TEST BED CONCEPT AS A MEANS OF INTRODUCING NEW TECHNOLOGY

A.L. Thompson, E.E. Weismantel and D.M. Comassar
The Aircraft Engine Group
General Electric Company
Evendale, Ohio 45215

ABSTRACT

The rapid evolution of ultrasonic testing technology over the last ten years has found industry unable to test or apply many of the new concepts resulting from this work due to limited facility resources to adopt these advanced methods. The testing of these methods is a desirable sequence in the evolution of new ideas to production usage and in many cases would require a test bed on which to try innovative ideas. This test bed concept would provide an avenue to resolve applications problems which might otherwise overshadow the significance of technology innovations. The availability of a test vehicle with which to prove or if necessary further modify these growth ideas further benefits these accomplishments by verifying their validity and performance. In recognition of this need, a program has been undertaken to establish an advanced ultrasonic work station with the ability to function as a test system for the application of these concepts to commonly encountered inspection tasks.

The present system contains all solid state instrumentation designed around the latest electronic concepts and features extensive computer interfacing with regard to both signal handling as well as command and feedback systems. The specially developed ultrasonic instrumentation contains programmable gates and interface synchronization and provides the capability to process the full R-F waveform during test. Output from the ultrasonic instrument is processed through a high speed digitizer between the instrument and the computer which is dedicated primarily to data acquisition, analysis and retention. Two-way communication linkages exist between the ultrasonic instrument and the computer as well as between the computer and the motion and position control to allow the incorporation of signal correction techniques to accomodate material attenuation, surface lens effects due to radii, etc., so that the computer can judge signal significance incorporating these corrections. Data output from the test is supplemented by graphic displays allowing the presentation of planar and rotated views with the expansion capability for the examination of selected volumes. This system is currently being applied to the evaluation of specially contoured shapes for advanced turbine engine programs in which signal characterization will play a significant part in the data analysis.

INTRODUCTION

The constant emphasis on improved production efficiency and productivity that has typified twentieth century industry has resulted in numerous changes in manufacturing methods and concepts. However, the changes that are incorporated are notas readily accomplished as one might imagine since minor changes in routine are often reflected in immediately increased costs even though, in the long run, the change might benefit overall cost and quality. The target of improved product cost resulting from increased efficiency in the use of materials, increased production capacity and increased productivity is a powerful driver that can make promising process innovations successful. Seasoned manufacturing management readily recognizes the importance of gaining the acceptance of new methods by the operating components before new ideas are fully committed to production. As a result, many manufacturers have adopted the concepts of prototype processes, pilot lines and the like to initially debug new methods, demonstrate capability and overcome those problems that might adversely influence the cost, productivity and permanence of these innovative methods.

This same approach influences the introduction of changes in the nondestructive test processes, such as ultrasonic inspection. In the case of the quality oriented processes, the gains obtained from technology advancements can be more difficult to introduce than are changes in the manufacturing processes where improvements are mostly related directly to the cost and thru put of the process. Improvements in flaw detection capability or significant changes in the the acceptance criteria applicable to hardware must first gain engineering acceptance before becoming a basis for product acceptance. Once engineering acceptance is achieved, the gaining of manufacturing acceptance further requires the proof that the change in method can be accomodated in the production area with minimal impact on production cost.

It has only been in the past ten to twenty years that a wide enough technical base has been established to regard nondestructive testing processes as technologies rather than skills. NDE as an art really came into being in the Second World War and the technology base currently is much more in its infancy than are most engineering and manufacturing oriented technologies. Until recently, even the advanced industries had not considered then NDE processes as much more than quality checks in the manufacturing cycle rather than information tools. Consequently there was little impedence for improving NDE processes to obtain more information from the inspection process itself.

In the electronically oriented processes, such as eddy current inspection and more notably in the ultrasonic area, the inspection processes have benefited markedly from very rapid advancements, resulting from the evaluation of solid state electronics. This situation has given impetus to the understanding of the "whys and wherefores" of the inspection process rather than the "how-to-apply the process" emphasis that had existed previously. Heretofore, equipment noise, lack of stability or drift, lack of equipment standardization, etc., had precluded the ability to characterize waveforms of any significance. In addition, the response time of earlier forms of signal processing was not adequate to handle the very large quantities of data obtainable from the inspection process. The advent of solid state circuitry, high speed data gathering and computing capability vastly increased the potential of these processes.

Many new ideas in information gathering are evolving from these more recent advancements in equipment capability and a markedly modified approach to materials interrogation is forthcoming from this emerging technology. Typically, many of the accomplishments now resulting from the ARPA/AFML supported studies in Quantitative NDE require further demonstrations of validity and usefulness to gain generally broad acceptance and application to every day inspection tasks. The developement of new concepts for ultrasonically assessing, defining and quantifying flaw types, size and geometry resulting from these research programs must have a more direct avenue to the practical task of hardware inspection if the journey from the laboratory to industrial use is to be shortened. These advanced approaches to the inspection of materials face a potential barrier in the lack of suitable resources to test these innovations since normally available production oriented equipemnt is too limited in capability to serve these purposes.

A surprisingly large amount of inspection equipment existing in industry today is still of the older vintages, and, where many facilities may have solid state instrumentation, much of it is based upon 1950-1960 design concepts. Basically, many of the users of the inspection processes are still trying to accommodate the "how-to-apply" of the process since it is only the more technically advanced industries that have the incentive to strive for the benefits that might be attainable through the development of sophisticated techniques.

However, many of the suppliers of electronic inspection equipment are atuned to the demands of the market, the bulk of which is oriented to less ambitious commercial tasks. Because of the limited size and resources, these suppliers are not normally in the position to lead the industry by furthering the advancements in inspection technology. So it remains that, if improvements are to be gained in the amount of quantitative information attainable from these inspection processes, the advanced technology industries, namely aerospace and nuclear must fill this need. Without the testing and proving of the accomplishments forthcoming from the work aimed at upgrading the ultrasonic technology base, in fields ranging from the improvement of transducers to the definition of frequency response, scattering and imaging, their value could well go unnoticed and materials inspection practices would continue to follow the limited horizons of present production methods. Today's production methods rely primarily upon the measurement of response amplitude as a gage of acceptability or rejectability of the product, although it is broadly known that this amplitude information is perhaps only ten percent of the information available from the interaction of the response source and the sonic beam. The inability of commercially available equipment to work with much more than this is one of the inhibitors to the growth of application technology in the field of ultrasonics. The high level of sophistication coming from presently active development programs requires a degree of proof and demonstration beyond that which would normally be required for more straightforward process advancements. What is now needed is a test bed in which to test this evolving technology in order to sense out and prove the real potential of new innovations. This test bed would work under the conditions normally encountered in the production inspection of hardware while providing the inspection data accumulation and data processing capability needed to exercise the new ideas. It is most important that the presently subtle influences on the inspection process be eliminated or at least controlled to such a degree as to minimize their effects on the process so that the inspection innovations can truly be assessed. In a test bed arrangement, this can be done in a work environment that would simulate the conditions normally expected of a production system applied to production hardware.

Several years ago, the Aircraft Engine Group of the General Electric Compnay, began an effort to bring further sophistication to the ultrasonic inspection process. This effort has resulted in the establishment of a system which minimizes human involvement in the inspection, as well as providing a test bed for advanced inspection concepts.

Long range goals and targets for this inspection system were established. Commercially available instrumentation and facilities to act as base for development work were sought; neither electronic equipment nor the mechanical elements of the workstation were available to serve our purposes. Therefore, the program first started with the design and fabrication of the present workstation which is aimed at the testing of new inspection ideas prior to production applications. Basically, the test bed consists of four separate elements.

1. Electronic Instrumentation
2. Signal processing, analysis, computation and decision making components
3. System Motion Control
4. Mechanical System

ELECTRONIC INSTRUMENTATION

At the time this activity was started a survey of available ultrasonic instrumentation could not identify any available or near term instrumentation that would meet required system requirements which were:

1. Ability to process the total R-F waveform for subsequent signal analyses and interpretation
2. Capability of complete computer interfacing so that the resulting system could be truly computer controlled relative to establishing the various instrument settings, gates, etc.
3. Practically no instrument effects on the nature of the received signal
4. Very low instrument oriented background

At that time, a detailed specification was established for the electronics system and a contract with our Corporate Research and Development Center at Schenectady was placed for its design and fabrication. The resulting prototype system was truly a first of its kind and met most of the original design specifications. This prototype was used for our early work and we subsequently procured a second iteration of the design (illustrated in Fig. 1) which now is in development use. This new electronics package has the following capabilities:

- Spike pulser
- Receiver bandwidth - .5 MHz to 18 MHz
- Programmable attenuator
- Waterpath delay/main data gate
- Pulse repetition rate - 10 Hz to 5 KHz
- Analog alarm outputs.
- Hewlett-Packard 182C scope
- Radio frequency and full wave rectified display
- Fully computer compatible
- Synchronizer - Keyboard readout
- Pulse trigger on/off
- Interface synchronizations of gate start
- Gated radio frequency and video output
- Digital readout of peak amplitude available

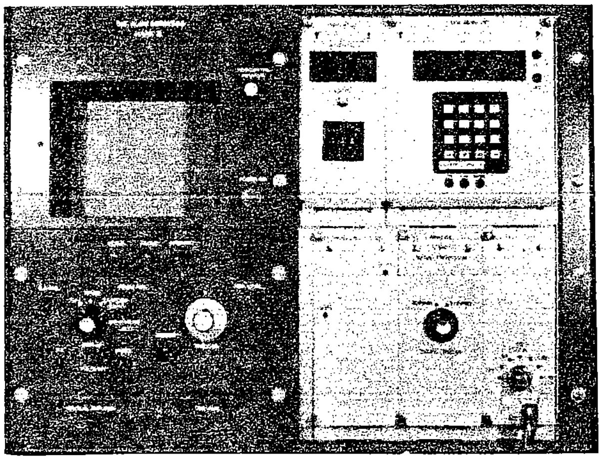

Fig. 1. Advanced computer interfaceable ultrasonic instrumentation

SIGNAL PROCESSING, ANALYSIS, COMPUTATION AND DECISION MAKING COMPONENTS

The components of the system that are involved with the signal processing, data analysis, computation and decision making include the Biomation 8100 Analog to Digital Converter, and the Digital Equipment Corporation PDP 11/55 computer illustrated in Fig. 2.

Biomation 8100 - The Biomation 8100 is a high speed analog to digital converter which is utilized for digitizing the radio frequency waveform as it comes from the ultrasonic instrumentation so that the system computer can further process and analyze the waveform information. The purpose of processing the total radio frequency waveform is to provide the capability to perform Fast Fourier Transforms (FFT) and spectral analysis of the inspection data as the need and technology develops.

PDP 11/55 Computer - The system computer performs a variety of tasks. These include setup and control of the Biomation 8100 and ultrasonic instrumentation with regard to data acquisition and inspection sensitivity. The computer's main task however, is to provide the signal analysis and decision making for the system. This includes performing a Distance Amplitude Correction for each pulse of data, correcting for signal degredation caused by lens effects of curved surfaces, as well as analyzing the amplitude of each pulse of information. Also, if during the course of an inspection a significant indication is detected, the computer must store all amplitude and positional information for further reference.

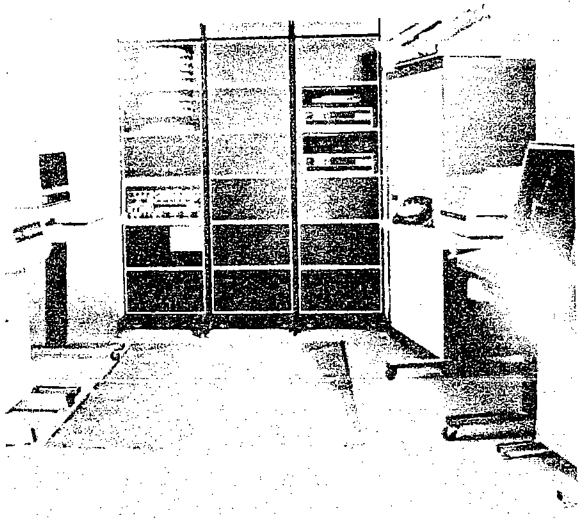

Fig. 2. PDP 11/55 computer and peripherals

SYSTEM MOTION CONTROL

The motion control of our ultrasonic inspection system is provided by a numerical control (GE 1050) which can be seen in Fig. 3. The choice of using an N/C for this task was made for two reasons. First, production ultrasonic inspection at GE has involved the use of N/C controls for several years. This experience was drawn upon in specifying the automated inspection system. Second, the GE inspection system has as one intent the complex analysis of the total Radio Frequecy Waveform. This involves significant computer processing power and prohibits the use of the system's computer for both data analysis and motion control.

The General Electric 1050 numerical control differs from conventional hard wired N/C equipment in that this control is a series of microprocessors, one for each axis of motion. These microprocessors control the motion of the system in both simultaneous linear and rotary motion. The fact that the control is microprocessor based provides the benefit that the major portion of the control logic is software based. This allows greater freedom in utilization as well as modification. The software based aspect is also a benefit in that it enhances communication between the N/C and the system computer.

The N/C is programmed using a unique programming system developed by GE that allows for programming the N/C based totally on ultrasonic variables and not dependent on the conventional APT language most often used for N/C programming.

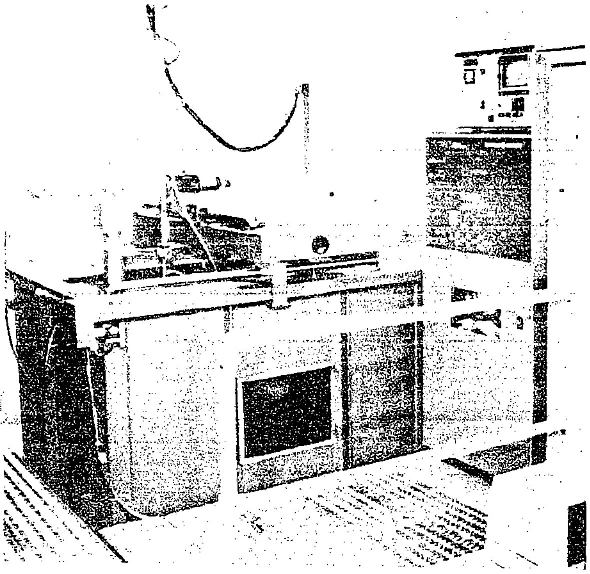

Fig. 3. Automated ultrasonic workstation including motion control - ultrasonic instrumentation and digitizer

MECHANICAL SYSTEM

The mechanical portion of the General Electric Inspection System was specified with rigidity and precision in mind. The mechanical system, shown in Fig. 3, consists of an immersion tank, rotating turntable with lift platform, three axis (X,Y,Z) bridge and double gimbal manipulator.

The immersion tank and turntable are fabricated of noncorrodible stainless steel. The turntable is completely enclosed to avoid any water turbulance at high rotational speeds. The lift platform provides the capability to load a part above water and then locate the part at a precise location below the water surface. The three axis (X,Y,Z) bridge is designed to machine tool accuracies for the rigidity and precision necessary to attain system reliability and repeatability requirements. The bridge provides the linear motion required to traverse a part during inspection. The double gimbal manipulator, also designed to machine tool tolerances, provides the rotary motions necessary to perform the inspection of complex contours.

These 5 axes of manipulator movement, 3 linear and 2 rotary, have been found to be necessary to perform the inspection of complex, contoured parts. The simultaneous movement of these 5 axes is accomplished through use of a mechanical system design requirements as shown in Fig. 4.

BRIDGE, X AND Y AXIS:

Positioning: ± 0.003 in./ft. (± 0.018 in. Total)
Resolution: 0.001 in.
Backlash: ± 0.001 in./ft.
Repeatability: ± 0.001in./ft.

SEARCH TUBE, Z AXIS:

Positioning: ± 0.003 in./ft. (± 0.012 in. Total)
Resolution: 0.001 in.
Backlash: ± 0.001 in./ft.
Repeatability: ± 0.001 in./ft.

SEARCH UNIT MANIPULATOR "a" AND "b" AXIS:

Positioning: ± 0.25°
Resolution: 0.1°
Backlash: ± 0.25°
Repeatability: ± 0.25°

ROTARY TURNTABLE, "c" AXIS:

Part Centering: 0.010in. TIR
Surface Runout (Full Load): 0.015 in. TIR
Elevating Positioning: ± 0.015 in.
RPM Constant Within 3% of Setting
Table to Bridge Parallelism (X Axis): ± 0.005 in./ft.
Table to Bridge Parallelism (Y Axis): ± 0.005 in./ft.
Table to Bridge Perpendicularity (Z Axis): ± 0.005 in./ft.
Table Lateral Movement: ± 0.010 in.

Fig. 4. General Electic near net shape ultrasonic inspection system - mechanical system accuracy requirements

THE SYSTEM IN TOTAL

Although each of the foregoing elements is unique and represents the latest of state-of-the-art technology, the real benefit from the system results when they each work in concert as part of an overall inspection operation. The following briefly describes the chain of communication and linkages already existing to provide a viable working production-oriented inspection system in which operator controls, influences and judgements are practically nonexistent. Figure 5 illustrates diagrammatically these relationships and communications linkages.

The inspection operation begins when the operator enters into the computer the part number of the component to be inspected. The inspection requirements for that component already exist in the computer memory from prior programming and/or communication with the CAD/CAM network. Information relative to the part configuration, required calibration level, the number and type of scans required, a definition of all manipulator movements, the scanning "evaluation" level, the evaluation accept/reject criteria are all in the computer file. The definition of the movements of the manipulator required to accomplish the inspection is transferred from the computer to the motion control. The inspection begins with the manipulator going from "home" position to that of locating the permanently fixed calibration block. The transducer is manipulated over the block in both longitudinal and shear positions to reach the prescribed calibration criteria, while the computer adjusts the instrument to provide the sensitivity level required for the inspection. Having established the inspection sensitivity, the transducer is moved to the inspection start position. Each step of the inspection operation is described for the operator in alpha-numeric form on the control display device so the operator can follow the inspection sequence. The manipulator guides the transducer through each of the 20 or so positions required to obtain total part interrogation.

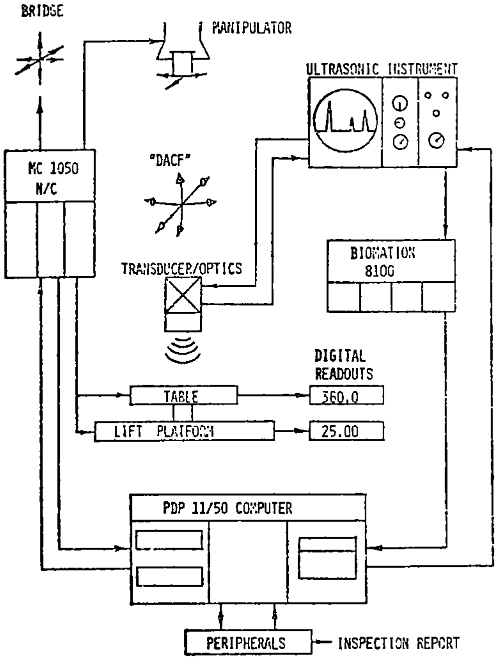

Fig. 5. Diagrammatic layout of near net shape system and communication linkages

During these movements, pulses from the instrument are interrogating the component relative to its internal quality. With the availability of the previously stored information relative to the part configurations, the computer continually adjusts the gating to exclude reflections associated with the front and rear surfaces. In addition, all returning signals are accessed relative to the part surfaces exposed to the beam, and returning signals, only slightly above the already low background noise level, are also considered relative to the depth below the surface where the signal is generated. The signal amplitude then is adjusted by the computer to accommodate the loss in signal strength due to attenuation. Adjustments in signal levels from reflectors on the near surface of the part also are adjusted automatically downward to accommodate the over inspections encountered in this area due to lens effects when inspecting cross section of any depth. As a result of these multiple corrections, each signal is considered at its "true" amplitude value.

With this information available, the computer considers the amplitude of the response in comparison with pre-established evaluation instructions. If the response amplitude is not considered significant, the data are discarded. However, if the responses exceeds the evaluation criteria, the response amplitude or the total R-F waveform of that indication can be digitized and entered into the computer memory along with the address location of all axes.

With the address of each suspect indication entered into the computer memory as it is encountered, the inspection continues uninterrupted until the total inspection sequence is completed. At this point, all suspect areas can be re-evaluated to better assess the character of the indication with already established evaluation routines. As an example, if a low level response was noted in a specific area, the computer would command the position control to return to that specific address. All axes would be located to satisfy the address requirement. At that point, an angulation maximizing routing would better assess the flaw to determine if, due to orientation, the signal could be increased above the level found during the scanning procedure. At this point, if an appropriate program were available, the R-F waveform response characteristics of the flaw could also be assessed from several positions. Once the evaluation data are obtained, then the computer can be programmed to treat the data in any prescribed way so as to make a decision relative to quality of the hardware or the nature of any suspect areas within it.

In this inspection system, we have available a total automated operating ultrasonic system which can be separately programmed to perform a specific or a sequence of pre-established inspection routines on live hardware configurations. The system can then subsequently process and manipulate the resulting resonse information in accordance with prescribed analysis routines, which include the processing of total R-F waveforms, or it can perform other manipulations required for enhanced flaw definitions. Thus, this powerful system becomes an available test bed which can further apply the theory and routines established in more limited laboratory evaluations. These approaches might enhance the assessing and quantifying of conditions associated with both the ultrasonic response character of different flaw types, as well as other effects. The successful testing of these technical developments under controlled conditions in real hardware with equipment adaptable to production use is one of the most pressing needs in bringing such advancements from the laboratory to production usage.

CONCLUSIONS

1. Advancements in ultrasonic technology offer the potential to gain a great deal more intelligence from the ultrasonic process than the type of inspecion data obtained heretofore.
2. A recently established test bed described in this paper can provide the facility capability to demonstrate the use of this advanced technology in hardware applications.
3. The demonstration of advanced technology applications on working production adaptable systems is a preferred direction to follow in gaining the acceptance of these advancements by the production oriented users.

DISCUSSION

Robert E. Green, Jr. (Johns Hopkins): Could I get the slide back that showed the performance characteristics themselves?

Dorothy Comassar (General Electric): Which performance characteristics?

Robert Green: What you talked about in the frequency range. It seems to me the bulk of the attenuation occurred using ten megahertz or five megahertz. If that's true, I don't understand the results.

Jerry Tiemann (General Electric): That's a typo.

Dorothy Comassar: That's a mistake.

Robert Green: What should it be?

Jerry Tiemann: Probably ten hertz to five kilohertz, but I'm not sure.

Dorothy Comassar: Let me check my write up. There were some errors in the slide.

Robert Green: It's very likely ten hertz to five kilohertz. The other question is why did you pick 18 megahertz as the limiting top frequency in the receiver band width?

Dorothy Comassar: I'm not really sure. Jerry, I'll pass that one on to you. That certainly met our needs and, I think, the system with the other constraints that we placed on it ended up in that range. I don't know that we designed it specifically for 18, but it did cover that range.

Jerry Tiemann: I think that arose from a tracing through of the minimum size flaw that we eventually wanted to detect which was of the order of a few mils.

Don Forney, Chairman (AFML): Another question over here?

George John (Aero Associates): How long does it take you to make a scan on the part that you showed?

Dorothy Comassar: We can achieve a 30 to 50 percent reduction in scan time merely by the automatic features of the system. A conventional system will not inspect that hardware. You have to have rectilinear shapes and a sufficient material envelope in order that the commercially available equipment will deal with it.

George John: So, what is the time?

Dorothy Comassar: An hour or so. I really would have to check if you want a precise answer.

George John: Well, it's not a minute.

Dorothy Comassar: No.

Don Forney, Chairman: Just one more question.

Harish Dalal (SKF Industries): You mentioned that to use the system all you have to do is to load the part and switch the system on and it goes. The sensitivity of the system also depends on the relationship between the transducer and the part.

Dorothy Comassar: One of the things I didn't mention because of the time is that the system automatically calibrates itself. There is a command, if you will, that starts the system. We can program in the sensitivity that we want to achieve and, resident in the tank, is the calibration block which sets the instrument setting.

Don Forney, Chairman: I'm afraid we've got to move on. Thank you very much, Dottie.