Characterization of Fan Station Airflows in the Heat Treatment Facilities at Wyman Gordon

April 22, 2010

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Abstract

This paper presents and discusses data collected from air quench fan stations at the heat treatment facilities at Wyman Gordon Forgings in Worcester, Massachusetts. Physical characterization of the fan stations was achieved though measurement of air flow velocities at several fan speed settings. Analysis of this data will assist in determining the exact level of uniformity across all three new fan stations, as well as comparing the new fan stations to the current one. This work is a critical component to the overall qualification of the new heat treatment facility and will aid in ensuring similar cooling characteristics of the new heat treatment facility's fan stations. Ultimately, this work will help in providing products with the same microstructures, properties and performance as those processed through the existing heat treatment facility.

Introduction

Wyman-Gordon Forgings has started qualification of a new facility to expand the capacity to heat treat. This facility included new fan air quench stations which needed to be compared to the existing fan station. Wyman-Gordon's process to qualify the new heat treat facility began with a thorough characterization of the new fan stations. In opening this new facility, Wyman-Gordon can expand capacity in order to handle increased customer demand, and continue to provide quality parts to their customer.

The goal of this project was to assist Wyman-Gordon in the physical characterization of the fan stations through measurement of air flow velocities. Initial results will be compared to a report for one fan station submitted previously by an outside engineering to assess the measurement system. After comparison to the data previously collected to establish repeatability, measurements from the two remaining fan stations will be compared to the first fan station to detect anomalies in uniformity. Using this data, differences in flow between quenching stations can be accounted for, and recommendations can be made to achieve similar results across all stations. Ultimately, this will help in providing products with the same microstructures, properties and performance as those processed through the existing heat treatment facility.

Heat treatment is a method used to change the physical properties of a material such as grain size, hardness, brittleness and so on. The specific application for Wyman Gordon's isothermal product line is hardware (mainly rotating disks and seals) for use in the hot turbine and compressors sections of jet engines. Nickel-base superalloys are the material of choice for these high temperature applications, which are quite metallurgically complex relative to other aerospace alloys, and which require specific thermal processing routes to obtain the desired properties. The forging feedstock is produced by powder metallurgy processing and then isothermally forged at the Worcester facility, prior to undergoing various machining operations and non-destructive testing.

At Wyman Gordon, heat treatment is used to develop a uniform grain size to meet customer specifications. Forced air cooling which is the preferred method of quenching, further improves the microstructure to meet the customer specified properties. Forced air has a low cooling capacity, making it the best option to obtain the required properties while minimizing residual stresses in the end product. Since heat treatment is the final metallurgical processing step in the production of Wyman Gordon's product line, consistency of the quenching equipment is of paramount importance.

Methodology

Purpose

The purpose of this MQP is to characterize the air velocities of the fan stations in the new heat treatment facility at Wyman-Gordon so as to detect differences between the fan stations and to help assess how to create uniformity across them. Each fan station in the new facility must be tested to verify that the speeds are consistent with the equivalent speeds of the current fan station. As previously stated, it is important to have the fan speeds to be consistent because if they are not, the materials heat treated at Wyman-Gordon may not be consistent. In addition to comparing measured data to previously obtained data, overall air velocity uniformity is assessed.

Equipment and Setup

The equipment needed to enable the testing are a wooden circular guide (Figure 1) numbered and spaced by the amount of points to be taken at that row (3, 7, 9, 11, 11, 13, 13, 13, 11, 9, 7, 3 from the back of the grid to the front) a pitot tube which measures the airflow, a metal channel implement that guides the pitot tube along the measurement grid, and a Shortridge ADM-880D digital airflow multimeter which records ten data points at each point in the grid. Each point on the grid is spaced 1.5 inches apart. The width of the fan station outlet is 20 in and the air flow measurements are taken 6.8 inches from the outlet. The average of the ten data points are calculated after all data is collected, and presented in a spreadsheet formatted to represent the measurement grid. At row 3 there are three points, at row 7 there are seven, and so on. There is a total of 121 points in the measurement grid.

Figure 1: Test Rig set up on Fan Station 1 ("FS1")

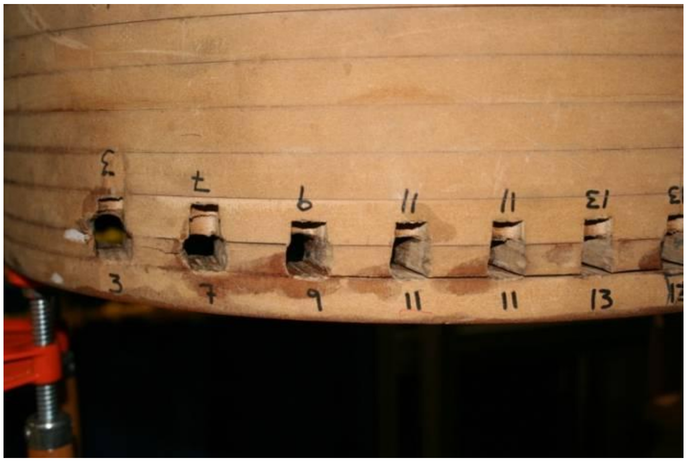


Figure 2: number system on wooden guide

Figure 3: Pitot Tube

Figure 4: Shortridge Multimeter

Testing

The new fan stations are controlled by variable frequency drives (VFD), with several available RPM settings. To give a wide range of velocity outputs to characterize, six speeds are measured for the bottom fan and seven for the top. The two best speeds to match the existing fan station were determined before the start of the project through thermocoupled piece experiments. The existing station is not controlled by VFD – therefore these speeds are the most important in terms of fan station comparison, since it represents the cooling process for a variety of parts.

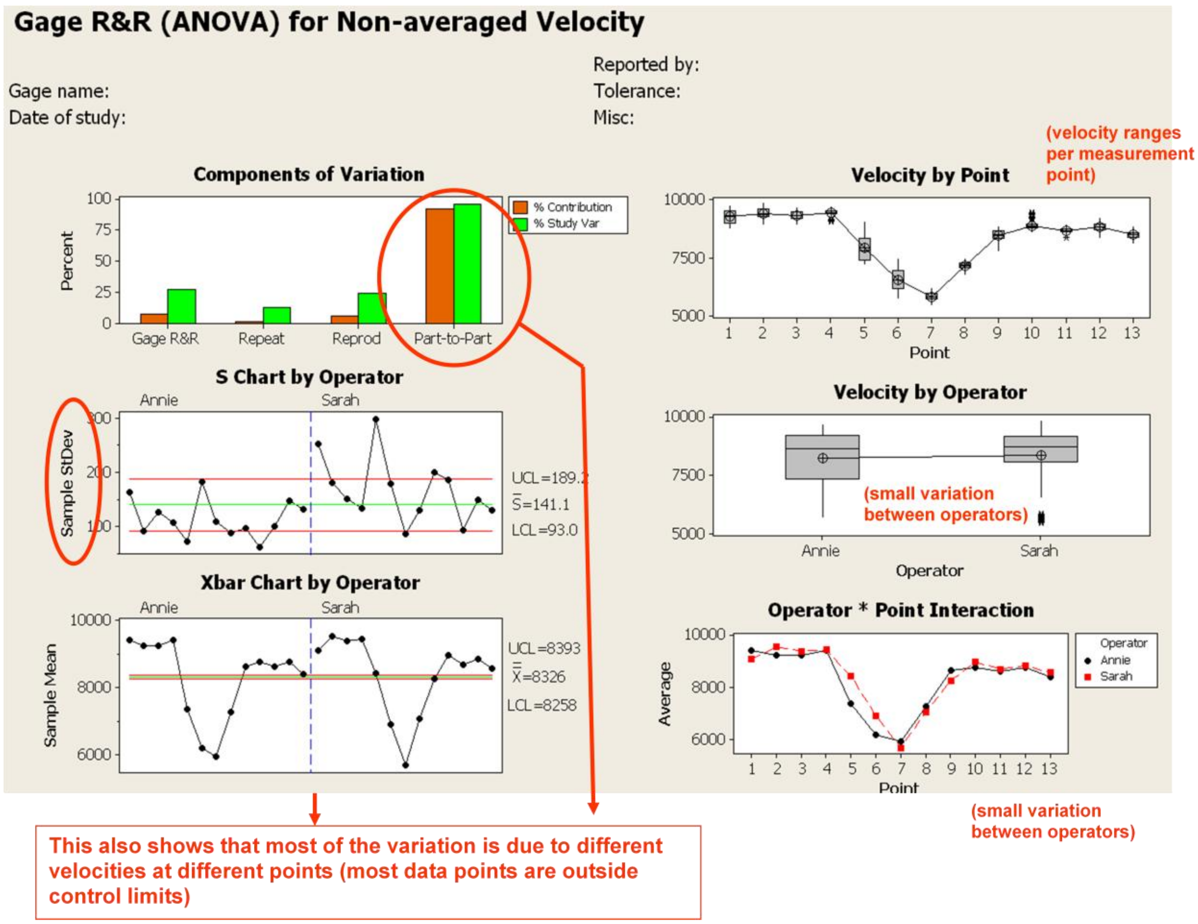
For each speed one member of the team holds the pitot tube at a point and the other team member uses the Shortridge multimeter to record ten data points, which are automatically stored in the unit's memory. When this is done, the recording team member gives the ok to the pitot tube team member to go to the next point. Measurement of velocities at each speed starts from the middle point of the innermost row (at the back of the fan station) and proceeds to the next row towards the front of the fan station.

Data Presentation

After data is measured, it is uploaded to the computer. Using a VBA macro in Microsoft Excel, each set of ten data points corresponding to each of 121 measurement locations are averaged, and then placed into their corresponding location in a grid in an Excel spreadsheet. This grid represents to layout of the measurement grid, and is used as source data create velocity surface plots. These velocity data are subsequently used to make difference plots. These plots are crucial to analyzing the data as they give a visual representation of the velocity patterns measured. The difference plots are needed for comparisons from fan station to fan station, as well as for comparison of top to bottom fans at a particular fan speed. They show the differences in the velocities of the flow between fan stations, calculated by subtracting averaged velocities from their corresponding points in the measurement grid.

Accuracy of Results

In order to ensure the accuracy of the results and the consistency of the data taking, a Gage R&R was performed. A Gage R&R is a way to check repeatability and reproducibility of a measurement system with different operators. Both operators took four sets measurements along the center line of the measurement grid for the bottom fan of a particular fan station at the same specific speed.



This shows that the variation was not due to the way the data was collected, but by actual variation at different point along the measurement grid. In the S Chart by Operator graph, this shows the acceptable range of variation that the operators were allowed to be in. It shows there was little variation and the operators were in fact within the acceptable range. In the Velocity by operator chart, there is little variation between the two operators; this proves that the method of measuring can be repeated by anyone and the results will be comparable. These graphs show that the measurement system is reliable and repeatable.

Gage R&R Study - ANOVA Method

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Point	12	1269072009	105756001	32.179	0.000
Operator	1	3833934	3833934	1.167	0.301
Point * Operator	12	39438216	3286518	143.904	0.000
Repeatability	1014	23157935	22838		
Total	1039	1335502093			

Alpha to remove interaction term = 0.25

Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	105483	7.61
Repeatability	22838	1.65
Reproducibility	82645	5.96
Operator	1053	0.08
Operator*Point	81592	5.89
Part-To-Part	1280869	92.39
Total Variation	1386351	100.00

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)
Total Gage R&R	324.78	1948.69	27.58
Repeatability	151.12	906.74	12.83
Reproducibility	287.48	1724.88	24.42
Operator	32.45	194.67	2.76
Operator*Point	285.64	1713.86	24.26
Part-To-Part	1131.75	6790.53	96.12
Total Variation	1177.43	7064.61	100.00

Number of Distinct Categories = 4

A good Gage R&R is indicated by a % contribution of repeatability plus reproducibility less than 10%. This Gage R&R's % Contribution is 7.61%. Most of the variation in measurements is due to "part-to-part", in this case this is measurement location along the grid. A further indicator of a satisfactory Gage R&R is a %Study Var for "Total Gage R&R" of less than 30%. As seen in the bottom most table, the total gage R&R for this analysis is 27.58%. Lastly, the number of distinct categories that the analysis sorts the data into is 4. This says that the measurement system adequately detects differences between the velocity measurement points.

From this Gage R&R it can be concluded that the method of taking measurements is repeatable amongst different operators, and is therefore a reliable measurement system for the goal of this project.