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In-line Pyromaitre Furnace
Validation and Comparison with Current process

Home Office Engineering

[redacted] **In-line Furnace Validation**

June 30, 1997

[redacted]

[redacted]

SMI

I. Introduction

A new stress relieving furnace, Pyromaitre (Pyro), has been purchased and implemented into production for the GM [redacted] valve spring at the [redacted] plant. The Pyromaitre is an electric furnace with an adjustable control panel for temperature as well as belt speed. The furnace is divided into three temperature zones; entrance, middle, and exit. Each zone is equipped with its own temperature control setting, actual temperature readings resulting from inborn thermocouples in the furnace, and adjustable alarm settings for variance between temperature settings and actual as well as for belt speed. The Pyro is equipped with five high speed air circulating fans in order to achieve a uniform heat distribution throughout the entire heating cycle (7½ minutes with 4 minutes at temperature) of the furnace. The total cycle time from coiler to the end of the conveyor belt is 9 minutes as opposed to 35 minutes for the conventional furnace (Becker). It is approximately ⅓ the size of the Becker furnace which results in a much shorter pre-heat time and correlates into increased production time. The reduction in size also allows for more manufacturing space for future expansion and easier accessability of other machinery. Four tests (tensile, micro hardness, relaxation, and fatigue) were used to determine that the new furnace is as good as or better than the furnace currently being used for production.

II. Objective

The goals of the validation experiment were:

- To show that the Pyro furnace is as good as or better than the conventional furnace currently used for stress relieving.
- To determine the optimum time and temperature relationship for stress relieving of the [redacted] spring through the Pyro furnace.

III. Discussion

In order to determine the effectiveness of the Pyromaitre furnace, it needed to be compared to a benchmark. The benchmark used was the Becker furnace which is currently stress relieving the GM [redacted] The first step taken was to establish the best time and temperature relationship needed for stress relieving the [redacted] springs. The belt speed was set at 25 inches/minute resulting in a stress relieving time of 7½ minutes (total cycle time of 9 minutes from coiler to the end of the conveyor belt with 4 minutes at temperature). The initial testing of the Pyro was to determine at which temperature would be best suited for stress relieving tensile samples in order to keep the average load within ±1% of the average load of tensile samples stress relieved through the Becker at the current production temperature setting of 800°F. A full coil of 0.187" OT Cr-Sil VSQ wire was placed into quarantine only to be used for this experiment in order to to maintain consistency. Four tensile samples from the quarantined coil were stress relieved through a fully loaded Becker furnace and tests were conducted. The test was conducted exactly the same way two more times and the results were averaged together in order to average out any variance in test results that may have occurred. These results were then compared to the tensile tests from the as received wire samples in order to determine if the heat treating was reducing the tensile strength of the wire. In order to eliminate a test variable, the temperature on the Pyro was adjusted to equalize the tensile strength of the Becker samples versus the Pyro samples. Tensile samples were placed into a fully loaded Pyro and a temperature setting of 805/795/795°F (the 805° being the entrance zone) resulted in equalized tensile strengths. The extra 10 degrees in the entrance zone is to get the parts up to temperature as quickly as possible without exceeding the 795°F target temperature. All of the tensile tests were conducted with wire from the quarantined coil. The [redacted] springs, from the quarantined coil, were then run directly into the Pyro furnace under normal production conditions. Three springs were attached to a three lead traveling thermocouple and placed at the left, middle, and right sides of the Pyro and a chart recorded the time and temperature of the springs. Four more tensile samples were run in conjunction with the traveling thermocouple for verification of the previous tensile test results. Spring samples were also run through the existing process (Becker) with the same traveling thermocouple and four more tensile samples. The Pyro was stress relieving approximately 640 lbs/hr while the Becker was stress relieving approximately 690 lbs/hr. Micro hardness tests were conducted on springs stress relieved through the Pyro and the Becker, as well as non stress relieved springs. Likewise, hardness profiles were conducted on the wire samples stress relieved through the Pyro and Becker as well as the as received wire samples without stress relief. The [redacted] springs were then tested on a 20 station rotary cycle fatigue tester at Home Office for 50 million cycles, 10 from the Pyro and 10 from the existing process (Becker). Each spring was pressed solid three times and the solid height was recorded. Load 1 was then recorded for each spring at the height of 1.88" and Load 2 was recorded for each spring at the height of 1.20" prior to testing. The fatigue tested springs were analyzed in terms of failures and relaxation (load loss).

IV. Result and Conclusions

The comparison of the micro hardness tests on the stress relieved springs reveal that the Pyro furnace had a slightly higher average hardness (0.4 HRC) than the Becker. The average hardness of the stress relieved wire samples is the same through the Pyro and Becker at 50.7 HRC, only 0.1 HRC lower than the average hardness of the as received wire samples. The tensile strength of the Pyro is slightly lower than the Becker with 275.7 ksi versus 275.9 ksi whereas the as received wire samples had an average tensile strength of 275.9 ksi.

In terms of manufacturing issues, the Pyro furnace has several advantages over the conventional furnaces currently in use [redacted]

1. The belt speed and temperature settings can easily be adjusted by means of a Programmable Logic Control (PLC).
2. Due to the high velocity fans installed in the Pyro furnace, the rate of heat exchange is considerably greater than the Becker. This higher rate of heat transfer enables the total cycle time (from coiler to the end of the conveyor) to be reduced from 35 minutes in the Becker to 9 minutes in the Pyro without any measurable effect on the final average hardness and range of hardness on the wire samples or the stress relieved springs.
3. The Pyro furnace is approximately ⅓ the size of the Becker which allows more floor space for expansion and easier accessability of other machinery. Resulting from the smaller volume and mass, the Pyro can be raised to operating temperature in just 10 minutes compared to 45 minutes for the much larger Becker furnace. This reduction in time results in an increase of nearly three more hours of production time for a five day work week.
4. The Pyro is equipped with a software package that relates time, temperature, weight, and type of material which graphically displays the time and temperature curve that the springs will be exposed to.
5. There is likely to be a substantial savings of energy with the electric Pyro as opposed to the gas powered Becker furnace. However, this won't be known until the production parameters for both furnaces are equalized and compared.

By the results, forced air (Pyro) type of furnace has demonstrated that it is sufficient to raise the springs to the desired temperature of 795°F and held there for a soak time of 4 minutes (total cycle time of 9 minutes with 7½ minutes being exposed to heat) to achieve full stress relief as opposed to a total cycle time of 35 minutes (20 minutes of heat treatment with 10½ minutes at temperature) in the conventional furnace (Becker). Tests conducted on the tensile strength, hardness profiles, relaxation, and fatigue cycling confirm that the springs processed through the Pyro performed equally as well as the springs processed through the traditional furnace in nearly ¼ the amount of time. During the course of time, springs that are stress relieved through the Becker furnace will be compared to springs through the Pyro furnace by measuring the residual stress levels with the use of x-ray diffraction.

PYRO DOE

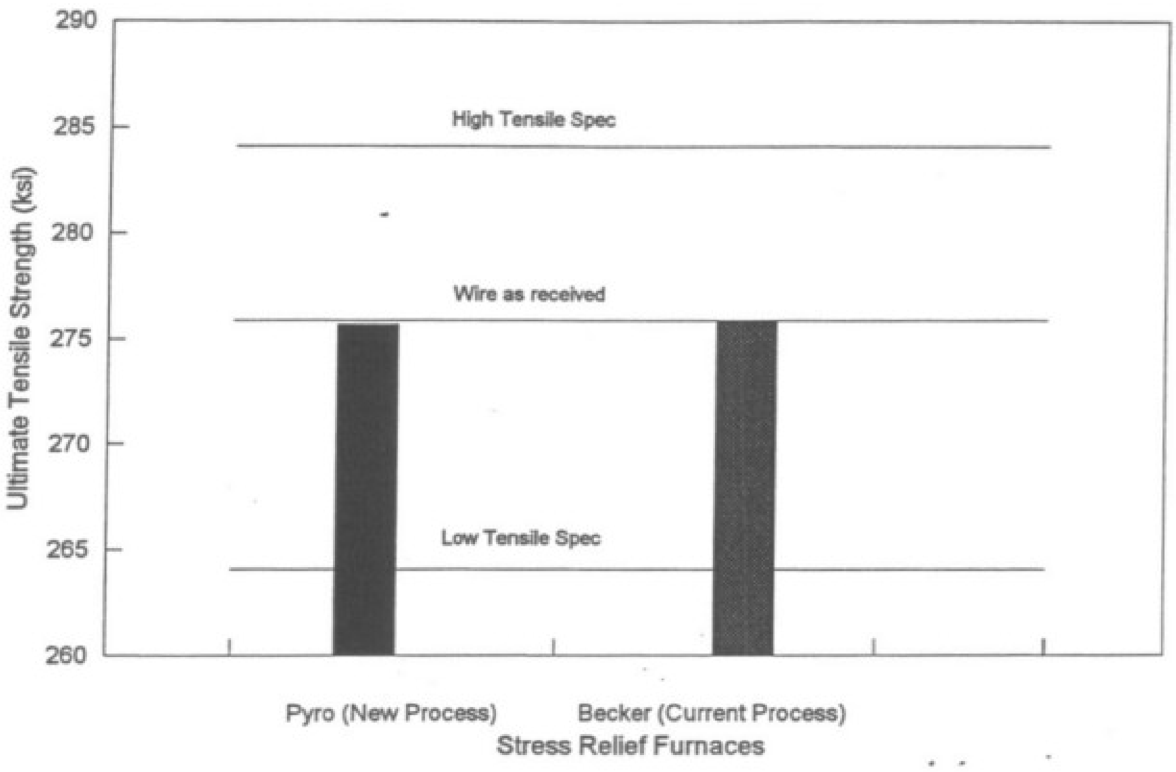
[redacted]

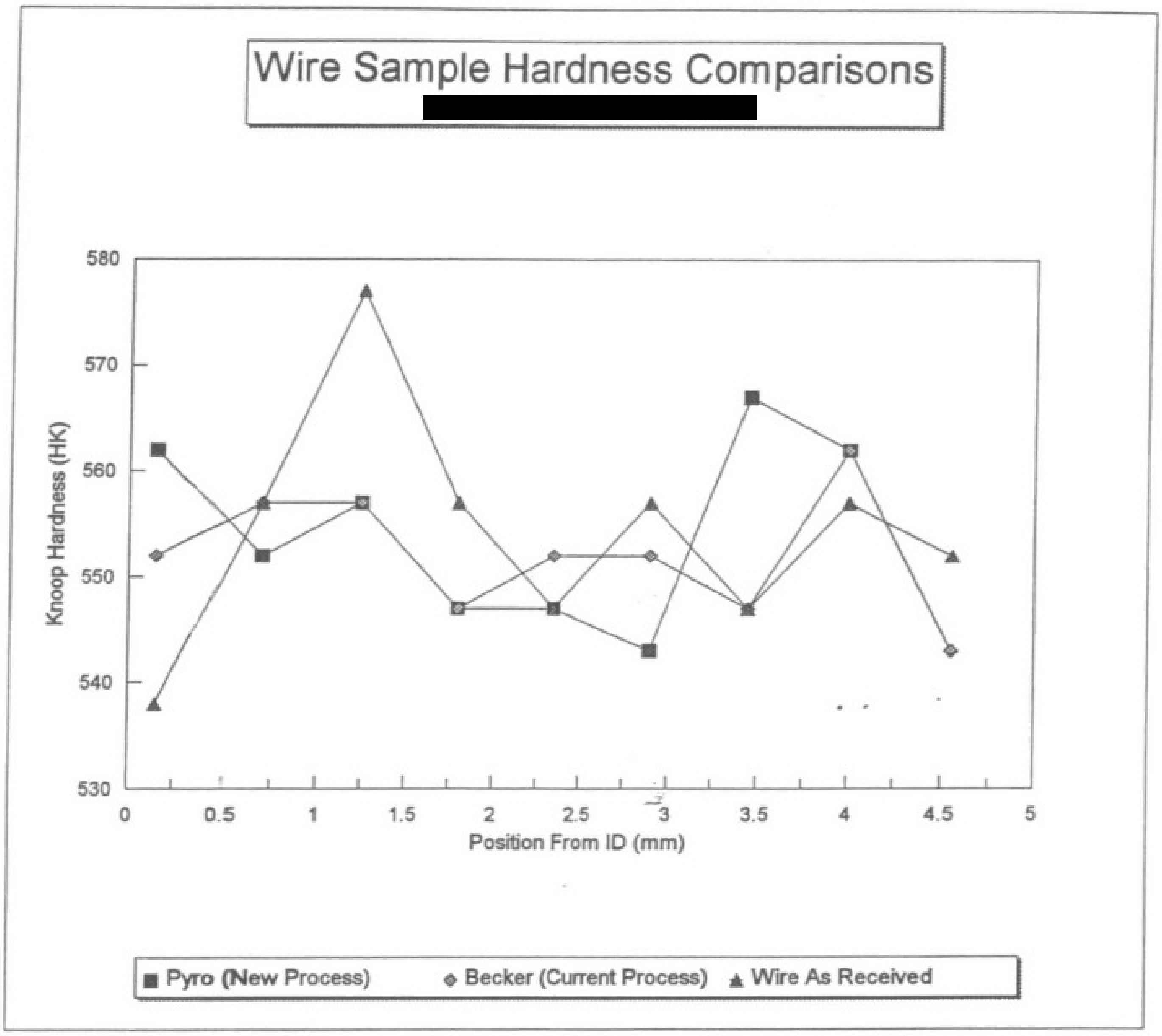
Wire Samples

Position From ID	Knoop Hardness (HK)			Rockwell C Hardness (HRC)		
	PYRO 805/795/795F	Becker 800F	As Received	PYRO 805/795/795F	Becker 800F	As Received
0.15	562	552	538	51	51	50
0.70	552	557	557	51	51	51
1.25	557	557	577	51	51	52
1.80	547	547	557	50	50	51
2.35	547	552	547	50	51	50
2.90	543	552	557	50	51	51
3.45	567	547	547	51.5	50	50
4.00	562	562	557	51	51	51
4.55	557	543	552	51	50	51
AVG	554.9	552.1	554.3	50.7	50.7	50.8
Range	24.0	19.0	39.0	1.5	1.0	2.0

Tensile Test Comparison

[redacted]




Wire Sample Hardness Comparisons
[redacted]
580
570
560
550
540
530
Knoop Hardness (HK)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Position From ID (mm)
Pyro (New Process)
Becker (Current Process)
Wire As Received

PYRO DOE

[redacted]

Tensile Tests
High Spec: 284.1 ksi
Low Spec: 264.1 ksi

Becker (800F)
(Current Process)
Full Loads

Test 1

Load (lbs)	UTS (ksi)
7574	275.2
7578	275.4
7564	274.9
7583	275.5
7574.8	**275.3**
19.0	**0.6**

Test 2

	Load (lbs)	UTS (ksi)
	7520	273.3
	7518	273.2
	7525	273.4
	7523	273.4
AVG	**7521.5**	**273.3**
Range	**7.0**	**0.2**

Test 3

	Load (lbs)	UTS (ksi)
	7502	272.1
	7502	272.1
	7510	272.4
	7504	272.2
AVG	**7504.5**	**272.2**
Range	**8.0**	**0.3**

Test 4 (with thermocouple)

	Load (lbs)	UTS (ksi)
	7597	275.7
	7608	276.1
	7607	276.0
	7599	275.7
AVG	**7602.8**	**275.9**
Range	**11.0**	**0.4**

Pyro
(New Process)
Full Loads

Test 1 (795/785/785F)

Load (lbs)	UTS (ksi)
7586	275.6
7585	275.5
7601	276.1
7587	275.6
7589.8	**275.7**
16.0	**0.6**

Test 2 (800/790/790F)

	Load (lbs)	UTS (ksi)
	7575	275.0
	7564	274.6
	7577	275.0
	7587	275.4
AVG	**7575.8**	**275.0**
Range	**23.0**	**0.8**

Test 3 (805/795/795F)

	Load (lbs)	UTS (ksi)
	7569	274.7
	7549	274.0
	7563	274.5
	7565	274.6
AVG	**7561.5**	**274.5**
Range	**20.0**	**0.7**

Test 4 (805/795/795F)
With Thermocouple

	Load (lbs)	UTS (ksi)
	7584	275.8
	7586	275.9
	7575	275.5
	7583	275.7
AVG	**7582.0**	**275.7**
Range	**11.0**	**0.4**

Wire As Received

Load (lbs)	UTS (ksi)
7571	275.6
7581	276.0
7585	276.1
7581	276.0
7579.5	**275.9**
14.0	**0.5**

Pyro (New Process)
Test 4 (805/795/795F)
With Thermocouple

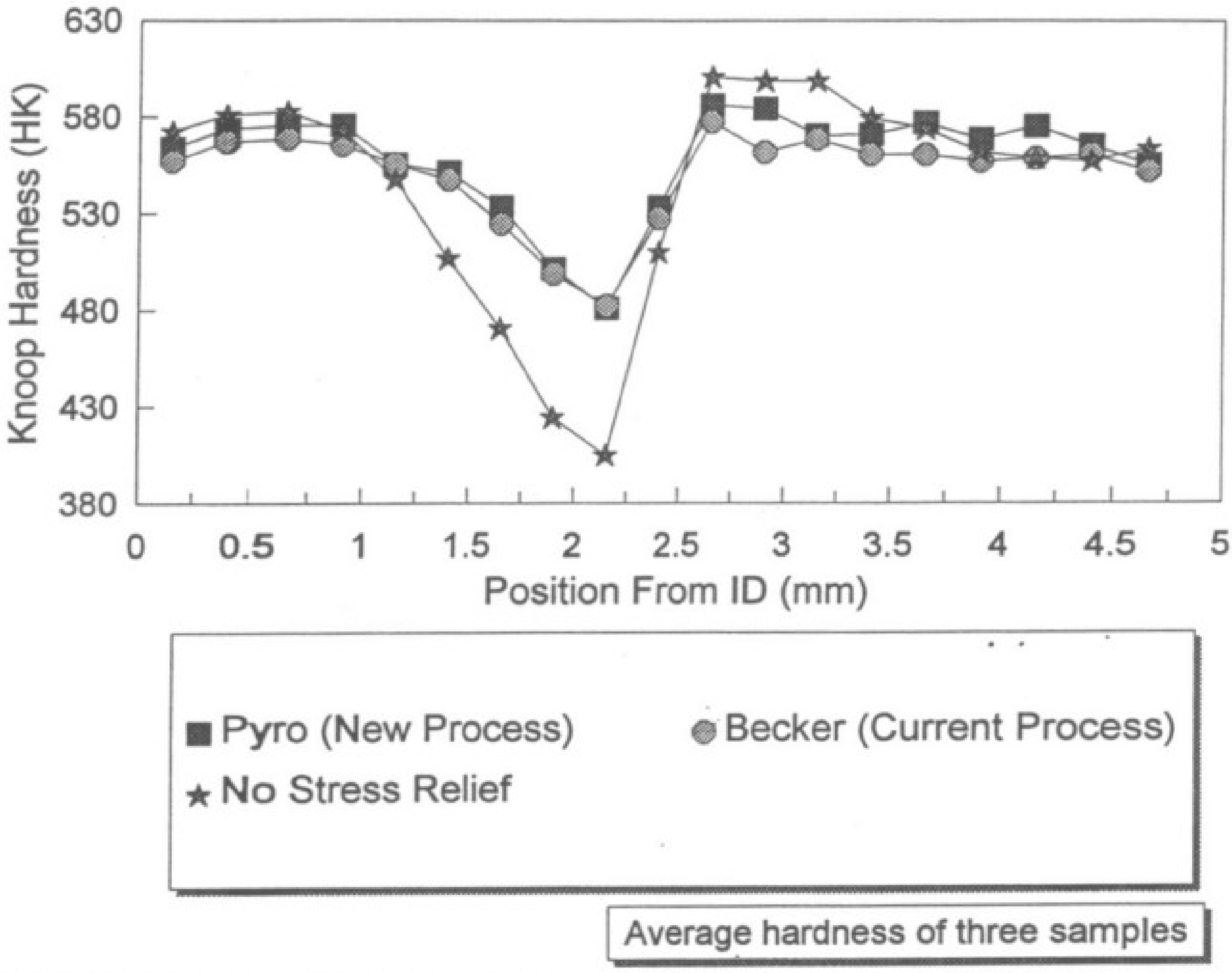
	Load (lbs)	UTS (ksi)
	7584	275.8
	7586	275.9
	7575	275.5
	7583	275.7
AVG	**7582.0**	**275.7**
Range	**11.0**	**0.4**

Becker (Current Process)
Test 4 (800F)
With Thermocouple

	Load (lbs)	UTS (ksi)
	7597	275.7
	7608	276.1
	7607	276.0
	7599	275.7
AVG	**7602.8**	**275.9**
Range	**11.0**	**0.4**

Spring Sample Hardness Comparison

[redacted]



[redacted]

Pyro (805/795/795F)
Full Load

Position From ID	Knoop Hardness (HK)				Rockwell C Hardness (HRC)			
	Sample 1	Sample 2	Sample 3	AVG	Sample 1	Sample 2	Sample 3	AVG
0.15	572	557	562	*563.7*	52	51	51	*51.3*
0.40	567	577	577	*573.7*	51.5	52	52	*51.8*
0.65	577	583	567	*575.7*	52	52	51.5	*51.8*
0.90	567	583	577	*575.7*	51.5	52	52	*51.8*
1.15	552	562	552	*555.3*	51	51	51	*51.0*
1.40	543	567	543	*551.0*	50	51.5	50	*50.5*
1.65	529	547	524	*533.3*	49	50	49	*49.3*
1.90	507	494	502	*501.0*	48	47	47	*47.3*
2.15	486	482	474	*480.7*	46	46	46	*46.0*
2.40	529	538	533	*533.3*	49	50	49	*49.3*
2.65	583	593	583	*586.3*	52	53	52	*52.3*
2.90	577	588	588	*584.3*	52	53	53	*52.7*
3.15	572	567	572	*570.3*	52	51.5	52	*51.8*
3.40	567	562	583	*570.7*	51.5	51	52	*51.5*
3.65	577	577	577	*577.0*	52	52	52	*52.0*
3.90	567	567	572	*568.7*	51.5	51.5	52	*51.7*
4.15	572	577	577	*575.3*	52	52	52	*52.0*
4.40	567	562	567	*565.3*	51.5	51	51.5	*51.3*
4.65	552	557	557	*555.3*	51	51	51	*51.0*
AVG	555.9	560.0	557.2	557.7	50.8	51.0	50.8	50.9
Range	97.0	111.0	114.0	105.7	6.0	7.0	7.0	6.7

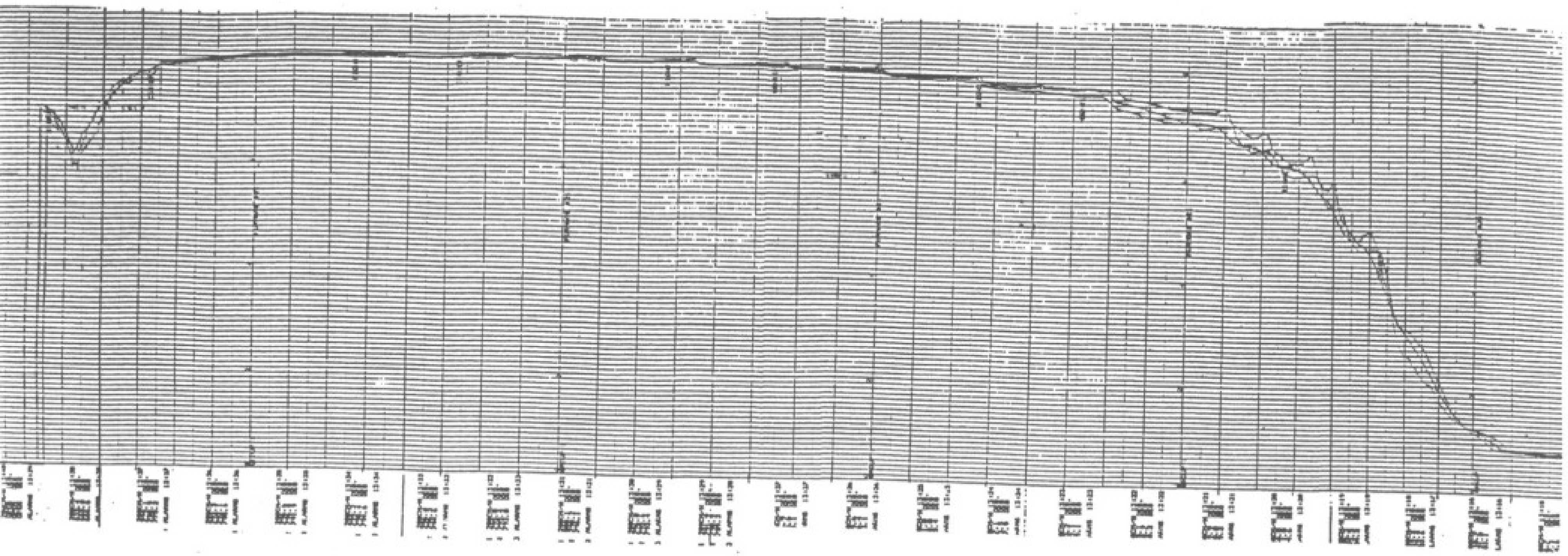
Becker (800F)
Full Load

Position From ID	Knoop Hardness (HK)				Rockwell C Hardness (HRC)			
	Sample 1	Sample 2	Sample 3	AVG	Sample 1	Sample 2	Sample 3	AVG
0.15	567	547	557	*557.0*	51.5	50	51	*50.8*
0.40	567	567	567	*567.0*	51.5	51.5	51.5	*51.5*
0.65	567	572	567	*568.7*	51.5	52	51.5	*51.7*
0.90	557	572	567	*565.3*	51	52	51.5	*51.5*
1.15	547	562	557	*555.3*	50	51	51	*50.7*
1.40	538	552	552	*547.3*	51	51	51	*51.0*
1.65	529	520	524	*524.3*	49	49	49	*49.0*
1.90	494	494	507	*498.3*	47	47	48	*47.3*
2.15	474	486	486	*482.0*	46	47	46	*46.3*
2.40	529	520	533	*527.3*	49	49	49	*49.0*
2.65	588	567	577	*577.3*	53	51.5	52	*52.2*
2.90	572	562	552	*562.0*	52	51	51	*51.3*
3.15	577	562	567	*568.7*	52	51	51.5	*51.5*
3.40	567	557	557	*560.3*	51.5	51	51	*51.2*
3.65	567	562	552	*560.3*	51.5	51	51	*51.2*
3.90	562	552	557	*557.0*	51	51	51	*51.0*
4.15	557	562	557	*558.7*	51	51	51	*51.0*
4.40	567	562	552	*560.3*	51.5	51	51	*51.2*
4.65	557	552	547	*552.0*	51	51	50	*50.7*
AVG	551.7	548.9	549.2	550.0	50.6	50.5	50.5	50.5
Range	114.0	86.0	91.0	95.3	7.0	5.0	6.0	5.8

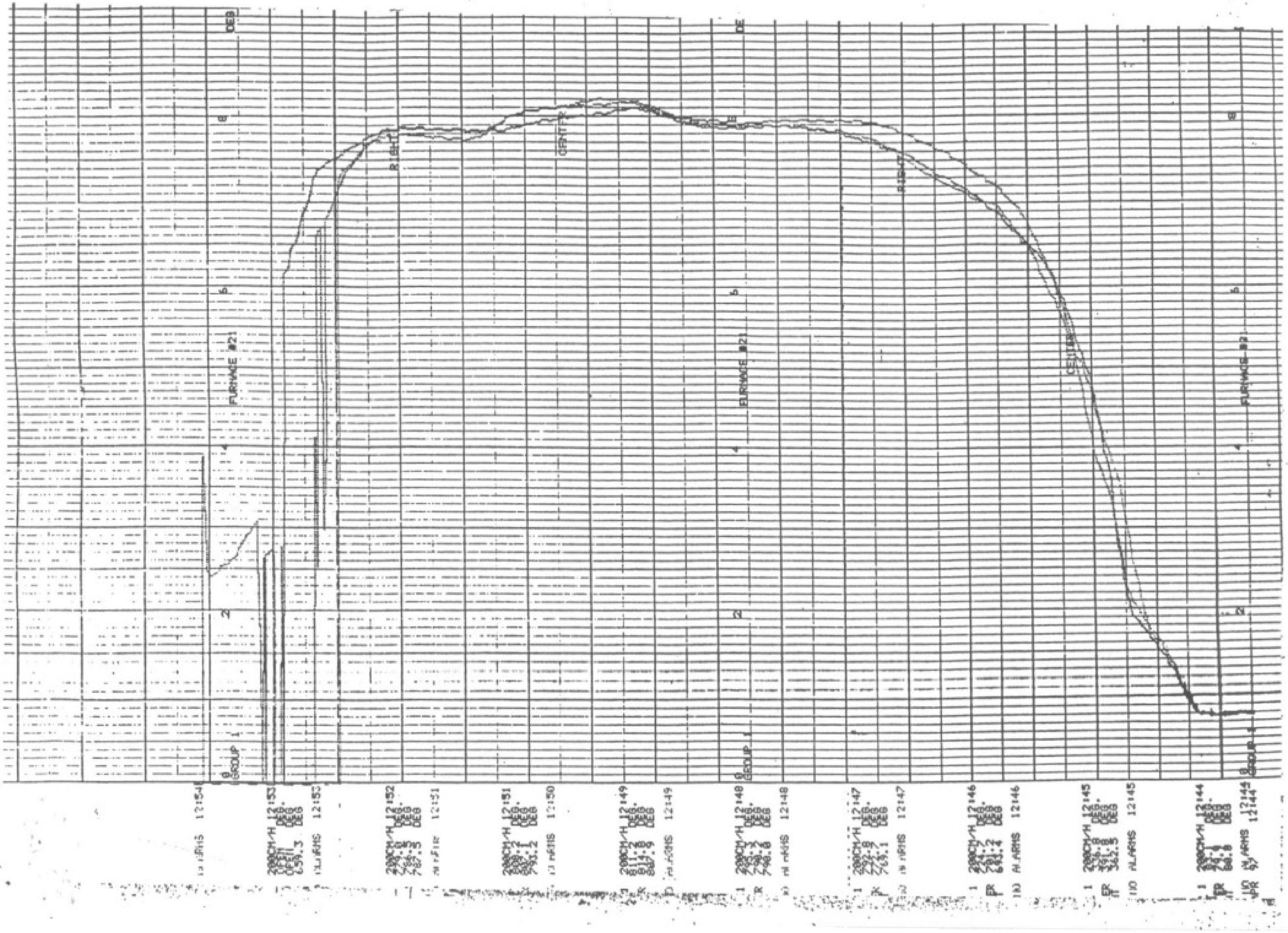
Non Stress Relieved Spring Samples

Position From ID	Knoop Hardness (HK)				Rockwell C Hardness (HRC)			
	Sample 1	Sample 2	Sample 3	AVG	Sample 1	Sample 2	Sample 3	AVG
0.15	577	583	557	*572.3*	52	52	51	*51.7*
0.40	583	593	567	*581.0*	52	53	51.5	*52.2*
0.65	583	593	572	*582.7*	52	53	52	*52.3*
0.90	562	593	562	*572.3*	51	53	51	*51.7*
1.15	543	557	543	*547.7*	50	51	50	*50.3*
1.40	502	520	498	*506.7*	47	49	47	*47.7*
1.65	455	494	463	*470.7*	44	47	45	*45.3*
1.90	428	428	418	*424.7*	42	42	41	*41.7*
2.15	405	395	415	*405.0*	40	40	41	*40.3*
2.40	511	507	511	*509.7*	48	48	48	*48.0*
2.65	604	599	599	*600.7*	54	53	53	*53.3*
2.90	599	604	593	*598.7*	53	54	53	*53.3*
3.15	610	593	593	*598.7*	54	53	53	*53.3*
3.40	567	588	583	*579.3*	51.5	53	52	*52.2*
3.65	593	572	557	*574.0*	53	52	51	*52.0*
3.90	567	562	557	*562.0*	51.5	51	51	*51.2*
4.15	567	557	552	*558.7*	51.5	51	51	*51.2*
4.40	577	543	552	*557.3*	52	50	51	*51.0*
4.65	577	557	557	*563.7*	52	51	51	*51.3*
AVG	547.9	549.4	539.4	545.6	50.0	50.3	49.7	50.0
Range	205.0	209.0	184.0	195.7	14.0	14.0	12.0	13.0

Becker (800°F)
Approx. 690 lbs/hr



Pyro (805/795/795°F)
Approx. 640 lbs/hr



[redacted]

[redacted] Report:
Customer:
[redacted] Division:
Part Number:
Wire Source:
Wire Size:
Material: [redacted]
Date: June 30, 1997

Introduction

A fatigue test was performed for the above mentioned part number by [redacted] Home Office Engineering. The test was conducted to validate the new Pyromaitre oven and to compare it with the existing stress relieving oven - Becker. Springs were cycled at elevated stress levels to induce failures of any inadequately stress relieved parts due to the residual stresses incurred from coiling.

Discussion

Ten springs stress relieved from each (Pyro and Becker) oven were fatigue tested for 50 million cycles on the Home Office 20 station rotary cycle fatigue tester. Each spring was pressed solid once and the solid height was recorded. Load 1 was measured at 1.880" and Load 2 was measured at 1.200". Springs were staggered on the upper and lower levels for uniformity. During cycling, oil at ambient temperature was sprayed on the springs to simulate the actual engine conditions.

Results

At the end of 50 million cycles, there were four spring failures. Two springs stress relieved in the Pyro oven failed. Two springs stress relieved in the Becker oven failed after about the same number of cycles as that of Pyro. Failure and load loss results are tabulated in the attached sheet. All the springs failed in fatigue [redacted] Pyro springs, on average, lost 1.9% load at the first height and 1.7% at the second height. Springs stress relieved in the Becker oven lost 3.9% load on the first height and 1.8% load at the second height.

Conclusion

Based on the failure and load loss results, the fatigue life of the springs processed in the Pyromaitre furnace are as good as, or better than the Becker furnace.

[redacted]
Applications/Test Engineer

Fatigue Test Table

[redacted] **Report:** [redacted]
Customer:
[redacted] **Division**
Wire Source:
Rod Source:
Part Number
Part Name:
Material:

Date Started: 05/19/97
Date Finished: 06/13/97
Prepared by: [redacted]
Test parameters:
Lift: 0.680 in.
Install Height: 1.200 in.
Speed: 2000 RPM
Oil Heat: On

Load 1 spec: 30.00 ± 2 lbs at 1.870"
Load 2 spec: 276.00 ± 8 lbs at 1.20"

Stress at Load 1: 15.8 ksi
Stress at Load 2: 145.3 ksi
Stress Range: 129.5 ksi

Spring	Solid Height	Before testing		After 50,000,000 cycles		Load 1 Loss		Load 2 Loss	
		Load 1	Load 2	Load 1	Load 2	Loss	Percent	Loss	Percent
ecker									
2	1.142	30.8	278.3			Failed at 37,496,200 ...			
3	1.370	28.6	272.0	28.7	267.8	-0.1	-0.3	4.1	1.5
6	1.143	30.2	280.0	27.7	274.7	2.5	8.1	5.4	1.9
7	1.140	29.9	276.1			Failed at 49,832,000 ...			
10	1.374	30.1	275.2	28.5	269.5	1.6	5.4	5.6	2.0
11	1.141	31.8	276.4	30.9	272.0	0.9	2.8	4.4	1.6
14	1.142	31.2	277.8	30.6	273.2	0.6	1.9	4.6	1.7
15	1.143	31.6	280.5	29.6	274.9	2.0	6.3	5.6	2.0
18	1.142	31.7	278.3	31.3	273.9	0.4	1.2	4.4	1.6
19	1.142	30.7	276.1	28.8	271.0	1.9	6.2	5.1	1.9
Pyro									
1	1.141	31.7	277.8	31.5	273.4	0.3	0.8	4.4	1.6
4	1.142	29.0	275.9	27.8	270.5	1.2	4.2	5.4	1.9
5	1.311	29.6	273.2	29.7	268.6	-0.1	-0.3	4.6	1.7
8	1.138	31.0	274.2	28.8	267.8	2.2	7.1	6.4	2.3
9	1.137	29.8	274.4	29.8	270.5	0.0	0.0	3.9	1.4
12	1.143	29.4	278.6	29.1	273.9	0.3	1.2	4.6	1.7
13	1.134	30.1	274.4			Failed at 48,878,800 ...			
16	1.136	31.5	276.6	31.3	272.0	0.2	0.5	4.6	1.7
17	1.138	30.6	277.6			Failed at 37,496,200 ...			
20	1.136	30.5	273.0	29.8	268.8	0.6	2.1	4.2	1.5
Average	1.188	30.6	277.1	29.5	272.1	1.2	3.9	4.9	1.8
Max. Beck	1.374	31.8	280.5	31.3	274.9	2.5	8.1	5.6	2.0
Min.	1.140	28.6	272.0	27.7	267.8	-0.1	-0.3	4.1	1.5
Average	1.156	30.3	275.6	29.7	270.7	0.6	1.9	4.8	1.7
Max. Pyro	1.311	31.7	278.6	31.5	273.9	2.2	7.1	6.4	2.3
Min.	1.134	29.0	273.2	27.8	0.0	-0.1	-0.3	3.9	1.4

Failures 2 - Pyro, 2 - Becker

[redacted]

Fracture Surface Analysis

[redacted] Report No.:	[redacted]
Customer:	
[redacted] Division:	
Wire Source:	
Part Number:	
Part Name:	Valve Spring
Material:	[redacted]
Date:	June 26, 1997

Sample Description

Two groups of springs were cycle tested, one stress relieved through the Becker oven and the other through the Pyro oven. Four springs failed on this test, two from each group.

Station	Group	Cycles to Failure	Fracture Position
2	Becker	37,496,200	3 coils from large diameter end coil.
7	Becker	49,832,000	2¾ coils from large diameter end coil.
13	Pyro	48,878,800	1⅔ coils from large diameter end coil.
17	Pyro	37,496,200	2 coils from large diameter end coil.

This report documents the fracture surfaces of these broken springs.

Examination

All four springs failed in torsional fatigue, initiating at the inside diameter, where the stress is highest. A transverse shear "facet" is at the initiation site. No discoloration is visible on the fracture surface showing that no cracks were present in the spring before fatigue testing. No mechanical defect are visible. Shot peening coverage is complete through out the springs.

Conclusion

The springs failed in high stress torsional fatigue. No defects were found.

[redacted]

cc: [redacted]