency. In other words we had rediscovered Larsen Miller without having ever heard of them. We soon after finally reached the 0 defect goal and ,250''CrSi car belt tensionner springs have been since then stress relieved in three minutes total cycle time. The three minutes cycle time is for sure the most striking feature of the process, but you must remember that it is a side benefit of the method. We didn't 10 years ago set sail to establish Olympic speed records. We where after quality targets and speed became a tool, a mean for us to reach 0 defect and meet the process requirements and satisfy our customer.

HEAT TRANSFER PHYSICS

Thermal energy can be transferred to a cold body via three channels: Electromagnetic radiation, Convection and Conduction.

Electromagnetic radiation is how the sun's energy gets to us from millions of miles away. Convection is how you warm up your freezing fingers in the winter by blowing at them with your warm breath. Conduction is how a cold metal pan handle gets hot on the stove. We in most of our ovens use all three channels and Figure 6 gives you an example of the results.

Pyrograph Heat Transfer Simulation Program

This software program is based on Heisler, (1986) unsteady state heat transfer equations for infinite cylindrical bodies. This work was originally started to find the difference between surface and the core temperature of a rapidly heated spring wire. We wanted to make absolutely certain that the core of wire got heated correctly. Pyrograph then gradually evolved to become a Pyro oven simulation, setup and documentation tool. Pyrograph is a computer assisted engineering (CAE) tool that brings science to the shop floor. Here is a demonstration of what this program does.

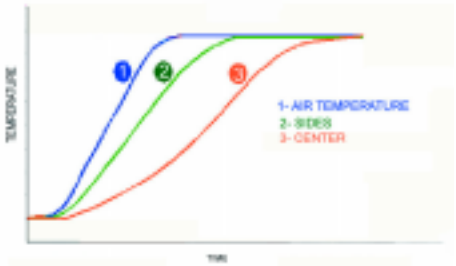

Fig. 5.Heat transfer uniformity in a loaded batch oven is nothing but uniform.

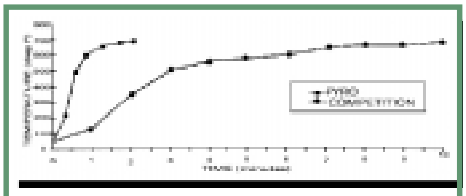

Fig. 6. Electromagnetic radiation is how the sun's energy gets to us from millions of miles away. Convection is how you warm up your freezing fingers in the winter by blowing at them with your warm breath. Conduction is how a cold metal pan handle gets hot on the stove. We in most of our ovens use all 3 channels.

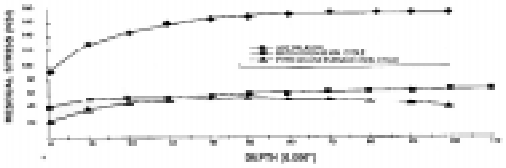

Fig. 7. Two studies were conducted to validate this process. A first one involves X-ray diffraction measures on car belt tensionner springs. A second extensive evaluation was done on valve spring.

	FIRST LOAD	SECOND LOAD
PYRO	1.90%	1.70%
XXX	3.90%	1.80%

Fig. 12. Load losses were measured at two heights. Load 1 was measured at 1.880" and load 2 at 1.200". Pyro springs, on average lost 1.9% load at the first height and 1.7% at the second height.

Pyrograph Live Demo Equipment

Pyro oven comes into 2 types. The Pyro Belt and the Pyro Disc. The Pyro Belt are from the outside similar to other belt oven but they have for the same belt size anywhere from two to four times the output. They are all mobile and capacity for a P-120 is well above one ton per hr. They are all electric and the large capacity models are also gaz fired.

The Pyro Disc is a totally new concept developed six years ago. Instead of a moving belt, we use a rotating disc to carry the springs. It is specialized to compression springs only. A Pyro Disc is well suited as a link in totally automated lines since the springs can be released at exit in a controlled manner with same orientation as they came in. All of Bombardier snow mobile suspension springs have been stress released in Pyro Disc for the past five years. Pyro Disc are also used intensively in valve spring production.

COMPARATIVE EVALUATION STUDIES

Two studies were conducted to validate this process. A first one involves X-ray diffraction measures on car belt tensionner springs. A second extensive evaluation was done on valve spring. (See Figure 7).

Car engine valve springs were stress relieved in a Pyro oven and a continuous conventional low speed oven under the following conditions: the Pyro cycle time was 7.5 minutes against 35 minutes for the conventional oven. The stress relief temperature was 800 F in both conditions and the following measures were gathered: tensile strength, hardness, micro hardness profiles, fatigue testing and load losses.

The tensile strength of the Pyro samples is slightly lower than the conventional oven with 275.7 Ksi versus 275.9 Ksi whereas the as received wire samples had an average tensile strength of 275.9 Ksi. (See Figure 8).

The average hardness of the stress relieved wire samples is the same (Fig. 4) through the Pyro and the conventional

oven at 50.7 HRC, only 0.1 HRC lower than the average hardness of the as received wire samples. The comparison of the micro hardness tests on the stress relieved springs (Fig. 5) reveal that the Pyro oven had a slightly higher average hardness (0.4 HRC) than the conventional oven. (See Figures 9 & 10).

A fatigue test was conducted to validate the new Pyro oven and to compare it with the existing equipment. Springs were cycled at elevated stress levels to induce failures of any inadequately stress relieved parts. Ten springs stress relieved from each oven type were fatigue tested for 50 million cycles. At the end of the test, there were four spring failures. Two springs stress relieved in the Pyro oven failed and two springs stress relieved in the conventional oven after about the same number of cycles in each condition. (See Figure 11).

Load losses were measured at two heights. Load 1 was measured at 1.880'' and load 2 at 1.200''. Pyro springs, on average lost 1.9% load at the first height and 1.7% at the second height. Springs stress relieved in the conventional oven lost 3.9% load on the first height and 1.8% load at the second height. (See Figure 12).

Based on the failure and load loss results, it is concluded that the fatigue life of the springs processed in the Pyro oven is as good or better than the conventional oven.

BENEFITS FOR THE SPRINGMAKER

Quality

The valve spring maker has cut dramatically on rejects, reprocessing and after one year hadn 't had a single field failure. The short cycle is very much appreciated by operators who get quick feedback and can therefore react promptly to keep the process under control.

Floor Space

The Pyro is approximately 1/3 the size of a conventional oven which allows more floor space for expansion and easier accessibility of the other machinery. Furthermore, they are mobile.

Efficiency

Resulting from smaller volume and mass, the Pyro can be raised to operating temperature in just 10 minutes compared to 45 minutes for the much larger conventional oven. This reduction in time results in an increase of nearly three more hours of production time for a five-day work week. Furthermore, a smaller oven with a smaller opening means less heat loss and more energy efficient operation.

Scientific

The Pyro comes with a software package (Pyrograph described above) that allows the spring maker to simulate the process before hand and pick scientifically the optimum operating parameters of the oven. ❖

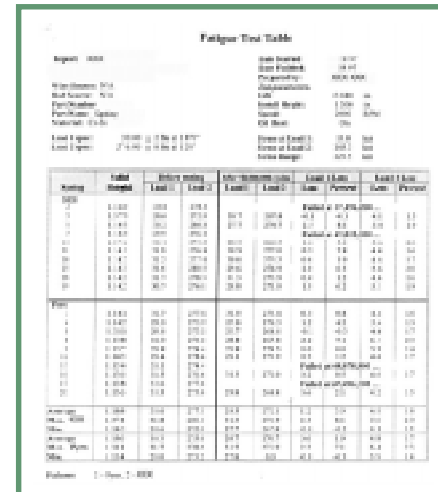

Fig. 11. A fatigue test was conducted to validate the new Pyro oven and to compare it with the existing equipment. Springs were cycled at elevated stress levels to induce failures of any inadequately stress relieved parts.

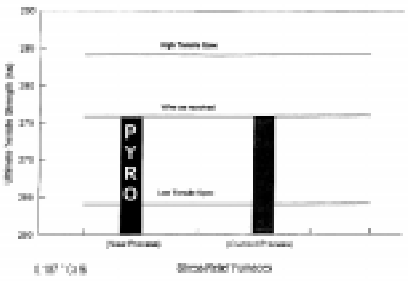

Fig. 8. The tensile strength of the Pyro samples is slightly lower than the conventionnal oven with 275.7 Ksi versus 275.9 Ksi whereas the as received wire samples had an average tensile strenght of 275.9 Ksi.

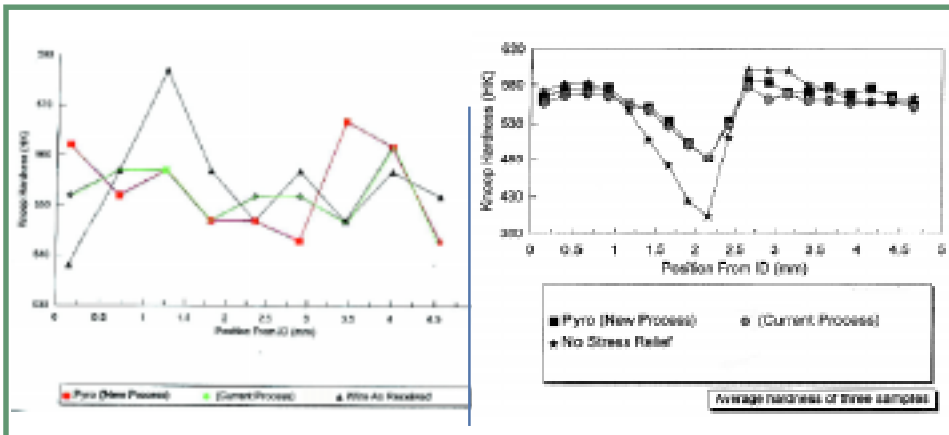

Fig. 9, left & 10, right. The average hardness of the stress relieved wire samples is the same (Fig. 4) through the Pyro and the conventionnal oven at 50.7 HRC, only 0.1 HRC lower than the average hardness of the as received wire samples. The comparison of the micro hardness tests on the stress relieved springs (Fig. 5) reveal that the Pyro oven had a slighly higher average hardness (0.4 HRC) than the conventionnal oven.