Statistical Process Control of Temperature Uniformity for Batch Furnaces

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"Commercial Heat Treater merges aerospace requirements with statistical process control to improve the furnace preventative maintenance program."

Background:

Statistical Process Control (SPC) is a common technique today used in manufacturing to insure the quality of the product being produced. Typically, it is applied to continuous or semi-continuous processes where a dimension or feature of the product is measured on a random sample taken over time. This data can be analyzed using statistical techniques to determine if a particular process is 1) capable of producing the desire dimension or feature and 2) whether or not this particular run of product is statistically in tolerance to a given acceptance level. Timely adjustments can be made to the process to insure that the process stays within defined limits of control.

Hayes Heat Treating utilizes SPC to analyze the data created during a temperature uniformity survey. Hayes Heat Treating, who is approved by NADCAP (National Aerospace and Defense Contractors Accreditation Program) for heat treating, follows the requirements of AMS 2750 when performing temperature uniformity testing. The requirements stated in AMS 2750, for performing temperature uniformity of batch atmosphere and vacuum furnaces, gives you the guidelines needed to set up a SPC capability study on a furnace. It states the frequency of testing, load configuration, required tolerance sample size and frequency of sampling. Instead of looking at a particular run of parts or series of runs, this technique looks more at capability of the furnace to perform a given function such as tempering or hardening. It offers the consistency and repetitiveness that is needed to develop useful statistical data that maybe lacking in production batch runs.

For commercial heat treaters, it can be difficult to apply meaningful statistical techniques to the process when using batch furnaces. Batch furnaces used at commercial heat treaters are commonly performing a multitude of processes. There can be several jobs from different customers in the furnace at the same time. The load size, temperature and time at temperature may change with every run. One processing batch may be a customer's entire month's production. There is no immediate feedback from the measured data on the product such as hardness to make any adjustments to the process such as you may have with a continuous process.

Another difficulty is the commercial Heat Treater has no control over the raw material or physical dimensions of the parts as received from the customer. Changes in the received material can affect the final product results. For example, changes in heat chemistry for tool steels can alter their hardenability enough to affect required tempering temperatures in order to achieve the final hardness requirement. The shape of the parts may add to inspection error. Use of alternate inspection scales, correction factors for cylindrical shapes all add a variation and possible error to the true measurement of the hardness.

Data Collection Technique:

The temperature surveys are conducted per the requirements stated in AMS 2750 "Pyrometry". The number of thermocouple sensors will be a minimum of five and a maximum of nine for the furnaces used at HHT. For a nine-thermocouple configuration used in a box-shaped heat zone, the thermocouples are located in each corner and middle of the working zone. The corner positions represent the extreme positions within the work zone that parts could be located during a production run. This is achieved by using a metal frame with welded test slugs in each position. The end of the thermocouple is inserted into the test slug in order to hold it in this position during the survey. Each thermocouple is attached to a multi-point chart recorder for data collection. The multi-point chart recorder and the thermocouple wire are calibrated in accordance with AMS 2750 as test instrument and test sensors, respectively.

The furnace is loaded with the metal frame of test thermocouples and is brought up to the survey temperature. The chart recorder documents the readings by creating a continuous curve of the test thermocouples. Once equilibrium is reached, such that there is no continuous rise in temperature of any of the test sensors, the chart recorder can be re-programmed to record in a table format. Data is collected every five minutes for a total of 30 minutes. While this is test data is being collected, a log of all working sensors shall be taken at the same time intervals as the test sensor data. Hayes Heat Treating achieves this data collection from the working sensors by using a Marathon Monitors Process Master data collection system. The data from the test sensors and the working sensors will be combined and analyzed to determine the furnace capability and the ability of the working sensors to properly represent the temperature of the work zone during normal production.

Data Analysis:

The test sensor data is evaluated first for temperature uniformity to the appropriate requirements in AMS 2750. Allowable temperature tolerances range from ±10°F to ±25°F for the processes that Hayes' performs. Each furnace has a designated allowable tolerance to which the uniformity data will be compared to determine acceptance. The raw data from the test sensors and test instrument must be corrected for any known deviations in reading as noted on the certification for the test thermocouple wire or in the previous test instrument calibration. The minimum and maximum corrected readings obtained during the 30-minute time interval are compared to the acceptable temperature tolerance for the furnace being surveyed.

Once the furnace has been accepted to the requirements of AMS 2750, a capability study is performed on the data. The table of data collected on the test chart recorder is entered into a spreadsheet and corrected using the appropriate correction factors for the test sensors. The working sensor data collected by the Marathon Monitors system is entered into the same spreadsheet for the same time interval. Now, this data is in a format that can be statistically analyzed to determine the capability of the furnace based upon all readings taken during the survey.

(Note: There are numerous software packages available on the market to be able to perform the statistical analysis work. The writer has chosen at this time to use a standard spreadsheet and designed it especially for each particular furnace.)

Histograms, X-bar and R Charts, and time temperature charts can be created once the data has been recorded. Hayes has chosen a specified limit of acceptance for the percentage above the upper specification limit and percentage below the lower specification limit. In this type of study, the out of specification is not parts per million of product, but rather specific regions within the working zone that are not in tolerance during the 30 minute test.

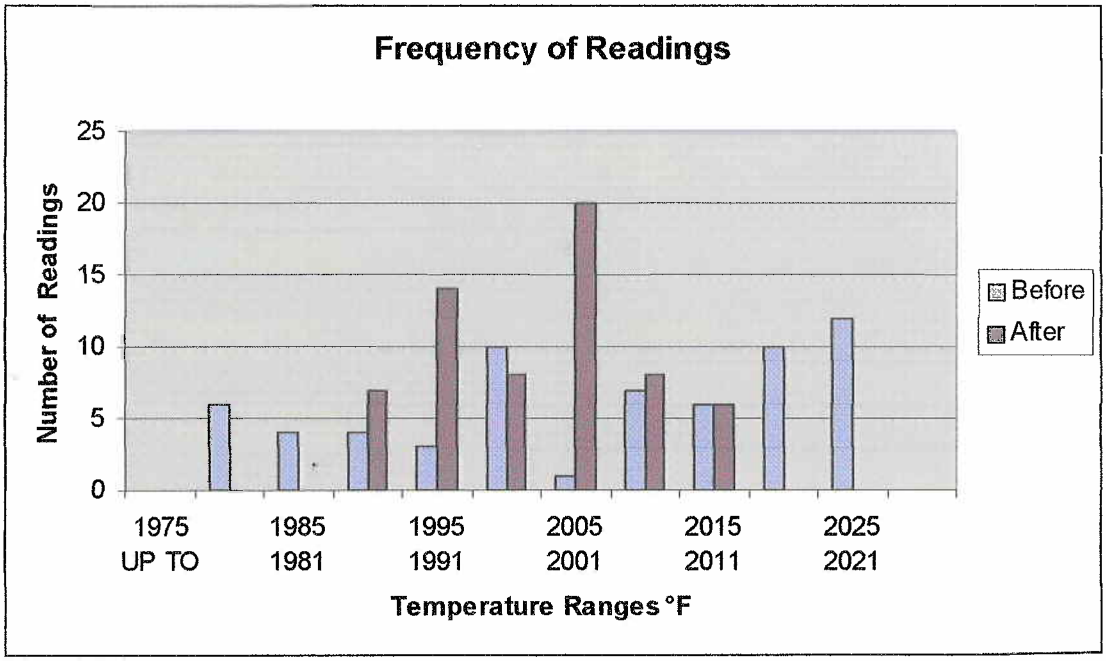
Using standard Cp. and Cpk numbers equal to or greater than 1.33 may not apply for this type of study because the sample is not perfectly random. The locations of the sensors do not change during the test and they are placed in locations, which represent extreme points in space of the working volume. Hayes has set a limit, which predicts when a furnace's uniformity is deteriorating or when the temperature control thermocouple location does not represent the center of the tolerance.

Case Study

A unique opportunity arose to perform a study of the effectiveness of this statistical technique for analyzing the temperature uniformity data. Hayes Heat Treating heat-treats balls for the bearing industry using a Hayes model VSQ vacuum oil quench furnace. A scheduled quarterly temperature uniformity test was performed on the furnace. The uniformity was acceptable to AMS 2750 requirements, but did not pass the Hayes statistical capability study. The SPC data indicated that there was a low temperature spot near the inner heat shield door. The door needed to have more insulation added due to wear. After the repair, the uniformity test was performed and its capability re-checked. The data indicated that the repair had made an improvement in the overall uniformity within the work zone.

	Before	After
Grand Average	2004	2001
Average Range	41.1	30.4
Estimated Standard Dev.	13.03	9.64
Capability Index, Cp.	0.63	0.86
% Below Lower Spec. Limit	1.29	.36
% Below Upper Spec. Limit	5.37	.62

The following histogram shows the improvement of the uniformity after the repair.

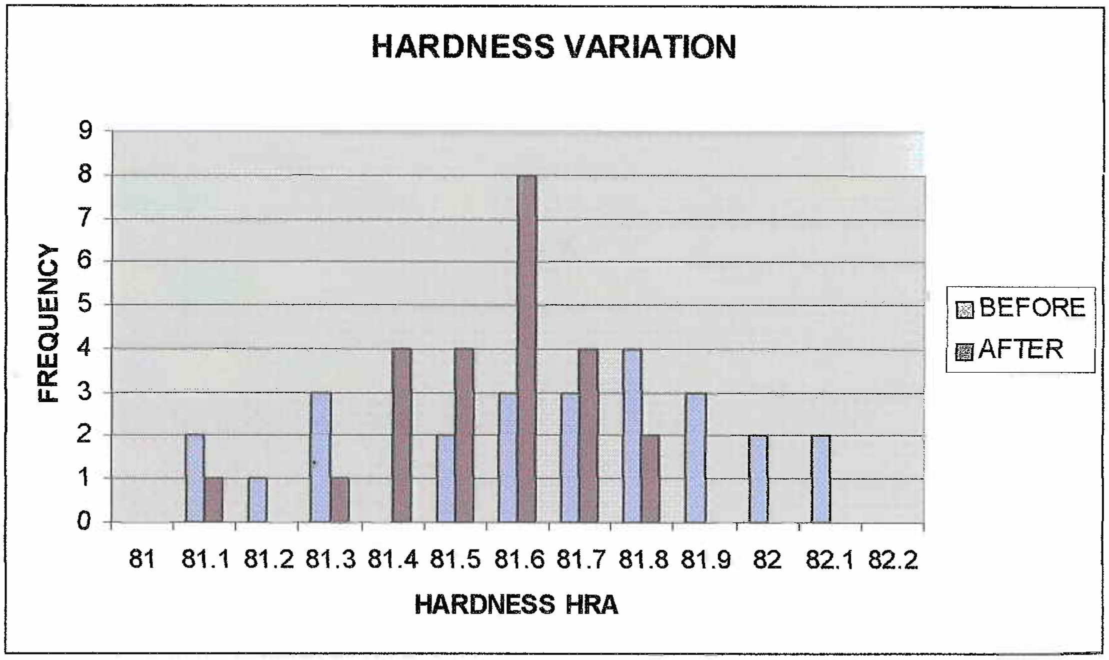


Two lots of 440C stainless steel balls were available for heat treatment during the time of the capability study. The process involves austenitizing followed by oil quenching and tempering. Two lots of balls of equal weight and from the same heat of steel were to be processed. One lot of balls was hardened before the rebuild of the door and the second was run after the rebuild. Both lots were tempered together.

A sample size of 25 balls was tested for hardness from each lot by creating parallel flats and checking the balls using Rockwell A scale. Here is the data for the two lots:

	Before	After
Sample Average	81.7	81.6
Sample Standard Deviation	0.30	0.16
Range	1.0	0.7

A look at the histogram of readings shows the overall improvement.



Conclusion:

The case study shows a strong correlation between a reduction in variance of the temperature uniformity and reduction of variance in hardness test results. By reacting to the results of the temperature uniformity survey before an out-of-tolerance condition occurred, resulted in no failures to the AMS 2750 requirement and the parts did not go out of tolerance for the hardness requirements.

The requirements of AMS 2750 for temperature uniformity testing is an excellent place to start when developing a statistical capability study for heat treating furnaces and ovens. It can give the heat treater a greater level of confidence that the equipment will be able to perform to the required temperature tolerances. When working to the requirements of AMS 2750, a heat treater should avoid failing a survey. If a survey fails, all jobs that were run in this furnace to the AMS 2750 requirement would have to be reviewed for affect and disposition. In a job shop environment, this can be a daunting task. Using statistical analysis techniques to monitor the temperature uniformity can eliminate such discrepancies.