S18-31
150488
p-4

N93-25579

ON MACHINE CAPACITANCE DIMENSIONAL AND SURFACE PROFILE MEASUREMENT SYSTEM

Ralph Resnick
Extrude Hone Corporation
8075 Pennsylvania Avenue
Irwin, PA 15642

ABSTRACT

A program was awarded under the Air Force Machine Tool Sensor Improvements Program Research and Development Announcement to develop and demonstrate the use of a Capacitance Sensor System including Capacitive Non-Contact Analog Probe and a Capacitive Array Dimensional Measurement System to check the dimensions of complex shapes and contours on a machine tool or in an automated inspection cell. The manufacturing of complex shapes and contours and the subsequent verification of those manufactured shapes is fundamental and widespread throughout industry. The critical profile of a gear tooth; the overall shape of a graphite EDM electrode; the contour of a turbine blade in a jet engine; and countless other components in varied applications possess complex shapes that require detailed and complex inspection procedures. Current inspection methods for complex shapes and contours are expensive, time-consuming, and labor intensive.

INTRODUCTION

An effort entitled "On-Machine Capacitance Dimensional and Surface Profile Measurement System" funded by the U.S. Air Force Wright Patterson Laboratories PRDA Program and performed by the MetreX Division of Extrude Hone Corporation seeks to address the needs of complex shape measurement and improve upon the use of the present technologies for performing those measurements. Recent advances in capacitance dimensional and surface roughness measurement provide a potential methodology for the verification of complex shapes. By building a capacitance probe or array and then scanning the workpiece, valuable information can be obtained about the surface under the sensor(s). This data can then be assimilated, translated, and transferred to the machining process controller for setup or corrective action. Since the cost per capacitance sensor is low and processing time is short, full form verification could be done quickly and inexpensively. Careful design and integration would permit the new measurement system to be installed in or near process.

The objective of this program is to develop and demonstrate a system to check and quantify dimensional information about complex workpiece shapes in a process environment on an automated machine tool. The proposer has established a partnership with Carrier Corporation of United Technologies on this program to establish key requirements, to review approaches and programs, to provide components, and to test results in a present process. Researchers at the University of Washington are working on design and analyzing mathematical models of the system as well as performing the environmental testing. The National Institute of Standards and Technology is providing the temperature, stability and dynamic testing and defined interface standards based on recently implemented Dimensional Measurement Inspection Specifications (DMIS).

PURPOSE AND OBJECTIVE

Identification of the Problem

The verification and inspection of complex shapes is far-reaching and significant. An improper profile on a gear can cause misalignment increasing gear noise and decreasing gear life. A cam with the wrong contour can cause erratic engine performance. The aircraft engine industry has many important complex shapes on important components and is highly representative of the requirements of industry in general. Aircraft turbine engine components require that their geometric form be accurate and consistent.

More efficient and predictable engine performance can be established if the engine components are maintained within the design criteria. To guarantee the components will meet performance specifications requires that the specific engine parts be gauged to the design criteria. For some simple components this gauging task is straightforward and easily performed; however, on complex components with intricate shapes and contours, specifically turbine blades and disks, Integrally Bladed Rotors (IBR's), and impellers, the gauging and design verification is detailed and complicated. Since the production of these components is performed on complicated machines with complex parts programs or intricate processes, the feedback of this test information is vital and timely for process and program control.

Present techniques for form measurement of complex aircraft engine components include Coordinate Measurement Machines (CMM's), Light Sectioning, SigmaFlex gauges, and even templates and feeler gages. All of these techniques are complex and/or labor intensive. The procedures are performed off-machine, at times even off-site, complicating the ability to transfer the valuable correction data to the manufacturing cell. Fixturing, programming and setup requirements are extremely time consuming and expensive. It has been estimated that the post-process dimensioning of a workpiece roughly accounts for between 20 to 40 percent of the total time to complete a machining operation, depending upon the complexity of the cut and the number of tools used in the manufacturing process.[1]

Since these parts are often processed on highly sophisticated and accurate machine tools, subsequent removal of a fixtured workpiece from the machine and transfer to a separate inspection device seems redundant and unnecessary. A more efficient and straightforward approach would be to instrument the machine tool performing the process with adequate probes and sensors that would easily interface, both in hardware and software, to the machine and would thus utilize the inherent accuracy capabilities of the machine tool to be the verification bed for the part. Potential errors inherent in the machine to inspection device transfer (and possible repetition) such as fixturing orientation could be avoided. Obvious time savings would be realized. In fact, in a recent study by Southwest Regional Institute for a project entitled "High Productivity and Precision Machining Program" for the National Center for Manufacturing Sciences (NCMS), the highest priority focus area with 81% of the surveyed in favor was In-Process Dimensional Measurement. This survey was conducted among numerous NCMS members which include a vast majority of the most noted domestic machine tool builders.[2]

The successful completion of the MetreX effort will help to strengthen the U.S. machine tool industry and help to build more efficient, higher performance aircraft turbine engines at more affordable costs, and help the entire U.S. manufacturing base by making possible the economic production of complex shapes–fundamental elements in a wide range of components used for military, industrial, scientific and medical purposes.

Research Objectives

The project is directed to the development and demonstration of a Capacitive Non-Contact Analog Probe (CNAP) and a Capacitive Array Dimensional Measurement (CADM) system for inspecting complex contours. This system incorporates technology developed by Extrude Hone's MetreX Division, and will provide a fast, low cost method of measuring complex shapes. In the case of the CADM, the gauge will measure a large number of points over a surface array that is electrically scanned in milliseconds, the time required being substantially less than existing methods. The technology is being further developed to be used on the machine tool, on-site, and consideration is being given to the requirements of measurement in various processing environments. Direct software interfacing techniques

[1] Air Force Wright Aeronautical Laboratories, "AFWAL-TR-88-4177 Final Report for 1 October 1987 - 31 December 1988," *Manufacturing Technology Program Assessment of New Sensor Technologies for the U.S. Machine Tool Industry*, Sept. 1988.

[2] Mechanical Technology Inc., *High Productivity and Precision Machining Program: Integration Plan*, NCMS-89-PE-4.1 (Ann Arbor: National Center for Manufacturing Sciences, 1990), p. 1-3.

are being researched and if necessary, developed to provide logical and straightforward communication to new or existing machine tools.

The project is validating the ability of the capacitance sensors to accurately and repeatedly measure the complex shape of a workpiece. Mathematical modeling of the designed sensor(s) and probes is being performed and analyzed. A demonstration lab unit and specifications for the equipment design with interfacing protocol to as wide a range of machine tool controls as practical to perform the inspection procedure on the machine tool are being established. In addition, the system's ability to withstand the rigors of a hostile machine tool environment are being tested. The research will culminate in the design, fabrication and test of the entire system, the integration of the system with a machine tool process, the optimization of the process and the demonstration of the total system capabilities.

Benefits

The opportunities to improve the performance of products and to permit innovative new designs for products that are dependent on components with complex shapes are limited by the high costs of producing the components and verifying their shapes. For example, involute gears are very sensitive to gear misalignment. If the profile of the gear is manufactured incorrectly, the subsequent misalignment will cause the shift of the bearing contact toward the edge of the gear tooth surfaces and transmission errors that cause gear noise. Much time and expense is spent in the design and engineering, as well as the manufacture of these gears simply to overcome the control variations of the gear producing process. An innovation to improve the manufacturing of gears by providing timely verification and subsequent correction of the process would provide a welcome technology edge to producers, end-users, as well as U.S. manufacturers of gear machine tools.

The need to verify complex shapes and accordingly correct their manufacturing processes has been recognized by the aircraft turbine engine industry. Numerous components in a jet engine including turbine blades, impellers, and Integrally Bladed Rotors (IBR's) possess complex contours and shapes and require very detailed and complicated inspection procedures. An inspection system incorporating dimensional and tolerance data measurement in a timely fashion as close to the manufacturing process as possible would lead to reduced inspection time and costs, higher standards of accuracy, increased workpiece throughput, and reduced machining labor costs.

As devices continually and increasingly employ complex shapes and near net-processed components gain popularity, the need to verify these components' complex shapes will grow accordingly. If the proposed system of near-process verification of those shapes finds successful integration, the subsequent growth of complex shapes and their manufacturing processes would be compounded. The expanded design opportunities for new products with special capabilities will offer significant performance and strategic benefits in a range of applications including turbine engine components, gears, and cutting tools.

RELATED WORK

Capacitance sensing technology has been used since the 1950's for measuring the thickness of metal strips and coatings, the expansion and fatigue of metals, and the size, depth and cylindricity of precision bores and shafts. One of the important benefits of capacitance in these and other applications lies in its ability to measure such parameters without actually contacting the workpiece surface. Other advantages include a high frequency response, excellent linearity and resolution, and convenient portability. Typical configurations of conventional capacitance dimensional measurement systems are singular or differential in application. Extrude Hone's MetreX Division has pioneered the effort to develop capacitance technology for surface finish evaluations, and has recently developed basic capacitance sensor array capabilities for shape, edges, proximity, and slip under a Phase II Department of Energy SBIR project.

The Division is currently working on a Phase II SBIR grant sponsored by NASA to demonstrate the feasibility of integrating all of the tactile attributes into a single sensor array, to develop software to control sensor scanning schemes and to establish adaptive grasping control algorithms.

One phase of the current Air Force project is to build on the results of this program to integrate the dimensional measurement capabilities of a capacitance array and probe to check the conformity of a complex workpiece shape to a known reference shape on the machine tool.

The Division was granted a license to patents and know-how covering the use of fringe-field capacitive technology developed at the University of Washington. The technology supplements the Division's existing techniques with surface profilometry and dimensional measurement capabilities. The Division has been working to incorporate this technology for those applications which require more than average surface roughness measurements. The advantages of current capacitance metrology including fast response time and rugged sensors for in-process inspection are enhanced and strengthened by this technology.

This technology was one of three selected for evaluation for the Automated Disk Slot Inspection System (ADSIS), an Industrial Modernization Incentives Program (IMIP) through Garrett Engine Division of Allied Signal Aerospace Company. The objective of the program was to develop an automated system of inspecting gas turbine engine disk slots using advanced inspection technologies to achieve enhanced accuracy, repeatability, and flexibility coupled with faster data acquisition. Under this program, a spherical capacitance prototype probe designed to interface to a Coordinate Measuring Machine was delivered. This single sensor probe provides noncontact dimensional data on turbine disk slots in a scanning mode without contacting the part. After initial evaluation by both Garrett and the National Institute of Standards and Technology (NIST), the capacitance probe was selected as one of the prime sensing technologies . The other technologies, conventional touch trigger and laser triangulation probes, were deemed too slow and not capable of being configured small enough to reach into the limited access areas required.

This Air Force effort is building on the results of these programs to establish the feasibility of integrating the measurement capabilities of this Capacitance Non-Contact Analog Probe to measure dimensions, features and surface characteristics in conjunction with an appropriate machine tool.

Bibliography

Garbini, J.L., L.J. Albrecht, J.E. Jorgensen and G.F. Mauer, "Surface Profilometry Based on Fringing Capacitance Measurement," *ASME Journal of Dynamic Systems, Measurement and Control*, Vol. 107(3), (September, 1985).

Garbini, J.L., F.T. O'Neill and J.E. Jorgensen, "A High Speed Fringe-Field Capacitive Hole Inspection System," *Modeling, Sensing and Control of Manufacturing Processes*, ASME, DSC-Vol.4, (1986).

Mathias, R.A. and J.L. Garbini, *An Advanced Force Sensor System for Unmanned and Flexible Manufacturing*, presented at the Sensor Technology for Untended Manufacturing Conference, Chicago, Illinois, SME Paper No. MS84-910, (1984).

Tsukamaki, T., J.L. Garbini and J.E. Jorgensen, "An Algorithm for the Control of a Bi-Stable Multi-Segmented Manipulator," presented at the Fifth IASTED International Symposium on Robotics and Automation, (November 12, 1984).