AC 2008-1748: ENGAGING ENGINEERING TECHNOLOGY STUDENTS USING A COORDINATE MEASURING MACHINE

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Engaging Engineering Technology Students using a Coordinate Measuring Machine

Abstract

Western Carolina University's Engineering Technology program prepares its students for a variety of industrial careers. Part of this preparation is based on the engagement model that pairs students with real-life industrial projects, benefiting both the student and the industrial partner. Haldex Hydraulics Corporation is a company that makes internal gear hydraulic pumps in Statesville, NC. The complex geometry of their pump housings creates a difficulty in verifying that dimensions are being maintained in the production process. In an effort to verify dimensional accuracy and to build a strong relationship with WCU, Haldex sent two different sets of pump housings and the corresponding gears for verification on WCU's coordinate measuring machine (CMM), a Zeiss Contura HTG. With over 200,000 in worldwide use, CMMs provide the flexible gauging and high precision required for today's stringent quality requirements. Using an undergraduate student's independent study project as the platform, these pump housings were checked against the engineering print for 42 dimensional requirements for one housing part number and 38 for the other. Considering the process capability index, C_p, as the primary tool measure of Haldex's ability to achieve Six Sigma (6σ) quality, the results from this study indicate a need for improvement: only one feature exceeded the C_p value of 2.0 required to claim 6σ quality with the average being 0.605, a level equivalent to 1.8-sigma. While this falls short of their goals, the results provided Haldex with the critical information they require to progress toward their goal of Six Sigma quality, and that same data set supplied valuable data to teach 6σ topics to Quality Systems, a junior-level Engineering Technology course. The hydraulic pump housing data set illustrates the use of the Six Sigma tools on a hands-on subject, which these ET students thrive on, as they prepare for their careers in manufacturing, design, quality, technical sales, and many others.

Introduction

Situated in the mountains of western North Carolina, Western Carolina University (WCU) is a comprehensive state university with approximately 9,000 undergraduate and graduate students. With a mission to engage with regional industry, the Engineering and Technology Department has built relationships with industrial partners such as Caterpillar, ConMet, Volvo, Blue Ridge Paper, and many more. This engagement effort has produced benefits that span all parties involved, including students, faculty, university, and industrial partners. The students have gotten real-life, industrial, hands-on projects that expose them to the challenges that they will face after graduation; they have also been exposed to potential employers through their project. The engagement model has benefited the involved faculty by exposing them to current industry needs, and keeping their skill set up-to-date.[1] The university has received a great deal of positive publicity through the exposure of industry to the facilities and human resources on campus. Industrial partners have seen benefits in several modes: they have received technical assistance at little or no cost to the company, while gaining exposure to a multitude of students, potentially their future hires. The manufacturing sector ranks number one in employment with 19.3% of all jobs in the region of the state.[2]

One of the regional employers that has cultivated a strong relationship with the university is Haldex Hydraulics, located in Statesville, NC. Haldex, headquartered in Stockholm, Sweden is an international corporation, providing products for the vehicle industry. The Statesville plant manufactures internal gear hydraulic pumps for heavy earth-moving equipment. Haldex has worked with the university on engagement projects to explore new designs, as well as to evaluate existing products. Over the past year Haldex has brought two different pump designs to campus for validation on the coordinate measuring machine (CMM), engaging faculty and students in the effort.

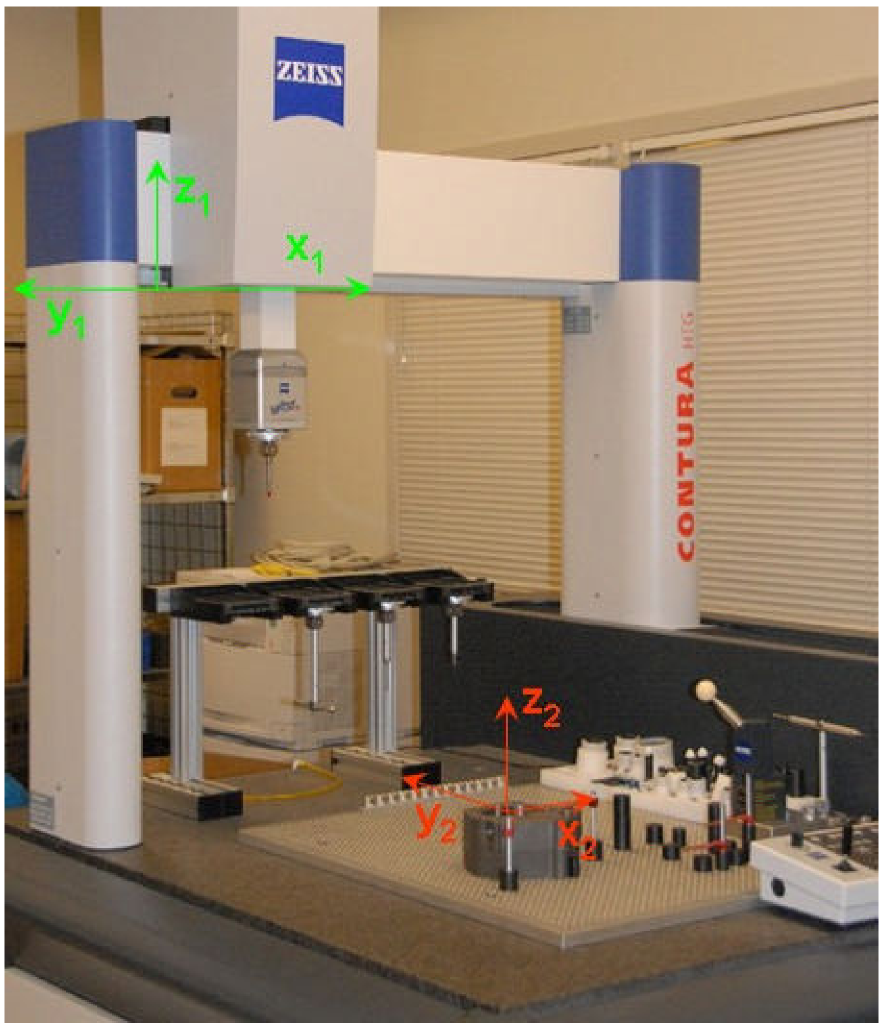

Figure 1: Coordinate measuring machine with x, y, z axes

Originally introduced in the 1960's, CMMs are high-precision flexible gages capable of measuring a wide range of geometries to micron-level precision.[3] The most popular configuration is one that moves on three independent x, y, and z axes with a probe that contacts the part being measured. Figure 1 shows the CMM used in this research with x, y, and z axes labeled on the pump housing being measured. The CMM has an absolute reference frame (x_1-y_1-z_1), and local reference frame (x_2-y_2-z_2) that is aligned according to the part geometry. The measurements can be taken manually, or by means of computer numerical control (CNC) interface. In this research, the programs were developed by manual means, then executed using the CNC mode.[4]

Overview of Coordinate Measuring Machine and Hydraulic Pump Housing

The CMM shown in Figure 1 was used to measure the pump housings in question; it is a Zeiss Contura model HTG from Carl Zeiss, Inc., based in Oberkochen, Germany. The x-y-z Cartesian coordinates allow the probe to reach any space within the defined workspace. At the end of the probe is an interchangeable stylus with an industrial spherical ruby (aluminum oxide sphere). The stylus can be exchanged to provide several different configurations and ruby diameters. The axes provide precision of 2 μm (0.000078 in)[5]—approximately 0.1 mil in machining terms (Note: a typical human hair is on the order of 50 μm). The CMM's CNC control is provided by Zeiss software called Calypso, which provides the tools for developing and executing the measurement plan.

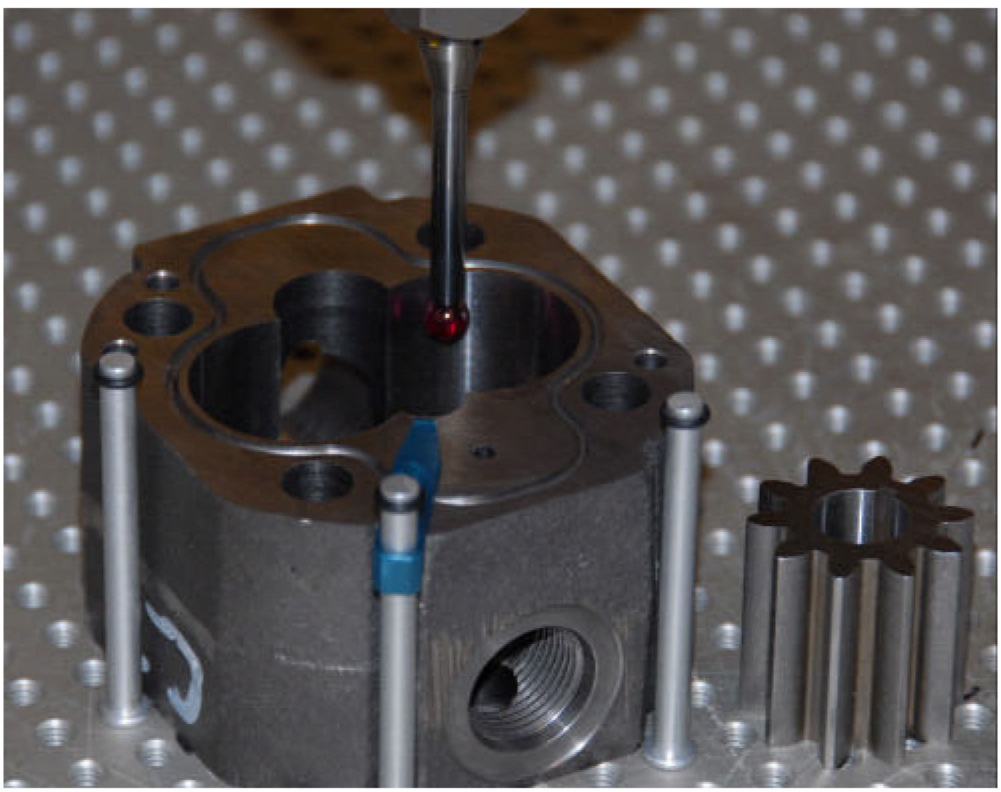

Figure 2: Pump housing and internal gear

Haldex provided two hydraulic pump housing designs for analysis. The pumps are produced for heavy earth moving equipment, such as bull dozers, front-end loaders, etc. Figure 2 shows one of the housings sitting next to one of the two internal gears that mesh inside the housing during operation. Measurement for the second pump housing has begun, but this paper focuses on the completed results of the first housing. Each pump housing has 42 features that required verification by Haldex. To obtain statistically significant results, 40 housings were measured and compared to the corresponding engineering specifications. The part features of the housings that were measured included bearing bores, gear bores, dowel holes, and planar surfaces. The measurements collected were parallelism, flatness, perpendicularity, location, and diameter, as detailed in Table 1 later in this paper.

Part Measurement and Results

For proprietary reasons, the engineering print cannot be presented, nor specific part results, but aggregate results are presented in this paper. As shown in Figure 3, the x-y-z orthogonal axes were aligned on the part as shown. The alignment routine was carried out for each housing, and is based on the generation of several key features, such as top plane and bearing bore cylinders.

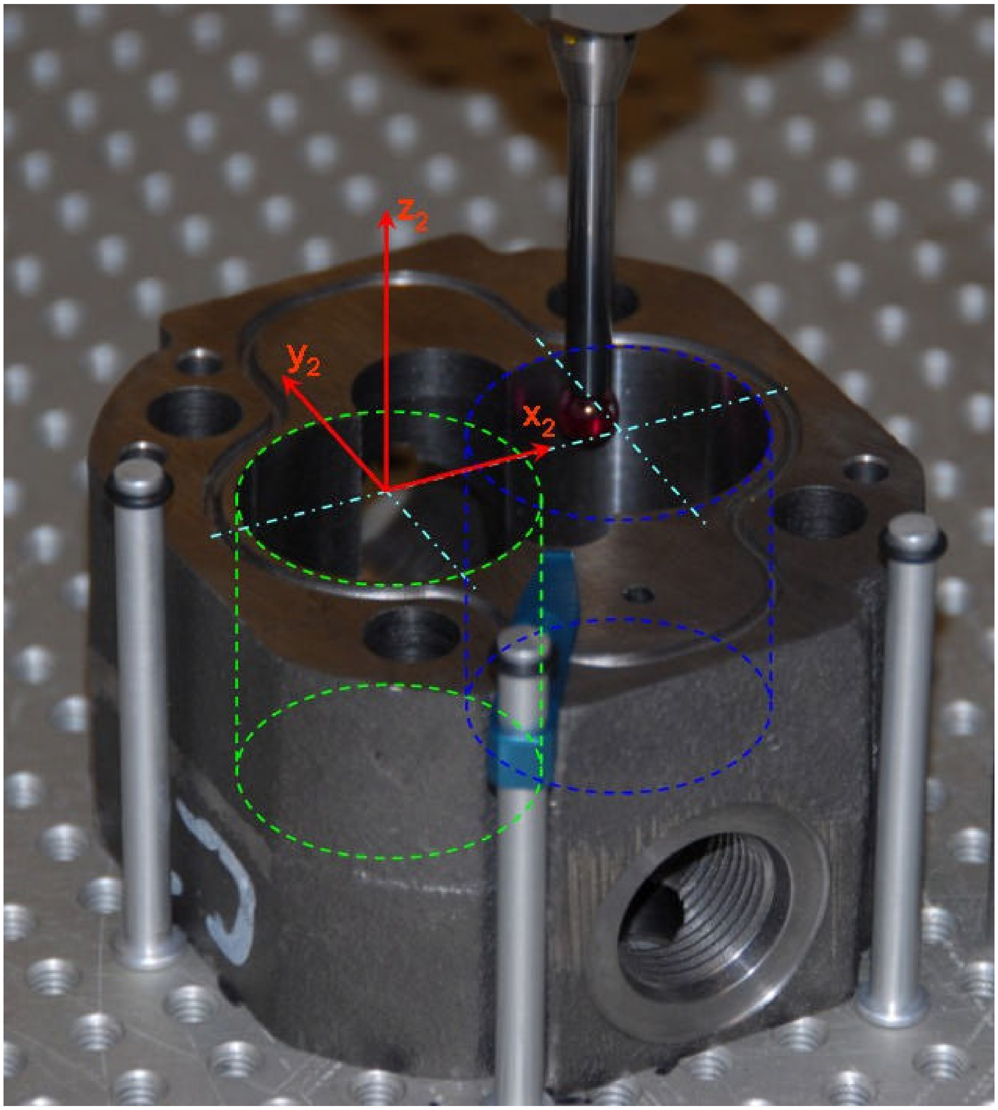

Figure 3: Axis alignment

The top plane was probed to establish the origin relative to the z-axis. The bearing bores (cylinders) were probed to establish location of the origin within the plane. Finally, the x- and y-axes were rotated about z until x pointed toward the center of the rightmost bore. From this alignment and housing orientation the features of interest were probed and recorded.

All 40 pump housings were checked for all 42 individual features, with a summary of those results shown in Table 1. The capability indices, C_p and C_{pk}, are calculated as follows:

$$C_p = \frac{USL - LSL}{6\sigma}$$

$$C_{pk} = \min\left(\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right)$$

USL = upper spec limit, engineering specification

LSL = lower spec limit, engineering specification

μ = statistical mean of the data set

σ = statistical standard deviation of the data set

Six Sigma quality requires that a C_p value of 2.0 be achieved; a C_p value of 1.0 indicates a three-sigma level of achievement, which falls short of current industry goals. The greater C_p, the better. C_p is by definition always greater than or equal to C_{pk}. If C_{pk} is equal to C_p, then it indicates that the process is well-centered between the upper and lower specification limits. A negative value for Cpk indicates that the mean falls outside the specification limits—not generally a good situation. As shown in the table, these data generally fell short of the goal of Six Sigma with one measurement, #30 Housing Height, achieving C_p=6.63. The average C_p level of 0.605 provides Haldex with information that can assist design and manufacturing engineers to improve their processes to strive toward higher quality levels.

Table 1: Pump Housing measurement results

Char #	Characteristic	Mean	St Dev	Cp	Cpk
1	Plane_E Flatness	0.000192	0.000086	1.93	0.74
2	Base-to-Plane_E Parallel	0.003801	0.002152	0.15	-0.28
3	GB-Plane Plane_E Parallel	0.000375	0.000298	0.11	-0.20
4	BBore_J Diameter	0.812391	0.000299	0.28	0.10
5	BBore_J Perpendicularity	0.000121	0.000110	0.46	0.37
6	BBore_H Diameter	0.812376	0.000343	0.24	0.07
7	BBore_H Perpendicularity	0.000146	0.000107	0.47	0.46
8	Bore Dist H-J 3d	1.250319	0.000640	0.39	0.22
9	GBore_A Diameter	1.480495	0.000482	0.24	0.07
10	GBore_A Location_X	0.000474	0.000757	0.33	0.12
11	GBore_A Location_Y	0.000445	0.000511	0.49	0.20
12	GBore_A Perpendicularity	0.000311	0.000293	0.17	-0.01
13	GBore_B Diameter	1.480446	0.000493	0.24	0.03
14	GBore_B Location_X	0.000724	0.000582	0.43	0.01
15	GBore_B Location_Y	0.000587	0.000584	0.43	0.09
16	GBore_B Perpendicularity	0.000234	0.000400	0.13	0.06
17	GBore Height_A	1.501956	0.000136	0.37	0.35
18	Dowel_A Diameter	0.219335	0.000070	0.96	-0.65
19	Dowel_A Location_X	0.875266	0.001126	0.22	0.14
20	Dowel_A Location_Y	0.875033	0.001488	0.17	0.16
21	Dowel_A Perpendicularity	0.000072	0.000042	1.20	0.58
22	Dowel_B Diameter	0.219946	0.000086	0.78	-2.90
23	Dowel_B Location_X	1.499366	0.001452	0.17	0.03
24	Dowel_B Location_Y	1.500388	0.000727	0.34	0.17
25	Dowel_B Perpendicularity	0.000359	0.000076	0.66	-0.26
26	Dowel_C Diameter	0.219220	0.000085	0.79	-0.08
27	Dowel_C Location_X	2.125062	0.001095	0.23	0.21
28	Dowel_C Location_Y	0.875282	0.001116	0.22	0.14
29	Dowel_C Perpendicularity	0.000125	0.000083	0.60	0.50
30	Housing Height	2.210263	0.000503	6.63	-8.13
31	Dowel_D Diameter	0.221186	0.000201	0.33	-3.30
32	Dowel_D Location_X	0.875672	0.000581	0.43	0.04
33	Dowel_D Location_Y	0.875536	0.000556	0.45	0.13
34	Dowel_D Perpendicularity	0.000188	0.000090	0.56	0.42
35	Dowel_E Diameter	0.219325	0.000089	0.75	-0.47
36	Dowel_E Location_X	1.500246	0.000798	0.31	0.21
37	Dowel_E Location_Y	1.499051	0.000905	0.28	-0.07
38	Dowel_E Perpendicularity	0.000172	0.000088	0.57	0.49
39	Dowel_F Diameter	0.219476	0.000107	0.62	-0.86
40	Dowel_F Location_X	2.125351	0.000498	0.50	0.27
41	Dowel_F Location_Y	0.874730	0.001211	0.21	0.13
42	Dowel_F Perpendicularity	0.000154	0.000085	0.59	0.57

Lessons Learned

As an independent study project engaged with industry, this study accomplished several goals and highlighted issues to correct in the future. The exposure for the student was extremely valuable: he learned critical metrology techniques that will aid him in his industrial career; he worked with Six Sigma quality tools that will be equally valuable; he engaged with a regional company with real business needs. Graduate students have typically been the source of manpower to work these engagement projects, but increasingly, senior-level students are showing the capacity to provide meaningful work to execute these projects through independent study courses. In the classroom, these data have proven valuable: ET 331 Quality Systems is a junior-level quality course that provides students with the analysis tools necessary to work in a Six Sigma quality environment. The data set collected in this study of the first pump housing provided real-life data that provides challenges in interpretation, unlike the simulated data that often depict an ideal world.

Another lesson learned is one that goes with any equipment-based laboratory work. The CMM did not cooperate during several points during the investigation, most notably at the end of the semester during the student's independent study. Though the program had been written for the second housing, sufficient data were not gathered to provide a complete report for the second housing. The lesson here is that "Plan B" must be developed at the outset, especially when dealing with lab equipment. Another lesson involved the time needed to actually develop the alignment procedure. Complex geometry and relatively small features can make for a difficult alignment process. Budgeting additional time on the front end of the project would have alleviated this issue.

Conclusion and Further Recommendations

Although the lessons mentioned above were obstacles to completing this project, the overall success was noteworthy. The senior student, working the independent study project, was exposed to the process of measuring with a CMM, a skill most useful in the manufacturing industry. In addition to developing skills on the CMM, he also put his quality systems course to good use in applying his statistical analysis tools. Haldex Hydraulics was extremely pleased with the data analysis on their pump housings—a task that their heavy production schedule prevents from happening on a routine basis. The faculty member continued to develop skills relevant to the industrial and academic worlds, using these real world data in the classroom for examples. The engagement model is one that has proven to benefit all those who are actively involved.

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