Non-Contact Capacitance-Probe System for Part Inspection

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Irina Ciobanescu Husanu, Ph. D. is Assistant Clinical Professor with Drexel University, Engineering Technology program. Her area of expertise is in thermo-fluid sciences with applications in micro-combustion, fuel cells, green fuels and plasma assisted combustion. She has prior industrial experience in aerospace engineering that encompasses both theoretical analysis and experimental investigations such as designing and testing of propulsion systems including design and development of pilot testing facility, mechanical instrumentation, and industrial applications of aircraft engines. Also, in the past 10 years she gained experience in teaching ME and ET courses in both quality control and quality assurance areas as well as in thermal-fluid, energy conversion and mechanical areas from various levels of instruction and addressed to a broad spectrum of students, from freshmen to seniors, from high school graduates to adult learners. She also has extended experience in curriculum development. Dr Husanu developed laboratory activities for Measurement and Instrumentation course as well as for quality control undergraduate and graduate courses in ET Masters program. Also, she introduced the first experiential activity for Applied Mechanics courses. She is coordinator and advisor for capstone projects for Engineering Technology.

Mr. David English

David English received and Associate in Electrical Technology Degree from New England Institute of Technology, presently David is about to complete his Electrical Engineering in Technology Degree from Drexel University. David has been employed in the power generation field for the past 10 years. The facility where David is presently employed is a natural gas combined cycle generation station which can generate up to 740MW that is distributed to the Southern New Jersey electric grid.

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Michael Hazm is a Manufacturing Systems Engineer at Pennsylvania Machine work , responsible for developing and implementing lean automation technologies to improve the productivity of the company operation. Pennsylvania Machine work manufacture high pressure pipe fittings for nuclear power generation, petrochemical, ship building, along with countless other critical industrial applications. Michael Hazm received an Associate degree in Manufacturing Mechanic from ISTA Morocco ,and an Associate in Robotic System from DCCC , and Mechanical Engineering Degree from Drexel University. Michael is a member of: American society of Mechanical Engineering and Society of Manufacturing Engineers.

Engineering Technology Student Project: Non-Contact Capacitance-Probe System for Part Inspection

Abstract

Inspection of parts for dimensional compliance is a common task in prototyping, manufacturing, and quality assurance. In prototyping and quality control courses, students gain an appreciation for the importance, intricacies, and often time-consuming nature of parts inspection that can negatively impact productivity. Here we report a student project for designing, fabricating, and testing a non-contact capacitive probe station that can check the pitch and surface figures of threaded parts featuring multiple thread sizes, with a cycle time of 5 seconds. The performance, cost, and capabilities can be compared to machine vision inspection of parts using a CCD camera and image analysis software. This desktop modular system can be retrofit to CNC machines for in-line, real-time inspection, and includes network data communication capability. This effort was an 8-month Senior Design capstone project for Engineering Technology students.

Introduction

Product inspection in a manufacturing context presents many crucial issues and essential concepts needed for industrial and mechanical engineering. Here we describe an undergraduate (Senior Design) project to monitor the geometric and dimensional conformance of machined metal parts. This project provides an instructive and representative case study involving specific issues of implementation such as contact vs non-contact probing, throughput (cycle time), sensitivity, automation, operator skill, and measurement cost, as well as more general themes such as sampling theory, geometric dimensioning and tolerancing, and quality assurances, Gage Reproducibility and Repeatability for Lean Six Sigma approaches to production and operations.

Educational Objectives

This paper describes a Senior Design Project for Mechanical and Electrical Engineering Technology and Industrial Engineering students. Its purpose is to offer an instructive case study where students address a technically challenging and commercially important opportunity in a manufacturing facility. Machining of metal parts, such as fluid system components, may not impress as cutting-edge high technology with much room left for innovation, yet there are numerous opportunities for modernizing shop operations to improve quality, productivity, and flexibility. As the US contemplates ways to 'recapture' manufacturing, especially in well-established sectors of the economy such as machine shops, it is important to retrofit state-of-the-art measurement technologies into production operations.

The project relied on knowledge gained from courses in: 1) circuit theory and electronics, 2) CNC and prototyping, 3) engineering materials, 4) Quality and Statistical Process Control, 5) microntrollers and microprocessors, 6) computer programming, 7) measurements and analysis, and 8) LabView and C/C++ programming, as well as allied course work in Technical Project Management, Engineering Economics, and Lean Six Sigma operations. Thus, the student performance on this project provides valuable feedback on successful attainment of educational objectives in these courses, their application to real world engineering, and their integration of knowledge to solve comparatively complex, multidisciplinary problem solving. At the end of Senior Design, the project was evaluated by twenty four faculty, researchers, and managers and engineers from industry.

The technical problem relates to a method to inspect machined parts, particularly thread geometry, for compliance. More specifically, students were tasked with designing a modular system that will quickly (cycle time of 5 seconds) check thread sizes (multiple thread pitches or multiple surface figures) on turned metal parts that would be easy to use, cost effective, and have networking capability.

Students from Electrical and Mechanical Engineering technology worked in groups of three, over an eight-month period for their Senior Design Project. The project was sponsored by a manufacturing company with immediate interest in implementing such a system. The students were advised by Engineering Technology faculty and Manufacturing Engineers at the sponsor company, but worked largely independently. **Figure 1** shows typical parts and **Figures 2** and **3** show the current method of using a thread gauge to measure compliance. Capacitance gauges (**Figures 4** and **5**) are cylindrical-shaped probes that generate an electrical (voltage) signal indicative of the space between the probe and the metal surface. The probe is inserted in a threaded, bored part, and centering of the probe is critical to accurately measure the thread geometry (**Figure 6**). **Figure 7** shows some representative capacitive sensor waveforms according to the probe diameter and target surface topology.

Design and Fabrication of Capacitive Sensor Measurement System

Figure 8 is the basic sequence of operations for capacitive probe measurements. **Figures 9** through **12** are CAD drawings and Solidworks™ renditions of the system**.** is the rendition of the measurement apparatus with details of each subsystem or components such as part clamp, probe holder. The metal components were made in aluminum machined by CNC. The electrical system, which controls the stepper motors, PC interface, and interfaces the capacitive probes) is shown in **Figure 13**.

System Operation

The completed system is shown in **Figure 14**. It is suitable for use on the shop or factory floor. **Figure 15** shows the loading of a part for inspection. **Figure 16** is the computer output, measuring the part compliance and adjudging pass/fail according to programmed criteria.

Currently, we are comparing the capacitive probe system performance with a more expensive machine vision system. Results will be presented at the conference and in the updated manuscript. The capacitive probes cost about $4000. About $1500 was spent for other materials and electronics.

Student Assessments and Discussion

Senior Design students made three oral presentations and detailed written repors to faculty (from host institution and other institutions including universities, community colleges, and research laboratories), and industry representatives from small and large companies, consulting firms, and government-funded organizations. The students were assessed by 24 evaluators based on the following criteria listed in Table **1**. In general, the production was a success as indicated by evaluator scores and very positive feedback from the industrial sponsor. This was an ambitious project for three students in an eight-month time frame, but nevertheless, the students were able for build an attractive, cost-effective system to perform automated part compliance measurements, potentially contributing to improved productivity.

Table 1: Project Evaluation

Criteria	**Score : 0 (unsatisfactory)** to 5 (excellent) [range] **average**
Demonstrates ability to apply knowledge of their discipline(s)	[3.2-4.8] **4.6**
Demonstrates mastery of the techniques and skills of the discipline	[3.1-4.9] **4.6**
Demonstrates mastery of tools (instruments, equipment, computers)	[4.2-4.8] **4.5**
Demonstrates ability to apply mathematics knowledge	[3.2-5.0] **4.5**
Demonstrates knowledge of foundation sciences (physics, chemistry, materials)	[3.2-4.8] **3.9**
Adequately reviews technical literature, patents, commercial alternatives and other prior art	[3.2-4.8] **4.0**
Produces a practical solution / working prototype	[4.4-5.0] **4.9**
Analyzes and evaluates functioning prototype, and assesses performance and whether satisfactory solution has been achieved	[3.0-4.8] **4.1**
Demonstrates specific knowledge and aptitude in Engineering Technology disciplines (electronics, circuits, mechanics, sensors, measurements)	[3.2-4.8] **4.3**
Demonstrates ability to analyze technology at the materials, components, devices, and systems levels	[3.0-5.0] **4.1**
Identifies adverse impacts and potential safety and environmental hazards	[3.2-4.8] **3.9**
Develops and evaluates alternative designs to minimize adverse environmental impact	[3.9-5.0] **4.1**

References

Capacitive displacement sensors (Microepsilon) http://www.micro-epsilon.com/displacement -position-sensors.html

Process Thread Inspection. http://www.productionmachining.con/in-process-thread-inspection

Capacitor Sensor Operation and Optimization, http://www.lionprecision.com/tech-library/technotes/cap-0020-sensor-theory.html.

Figure 1: Typical threaded pipe fittings where thread compliance needs to be closely controlled.

Figure 2: Conventional means of manually checking parts with thread gauges.

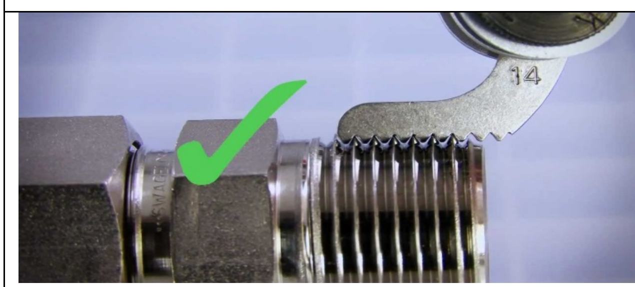


Figure 3: Manually checking parts with thread gauges.

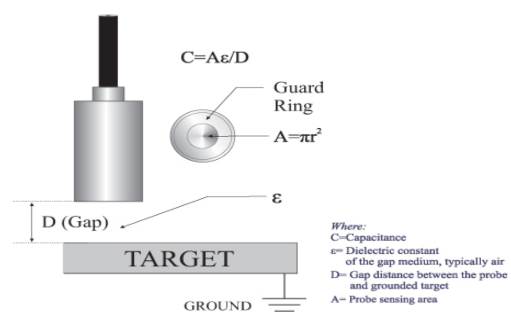


Figure 4: Capacitive probe schematic.

Figure 5: Capacitive probes.

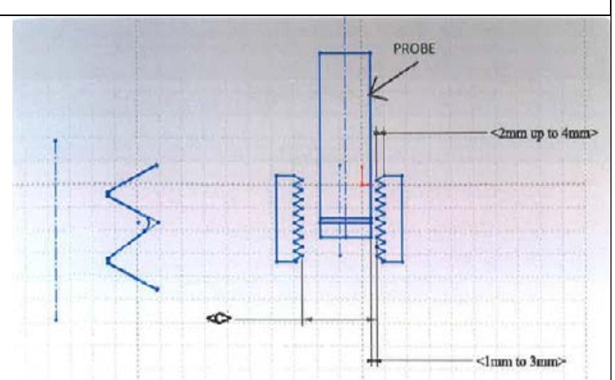


Figure 6: Part centering between capacitive probes.

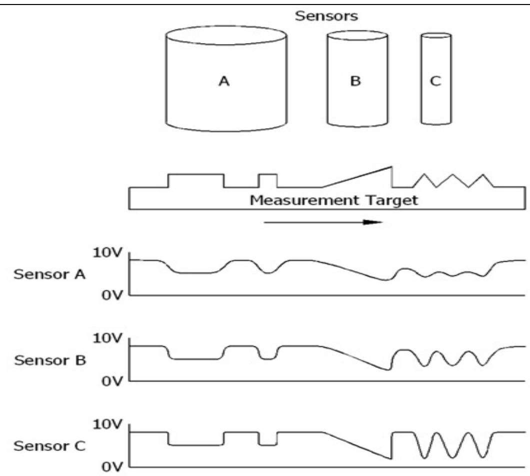


Figure 7: Sensitivity/resolution of probes of different diameter (output voltage signal) as probe travels along machined surface (measurement target).

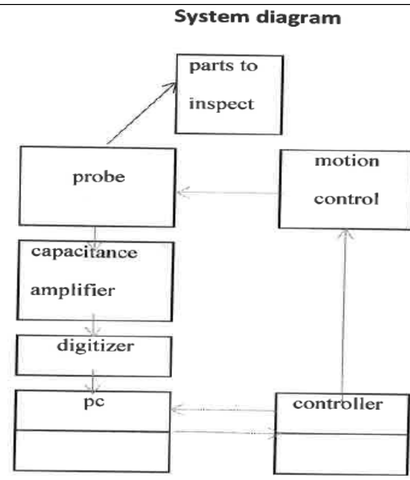


Figure 8: Operational flow chart for capacitive probe.

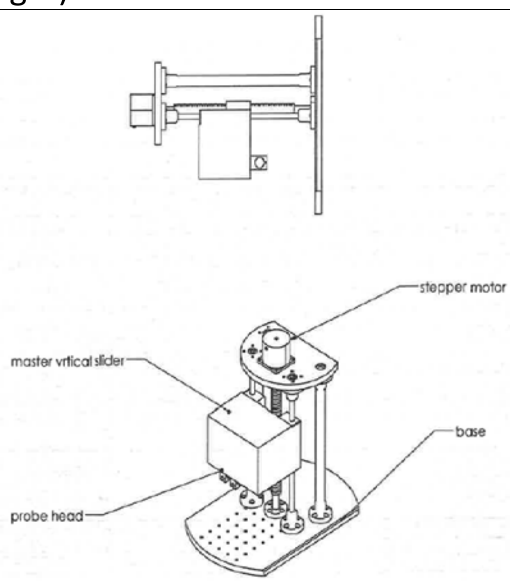


Figure 9: Capacitance probe platform design (Solidworks™).

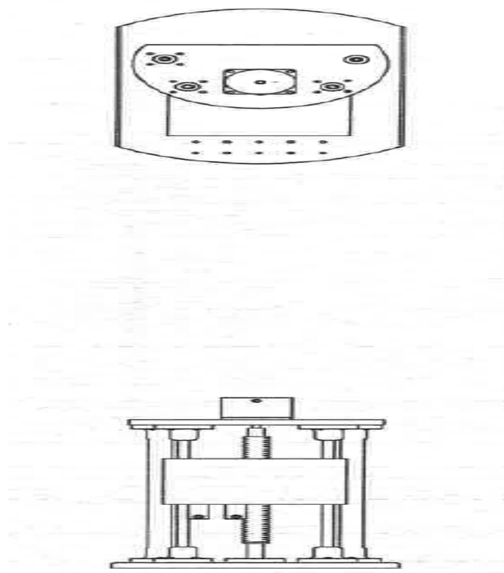


Figure 10: Sideview of probe holder.

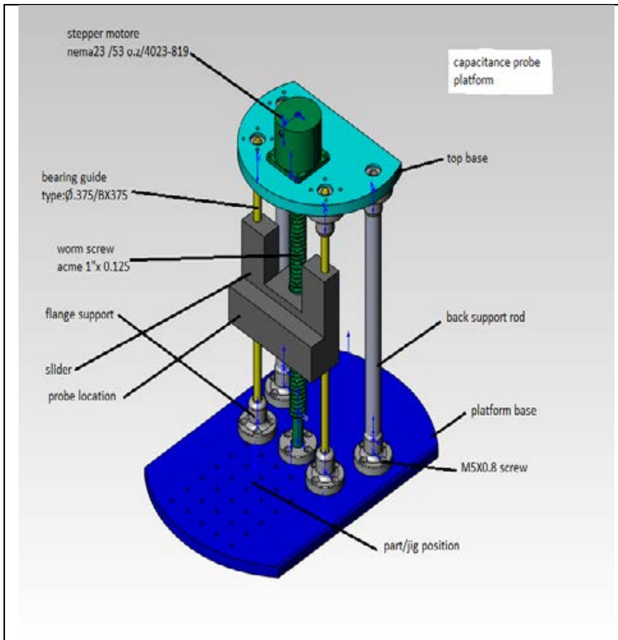


Figure 11: System perspective.

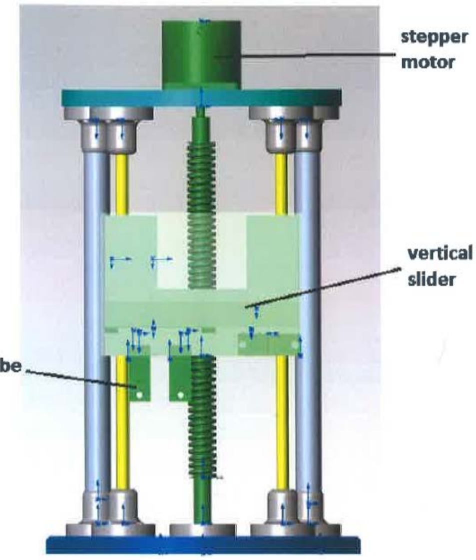


Figure 12: Sideview of probe holder.

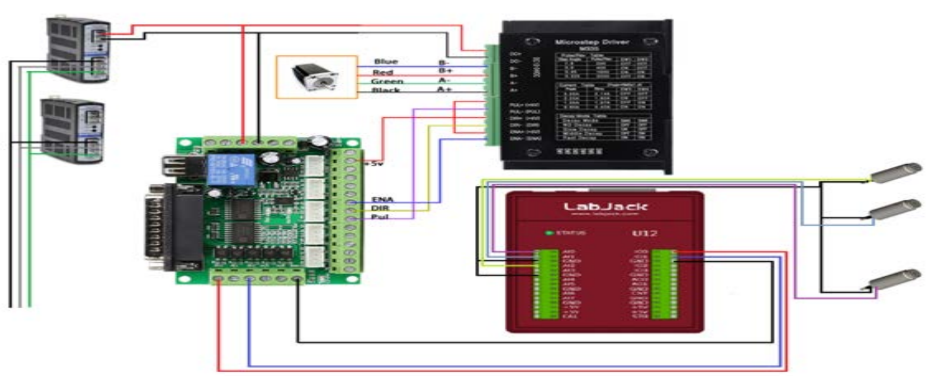
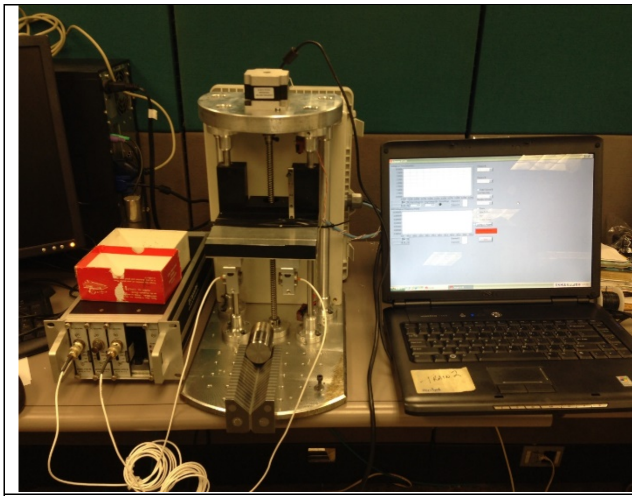


Figure 13: System electronics and control.



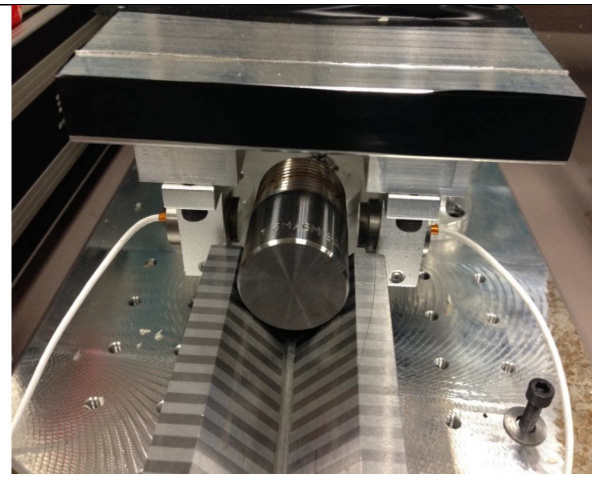


Figure 14: Capacitive Probe System in Operation.

Figure 15: Loading test piece into system.

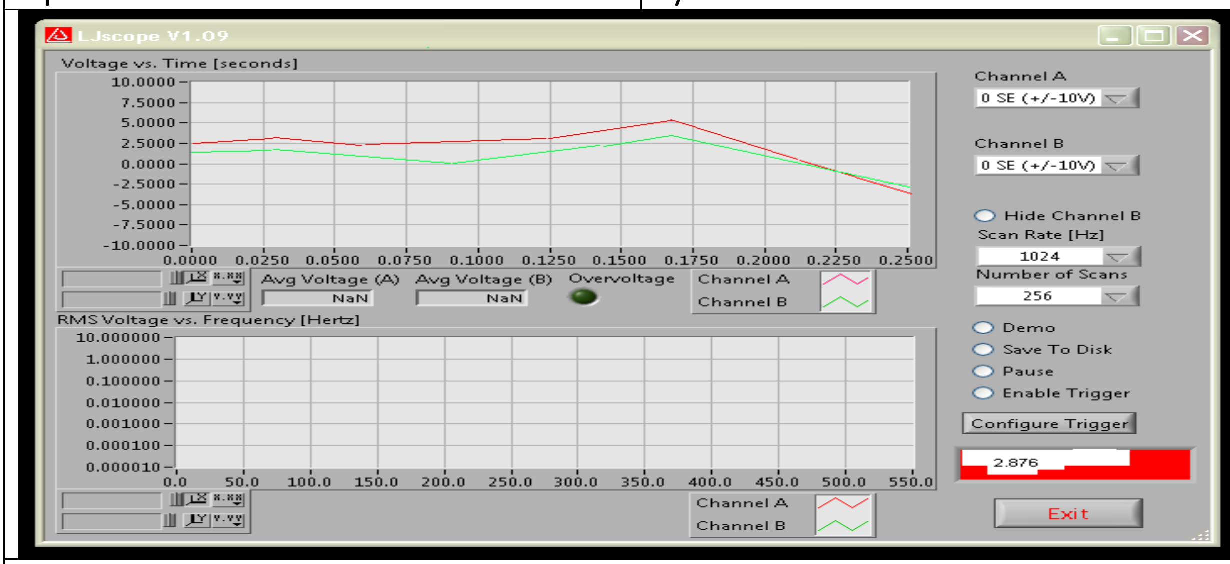


Figure 16: Computer interface showing measurement data.