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THREAD ROLL DIE MEASUREMENT SYSTEM

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ABSTRACT

The goal of this project is to develop an automated system for the measurement of thread roll dies for Precision Castparts Corporation SPS Fastener Division. The system is expected to measure all critical dimensions of the dies and provide a simple go no-go for die usability. A statistical database is also to be kept in order to analyze results and make accurate predictions about a die life cycle. It is anticipated to save time and money for PCC by accurately telling them if parts made will be in conformance before running product through the dies.

This team is working in conjunction with P11582, Rivet Inspection Automation. Their team is also working with PCC and Dr. Alan Raisanen and facing similar automation, range of usability and LabView integration problems. Together the two teams are working together to solve similar problems and provide PCC with two automated measurement systems.

NOMENCLATURE

MMC – Multiple motor control
MSD – Multi-disciplinary senior design
PCC – Precision Castparts Corporation
RIT – Rochester Institute of Technology
RRO – Radius run out
SPS – Specialty Pressed Steel
SQC – Statistical quality control
SQL – Structured query language (Sequel)

INTRODUCTION

Precision Castparts Corporation SPS Fastener Division uses flat and round dies to produce fasteners for the aerospace industry. The dies are produced by an outside vendor that uses a surface profiling tool to take measurements on critical dimensions. This process is time consuming and impractical for every die. SPS currently does not have their own system in place that can test the dies when they arrive. This results in wasted setup/production times and materials.

The mission of the team is to design and construct a tool to measure, inspect, and validate critical die dimensions. The data may be used to develop statistical process control and to help understand the wear on a die over its life.

The main deliverable of this project is not only to design a system capable of producing reliable measurement results on dies, but also to make the system inexpensive and simple enough to be rebuilt and delivered to multiple PCC facilities. As part of this deliverable our team had to successfully document all processes and develop training documentation and maintenance plans. Also since the PCC division we were working closest with is located in Jenkintown, PA, the ability of our system to be easily torn down and put back together after transport needed to be considered.

CUSTOMER NEEDS AND METRICS

From our initial project packet and a few discussions with PCC and Dr. Raisanen a set of achievable customer needs was determined. Three main categories were established to easily group certain needs together. Twenty-seven needs were discussed and an importance on a 1,3,9 scale with 9 being critical, was given to each one.

Category	Customer Need	Description	Importance
System	CN1	Training docs	1
	CN2	Training personnel	1
Measurement	CN3	Environmental protection	9
	CN4	SQC	3
	CN5	Small/portable	3
	CN6	Hold part w/o damaging	9
	CN7	Efficient	3
	CN8	Improve cycle time once database is established	1
	CN9	Compatible with multiple dies	3
	CN10	Low cost	3
	CN11	Automated	9
	CN12	Go/No-go display	3
	CN13	Verify conformance	9
	CN14	Computer to product interface	3
	CN15	Verify overall die shape	3
	CN16	Verify RRO	9
	CN17	Verify thread pitch	9
	CN18	Verify thread shape	9
	CN19	Clean parts before measurement	9
	CN20	Clean lens	9
	CN21	Shock resistant	3
	CN22	Fail-safe established if bad run	3
Database	CN23	Database collection	1
	CN24	Accurate database	9
	CN25	Verify with drawings	9
	CN26	Compare to same die	3
	CN27	Die numbering system	3

Figure 1. Customer Needs

From these customer needs a set of quantifiable metrics was established. Ideal and marginal values were determined and assigned an importance scale similar to the customer needs; 1 – preference, 3 – nice to implement and 9 – must have. Throughout our design these customer needs and specifications were what our team aimed to achieve.

Eng. Spec #	Importance	Specification	Unit of Measure	Marginal Value	Ideal Value
ES1	1	Weight	Lbs	> 100	< 100
ES2	3	Footprint Size	Sq ft	6	4
ES3	9	Cost	$	$ 10,000	$ 7,000
ES4	3	Cycle Time	Minutes	5	< 5
ES5	3	Die compatibility	Models	3/8" and 5/8" models	All
ES6	9	Total measured coverage	%		
ES7	3	Data storage	# dies		All
ES8	3	Customer ease			
ES9	9	Clean dies	%	95	100
ES10	9	Measurement precision	in	.001	.001

Figure 2. Engineering Specifications

CONCEPTS AND DESIGN

In order to ensure a fully functional unit that was able to meet the overall project goals, we came up with several ideas for designs. Different ideas for each of the subfunctions were brainstormed by the team as a whole. Three overall designs were created, all of which would meet all criteria. Pugh charts were used to score the different concept ideas. Each criteria, or scoring parameter, is given a weight and then compared to the base design. This base design, or datum, is switched and the process is repeated until each design has been compared to each other datum.

After completing the Pugh charts an overall design idea was achieved. It was determined that a complete structure would be built with linear stages and stepper motors. The die would be loaded onto the structure with a simple die fixture and then placed under a measurement sensor. By using this placement system the damage to the sensor is minimized. For software a LabView program would be designed and compared to known die in Excel.

MECHANICAL DESIGN METHODOLOGY

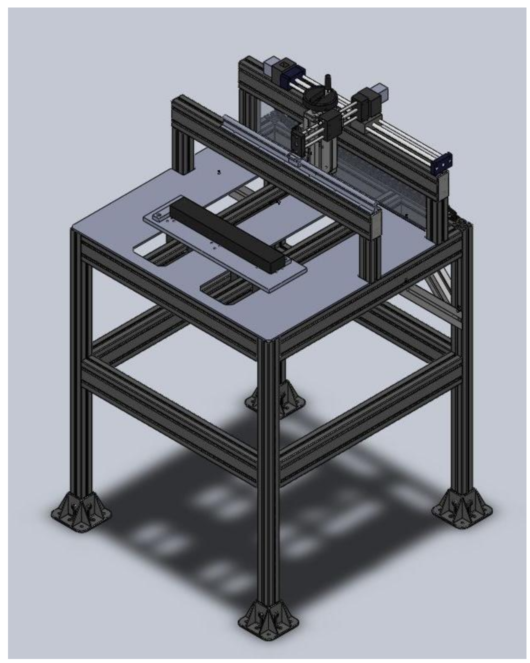

Figure 3. 3D Model Rendering of System

Structure

The overall structure is designed for simplicity and durability. The factory conditions that the system will be placed in made a sturdy base table and a small footprint essential. Since transportation to the final PCC facility also needed to be considered, the team settled on an extruded aluminum base structure.

To achieve a rugged extruded aluminum system we researched two main companies, 80-20 and Minitec. Both companies sell a variety of different sizes of extruded aluminum to build “erector set” type systems. The decision to use Minitec over 80-20 was made because Minitec was able to cut down the extruded aluminum to our specifications at their facility and ship to RIT as a kit. This saved on our machining time as well as provided a better accuracy than what we could have machined. Cost wise Minitec was very comparable to 80-20. Since Minitec is also a local company, located in Victor New York, we supported locally and were able to get our extruded aluminum system shipped quickly.

Beyond basic structural components, we were also able to purchase our linear slides through Minitec which allow the die to be placed and cleaned without fear of bumping the sensor. Once the die is affixed to the fixture and cleaned the fixture can be slid under the sensor along the same Minitec framing used for the base structure. Two parallel linear slides were used to achieve an easy slide of the die and fixture and to help prevent rocking of the fixture.

Die Fixture

The die fixture consists of a 20” x 6” x 5/8” block of cold rolled steel. To achieve a flat and parallel surface the steel plate was Blanchard ground. Three ¾” ball bearings create a simple three point plane upon which the die rests, so as to minimize area of contact. These three ball bearings can be moved around into two different configurations to easily hold a wide range of dies.

Along the same three point system three ½” dowel pins are press fitted into the fixture and create two edges, forming a 90° angle, against which the die rests. By press fitting the dowel pins we were able to assure that the force of the die hitting into them would not move them out of place. These dowel pins can also be moved to accompany a smaller set of dies.

In order to ensure the die is kept against all three dowel pins throughout measurement a simple clamping mechanism was created. Since the clamp didn’t have to provide much force but still must accompany a variety of die widths, a 2” diameter of aluminum circular stock was cut down to a ¾” height and an offset hole was placed. By using a thumb screw in the offset hole the clamp can easily be slid in and out of place and allow for a wide range of dies to be held in place.

The fixture is held in place onto the linear slides by four screws. Two ball latches are attached to the back of the fixture, locking it into place when it is under the sensor. A handle is also attached so the user can easily move the die fixture to and from the measurement area of the system.

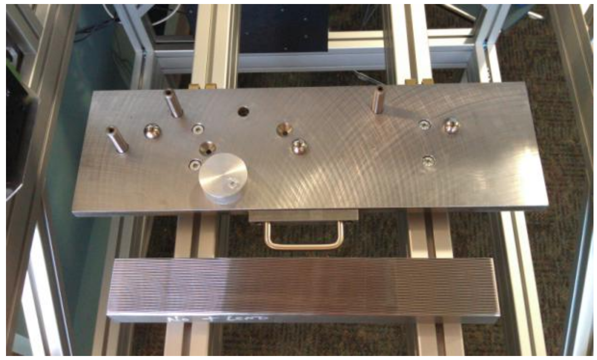

Figure 4. Die Fixture and Die

Gantry

The gantry system was one of the most crucial designs necessary to achieve a working product. In order to accurately measure the die, the gantry had to work seamlessly with the motion systems and run extremely smooth. To achieve the height necessary to clear die sliding under the sensor, more Minitec solutions were considered.

An additional six pieces of extruded aluminum were added to achieve necessary height and act as supports for the X and Y axis linear stages. Another key consideration was to keep the sensor easily within its measuring range. For this, a Minitec solution was initially considered but due to weight had to be eliminated. Instead a custom built lead screw positioner was designed and built. This allows the Z-axis to move up and down in order to keep the Keyence laser in range for dies with different thicknesses. We also had to make sure that the screw was strong enough to not unwind and lower the sensor while measuring. To keep this from happening, a spring was placed on the outside of the screw. When the system is in place, the spring is put into compression which keeps the system taught and in position. This allowed the sensor to be placed on the attached plate and able to be easily be cranked into its accurate measuring range.

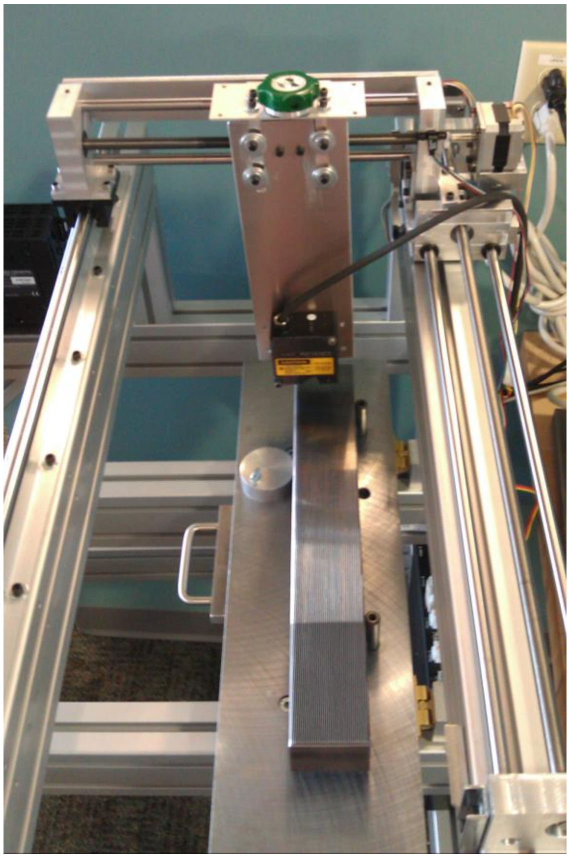

Figure 5. Gantry and Linear Stages Installed on Finished Structure

Linear Stages

After a lot of research and talking to different suppliers who make linear stages, it was evident that these stages would eat up too much of our budget. Since the laser was taking up about 75% of the money we had, the only way to go was to build the stages by hand. End blocks and stage bocks were designed using SolidWorks and machined out of purchased extruded aluminum blocks. Rods and lead screws were purchased from outside vendors.

The purpose of the linear stages is to smoothly profile the length and width of each die. The short axis linear stage is attached to the stage blocks of the long axis linear stage. When the long axis linear stage moves, it makes the short axis move across the die. This is so that the laser (attached to the stage blocks on the short axis linear stage) is able to scan across the threads on the die and read critical data at different increments across the face of the thread die.

Linear stages need to be machined with very high tolerances. In order for all of the components to work seamlessly together, every hole in the end blocks and stage bocks must line up perfectly. It was very difficult to achieve these high tolerances due to each block being machined by hand. CNC machines would have been a much better alternative to creating such precise blocks. However, lead time to get all of these components completed in time was far too long. This made machining each block by hand the only viable option at the time.

One issue that we found to be common during research was backlash in the lead screws. This is where the drive screw nut finishes a step from the motor, but still has some room to move due to the small spacing between the threads on the screw and the threads on the nut. In order to eliminate this issue, an anti-backlash nut is used. This nut has a spring attached to one side and keeps the back side of the nut in continuous tension. This pushes the threads on the nut to be in complete contact with the threads on the screw. This allows the system to have zero play and no steps will be lost between the linear stages, motors, motion controller and computer.

Making sure the alignment between the motor shafts and drive shafts on the stages is critical. When not aligned properly, the shaft will oscillate out of sync with the attached shaft. This causes the system to vibrate and smooth movement is completely lost. Since such high tolerances are needed for this entire system and some have been lost to human machining capabilities, the alignment is not perfect. However, to eliminate this issue, flexible couplings are able to be used and help out the issue in a big way. The flexible coupling allows the system to be out of line slightly, and still create a true turn in the lead screw – which leads to a smooth moving system.

The use of a guide rail system was implemented to save on machining time and money. The alternative would have been to machine another entire linear stage and connect it to a third stepper motor. This would have made programming even more complicated. Two motors would have to be seamlessly synchronized at all times and would have been very difficult to deal with. Also, to build another precise linear stage and purchase another long lead screw and long guide rails would have really eaten into the budget. For our motion controller to support three motors would have added extra costs as well. The guide rail system was easy and simple to implement into our design and when kept lubricated, moves flawlessly with the attached motor driven side.

Motion System

Due to the design of the gantry system and linear stage components a 2 axis motion control system was required. This system had to power 2 linear stages with either stepper or servo motors while being fairly easy to implement and control with Labview. Many options existed for motion systems so there was much deliberation over a vendor.

There were 4 vendors that were in contention that could meet the usability and feasibility requirements. The systems, Motion Group, National Instruments, Arduino , and Motion Direct, all had some advantages and disadvantages. National instruments was turned down due to its high cost, while the other vendors could all provide similar functionalities at a lower cost. Due to its ease of use and known functionality with Labview, The Motion Group, black box system was the chosen motion system. This system has a self-contained unit that can run up to 4 axis's. Motion Group also provided the correct size stepper motors that could successfully operate each linear stage.

The Motion Groups black box approach made the motion system implementation more flexible then other options. The box had a serial connection that Labview was easily able to control. Commands such as max speed, ramp up, homing position, and motion was done by sending ascii commands via serial sport and Labview to the unit. For the complete Labview program refer to the "Labview Integration" Section.

Sensor

To tell if the die is within specification a sensor must measure to 0.001" and compare those values with each value of an ideal die. Major and minor errors are taken into consideration and a simple yes or no is delivered to the user about the die usability. These yes's and no's are also stored, carried throughout the life of the die and will help more accurately predict die life.

Most sensors available to consumers are able to read out information, store values and compare them to known values. In our case the 0.001" accuracy was the toughest parameter to meet. At this accuracy the price of the sensor really becomes a large concern. Two companies sensor systems were researched, Keyence and Acuity. After talking with both companies and seeing a demonstration of the Keyence system running we knew both systems could achieve our metrics. In the end the sensor was chosen based upon the price and ease of availability.

Keyence had a few solutions that would work for our accuracy. One solution we considered was a 3D profiler. This profiler was capable of scanning our entire die in only two sweeps but was out of our initial price range costing $16-$18K. The 3D scanner could also compromise some of the desired repeatability we were trying to achieve. The other solution presented to us by Keyence was a 2D laser. This laser was an LK-H022 which was an ideal balance between repeatability, accuracy and cost. In the end our entire sensor package cost just over $9000 and represents the largest purchase our team had.

The laser measurements are sent through the RS-232 interface to our custom Labview program). The entire system was setup so it was possible to step our laser over the die and easily capture the displacement from the sensor. The program will first run the short axis, scanning across the die. Once the pass is complete, the program will move the long axis so another pass on the short axis can be completed; this process is repeated for the length of the die. Once the program is finished the data is exported to an excel spreadsheet. A Macro then calculates various parameters for each pass to determine if the die is within specification.

FIRMWARE DESIGN METHODOLOGY

LabView Integration

According to customer needs and specification, the final application had to have a certain ease of use factor as well as be able to control both the motion and laser systems. In order to satisfy these requirements National Instruments, LabView, was implemented. LabView allowed the team to have a graphical user interface so any operator could easily control the system, while the programming could take care of the more advance motion/laser system tasks.

There were definitely difficulties when working with the selected motion controller. The programming and commands to the black box were a little harder than expected. After long hours of cooperation with the Rivet Inspection Automation team we were able to develop the Labview program to easily control the system.

The programming was done in a way so it could be easily understood by most people with have a small amount of programming experience. There are four main steps the Operator must complete for the program to properly execute. First the specification file must be selected and loaded into the system. The file holds key specs about the die height, width, and pitch. Once this file is selected, the operator then selects the correct die pitch, size (stationary or reciprocating), and scan type. Second the laser and motor system serial ports are selected. Third, the operator gives the die an identification number and sets the location where the data file will be saved. Once these three steps have been completed, the motion system will home the laser to the proper position. The user can now click the "Begin Scan" button, and the system will run a calculated program, gathering displacement data across the die.

The die scanning program uses a state machine type architecture, meaning each activity that is performed is considered a "State". There is a set order to the states, such as choosing the correct die size before the scanning sequence begins. The operator must trigger the next state by inputting the information and clicking the Boolean toggle switch. The program will then switch to the next state. Once all the correct information is inputted and all the toggle switches set to true, the program can initialize and begin the scanning sequence.

The scanning sequence involves running the short axis, which the laser is attached to, across the face of the die. This accomplished by sending an ascii string to the motor controller with the correct number of steps to move. While moving the laser is taking in displacement readings. The laser is also controlled vie the RS-232 interface. The data "X" distance and displacement data are graphed in real time as well as exported to a comma separated file. The program will loop, using nested "for" loops, scanning across the die then, shifting down die based off the type of scan being performed. Once the program has finished the motors return the laser back to the home position, ready for the next die to scan.

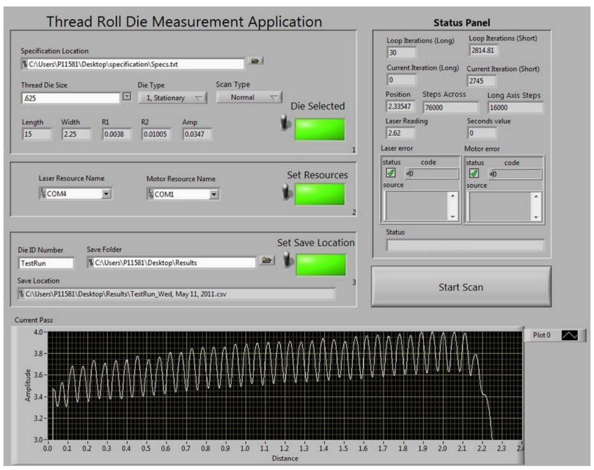

Figure 6. Example of LabView Program

Solving for Conformance

Solving for conformance initially seemed like an easy task. However once the shape of a thread was fully understood the problem became more complicated. The die presses threads that have nice rounded corners, not sharp edges. To complicate further the die must follow the same pitch as the final threaded bolt. This means the arrangement of each point varies as you move laterally along the die.

A basic geometric analysis was completed to develop an initial tolerance that conforms to die specifications. Each die thread was broken into six individual components and each was analyzed to determine what percent variation in each section would be allowed. This analysis was planned to be implemented in the current labView program but was not due to time and technical issues.

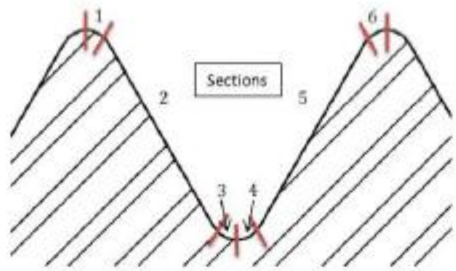

Figure 7. Break Down of Thread Sections

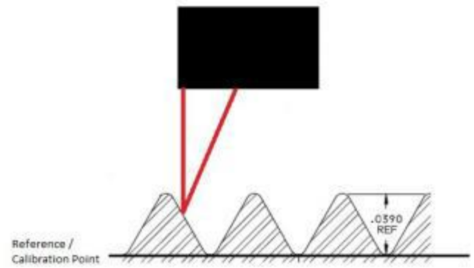

Figure 8. Geometric Analysis with Sensor

RESULTS AND DISCUSSION

Overall the project was a success. We were able to successfully measure a die and display the results in real time to LabView. The system has an ability to run continuously for multiple hours without issue, log multiple runs and even multiple dies.

The structure is very solid and incorporates a small footprint while providing easy access to all necessary components. The linear slides provide reliability and easy movement of the heavy fixture without concern of damaging the expensive sensor. Although the structure is very sturdy and reliable it is limited by shock absorption and partial difficulty to tear down, ship and rebuild.

The die fixture was successfully designed as an easily changeable system to accompany multiple dies. This allows PCC to implement the current system to various dies with little work.

One specification not met by our current system is the ability of a concise pass-fail readout. In order to implement a pass-fail a database needs to be created which has the location and measurements for each location measured by the sensor. Once this database is created then a pass-fail can be determined by comparing LabView's readout. A go no-go display can be added to simplify at this point.

Another specification which was not kept was the time to run a complete die measurement scan. Initially the lead time for a scan was set at 5 to 10 minutes. This initial quote was without understanding of how fast the system could run while taking accurate measurements. In testing of the system, the scan time to complete a die, scanning the across about 30 times, took approximately an hour, much larger the initially estimated.

CONCLUSIONS AND RECOMMENDATIONS

Even though the project was a success in accurately measuring and analyzing a die, there are failures to discuss as well. However, from these initial failures the system was more clearly understood and improved upon, giving us the successful system we finished. The customer will now be able to take measurements and see measurements at given areas of the die, which they were never able to do.

Learning from these failures the team would change several aspects of the initial design. Ideally the original Mintec Z-axis stage should be used. This stage is very sturdy and adjusts very smoothly but weighs significantly more than the custom built solution we used in the end. To deal with the additional weight the entire linear stage and motor system would have to be strengthened. For example ¾" to 1¼" linear guide rails should be implemented as well as increasing the drive screws to a diameter greater than 3/8". Expanding the guide rails and drive screws would cause a redesign of the end blocks and larger motors for better support and to compensate for moving of heavier components.

Other linear motion components were a learning experience. Our initial couplers took several iterations to perfect and a flexible coupler system was implemented on the final system. The flexible coupler system allows for small machining tolerance errors to be reduced and easily interfaces between different sized items. Self-aligning bearings were also something that could be used to eliminate other machining tolerances and binding issues.

Small improvements to the structure and die fixture could also be made. Shock absorption pads could be added to the feet to ensure that factory conditions would not cause a misread of the die. Proximity switches could also be added to the structure to ensure that the fixture is loading properly under the sensor.

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