Y-12

OAK RIDGE Y-12 PLANT

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Final CRADA Report
for
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THE DEVELOPMENT OF STRAIGHTNESS MEASURING EQUIPMENT

Paul D. Demint
Lockheed Martin Energy Systems, Inc.
Manny Abraham
UTE Straight-O-Matic

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ABSTRACT

This report details work performed between Lockheed Martin Energy Systems, Inc. (LMES) and UTE Straight-O-Matic (UTE) under the National Machine Tool Partnership program. This work included the design and construction of an automatic straightness measuring system capable of retrofitting to existing machines.

OBJECTIVE

UTE is a small company manufacturing equipment to straighten heat treated parts. Their product line includes several models of machines designed to straighten flat parts, forgings, stamped parts, motor armatures and rotors, cylindrical parts, and shafts. The objective of this CRADA was the design and integration of a straightness measurement system for the model 300-S machine, designed for the high volume, automatic straightening of shafts up to 2 feet long and 3/4 inch diameter. This measurement system must be capable of a maximum production rate of 1600 units per hour and will be modular in construction to facilitate retrofit to existing machines. To this end, it was agreed that all mechanical work was to be accomplished by UTE, the computer software and control systems were the responsibility of LMES, and the design work would be shared jointly between the two parties.

RESULTS

At the conclusion of this CRADA, a functional prototype measurement system had been designed and built in fulfillment of all stated CRADA objectives and milestones. Since that time, modifications have been made to the system resulting in a production ready measurement system available as an option on all new equipment purchases and retrofit on existing machines.

BENEFIT TO DOE

This work was funded by the National Machine Tool Partnership program that has the stated objective to ensure the remaining technical competence of the Nuclear Weapons Complex. This task provided skill enhancement in areas of inspection, on machine sensor development, machine control applications, and real time data analysis.

PRESENTATION OF WORK REQUIREMENTS

- . No major modification to machine design
- . Must be retrofittable to existing machine population
- . Must operate to 1600 units per hour
- . Must handle shafts from 1/8" to 3/4" diameter and up to two feet long
- . Shafts may contain areas of raised or recessed features requiring the system to ignore these discontinuities
- . Profile must be generated for the entire shaft length except areas of feature discontinuities

DESIGN

Since no major modification to the machine design was possible, part measurement would be performed after the part left the machine and while the next part was being straightened. In this way, no time was added to the straightening operation. When the part exited the machine, it rolled down an attached sloped incline into a collection bin. The measuring system design added a stop to the incline where a sensor would tell the control computer that a part was waiting for inspection. The system would then pick up the part and begin the inspection process. The requirement to measure 1600 units per hour allowed approximately 2.25 seconds per part for fixturing, obtaining part profile, performing required computations, and releasing the part. Several scenarios were discussed which would allow picking up the part and spinning it while collecting data down the length of the part, and reading the part run-out directly. However, due to variations in shaft diameter, part fixturing for rotation was not feasible within the time constraints. The final design for the prototype picked up the part, held it stationary, ran a Linear Variable Differential Transducer (LVDT) the length of the part to collect position information, and computed part profile from the collected data. Appendix 1 shows a block diagram of the control system used. Upon analysis of the collected data and comparison with previously stored acceptable limits, a determination was made as to the part acceptability. The stop was then released and the part was allowed to roll into the collection bin if it was acceptable, or the part was diverted into a rework pile if it did not fall within the acceptable range. This design presented several problems; part fixturing, feature avoidance, and sensor selection enabling location of the part center. The following sections detail each of these problems and the prototype solution.

SENSOR SELECTION

Because the part was not being rotated, the center location of the shaft could not be read directly from the data being collected as the sensor was moved down the shaft.

Therefore, a sensor arrangement was agreed upon which would allow for calculation of shaft center. Instead of using one LVDT and spinning the shaft, two LVDTs were used and rigidly affixed at 90 degrees apart. Appendix 2 details the mathematics used to calculate the shaft center location assuming that the shaft has a true radius. Using these LVDTs, a calibration is required to determine the sensor constant for each device being used. Appendix 3 details the method used to determine these constants used in the shaft center location mathematics.

To move the sensors down the part, a stage was built and connected to a CompuMotor via a lead screw. Move commands were sent to the CompuMotor controller from the control computer via an RS232 communication line. Appendix 4 details the configuration of the CompuMotor control system.

FEATURE AVOIDANCE

As the sensors moved down the part, any discontinuities in the part surface would cause the LVDTs to jump and report bad data. In addition, some of the expected features on typical parts would be large enough to destroy the sensors if they were to be ran over. To avoid these areas, a pneumatic cylinder was incorporated into the stage design which allowed the LVDTs to be retracted while the sensors were passing over areas of raised or recessed features. Software was written which held setup information for each part to be processed. This software collected information describing the part length, and areas to be avoided.

PART FIXTURING

It was decided that the part would be held at both ends and the sensor moved between the fixtures to collect data. However, because the parts were expected to be of varying diameters, a fixture design was required that would support any shaft diameter between 1/8" and 3/4" without extensive setup requirements when the shaft diameter changed. A split "V" block design was used at each end of the part. Figure 1 shows one set of the blocks. Using this design, the center location of the part will move as the part diameter changes so during setup, the sensor array location must be changed to compensate for the difference in part diameter.

Split "V" Block fixture design
FIGURE 1

INVENTIONS

No inventions were made or reported as a result of this CRADA.

COMMERCIALIZATION

This product is available as an option on all new straightening machines purchased from UTE or as a retrofit to existing machines.

FUTURE WORK

No additional work is forecasted between UTE Straight-O-Matic and LMES. However, UTE will continue to refine this product as required to support its customer base and LMES personnel will continue to use the experience benefitted from this venture in continuing work for the DOE.

CONCLUSION

As a result of a Cooperative Research and Development Agreement (CRADA) between UTE Straight-O-Matic and LMES, a prototype straightness measurement system was designed, built and demonstrated. This system is used to verify the straightness of heat treated shafts after undergoing straightening operations. Up to 1600 parts per hour ranging from 1/8" to 3/4" in diameter and up to two feet long may be inspected. Subsequent to the CRADA activities, UTE has produced a production ready version of this system that is currently available as an option on new purchases or as retrofit to existing machines.

Control Connections

* $(0,0)$ is theoretical crossing of LVDT's.

* (a,b) is center of shaft. Straight line from (a,b) to LVDT tip center $(-e,e)$ or (c,c) passes through tangent point of LVDT tip center and shaft.

* r_1 and r_2 are radii of LVDT tips. r_3 is shaft radius.

* f is the distance from $(-e,e)$ to (c,c) .

* F is the absolute angle between lines from center of LVDT 1 tip to center of LVDT 2 tip and center of shaft.

* G is the angle in the given coordinate system of the line between center of LVDT1 and center of shaft.

* E is the angle in the given coordinate system of the line between LVDT tip centers.

Calculation of Shaft Center from LVDT Measurements

* We start with measured values m_1 and m_2 from LVDT readings. We also have values of k_1 and k_2 that are assumed to be previously calibrated.

* The distance from $(-e, e)$ to $(0, 0)$ is calculated from the LVDT measurements:

$m_1 + k_1 + r_1$ is the distance from LVDT tip center to $(0, 0)$, which gives

$$e = (m_1 + k_1 + r_1) / \sqrt{2}, \text{ and similarly } c = (m_2 + k_2 + r_2) / \sqrt{2}$$

$$* f = \sqrt{(c+e)^2 + (c-e)^2}$$

$$* \cos(E) = (c+e) / f \quad \Rightarrow \quad \begin{aligned} E &= \arccos((c+e) / f) \quad \text{for } c > e \\ E &= -\arccos((c+e) / f) \quad \text{for } c < e \end{aligned}$$

* Generic triangle formula:

$$\cos(A) = (b^2 + c^2 - a^2) / 2bc, \quad \text{therefore}$$

$$\cos(F) = (f^2 + (r_1 + r_3)^2 - (r_2 + r_3)^2) / 2f(r_1 + r_3)$$

$$* G = E - F$$

$$\begin{aligned} * a &= (r_1 + r_3)\cos(G) - e \\ b &= (r_1 + r_3)\sin(G) + e \end{aligned}$$

Calibration of LVDT Measurements

• Assume LVDT's are 45 degrees to horizontal. Define (0,0) as the point where LVDT's theoretically cross.

• "d" is measured distance between LVDT points of contact in V-blocks.

• Distance from LVDT edge along 45 degree line to point (0,0) is "m+k", where "m" is the measured reading, and "k" is the offset constant to be calibrated for each LVDT.

$$\bullet \frac{d}{\sqrt{2}} = m + k$$

$$\bullet k = \frac{d}{\sqrt{2}} - m$$

• Calibration involves holding V-block piece horizontal, taking LVDT readings "m" when aligned in V-blocks, and using a known distance "d" to calculate "k" for each LVDT.

CompuMotor Connections

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