NDE OF HIP FABRICATED NEAR-NET SHAPED COMPONENTS

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ABSTRACT

We will describe an approach being taken to meet the challenge of inspecting near-net shape turbine disks. The inspection system to be described is based upon the concepts of computer controlled contour sensing and following, and high sensitivity ultrasonic instrumentation. The details to be presented will include the requirements that must be met by HIP processing technology to insure reliable inspection of components with as processed surfaces. The ability of this inspection system to provide the detailed defect size, shape and orientation information so critical to fracture mechanics lifetime prediction systems will be considered. This latter feature will become important as higher strength superalloys come into use for disk applications.

Introduction

Technologies are now being developed (HIP and isothermal forging) which will permit the fabrication of preform shapes very close to the final part geometry. This near-net shape fabrication philosophy has the potential for significant reduction in component cost over current fabrication methods because of more efficient use of material and reduced machining. However, these cost savings cannot be fully realized unless preform shape requirements set by current ultrasonic inspection procedures are eliminated or reduced. Current practice requires that the inspection shape be regular with rectilinear faces devoid of all tapered and curved surfaces. This requires that the inspection shape be several times more massive than the final shape. (Figure 1) In addition, the conventional systems used to inspect disk shapes have limited sensitivity to defects near the surface requiring a minimum of 0.150" overstock to obtain a reliable inspection throughout the volume of the final machined component. These NDE constraints severely limit the cost benefits that are potentially realizable by powder metallurgical processing techniques.

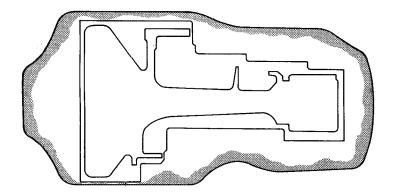


Figure 1. A comparison between the conventional forging, sonic and a near-net shape of a turbine disk.

Near-net shape fabrication results in approximately a 300% reduction in material. This savings can only be achieved if the sonic shape restriction imposed by the inspection process is eliminated.

Current NDE Practice

The primary NDE technique used to control the quality of turbine disk components is immersion ultrasonic inspection. Figure 2 is a schematic representation showing the essential features of this type of inspection system. The ultrasound beam emitted by the transducer is transmitted by the water to the surface of the component where it is partially reflected and partially transmitted through the interface. The physics of the interaction at this interface are well known; the significant features are that the maximum energy is transmitted through the interface when the ultrasonic beam is normal to the surface, Figure 3, and that when the beam is normal only 15 percent of the energy is transmitted through the interface. After passing through the interface, the transmitted beam can now interact with a defect; the ultrasonic energy reflected by the defect must again interact with the interface, losing 85 percent of its power before being received by the transducer. Typically, defect signals received by the transducer are 10-0 the amplitude of the signals transmitted by the transducer.

It should be apparent then that it is very important to maintain the ultrasonic beam normal to the surface of the component being inspected. It is for this reason that current practice requires that turbine disks be machined to

regular rectilinear shapes before ultrasonic inspection. With such a shape, it is easy to maintain normalcy while the disk is rotated beneath the inspection beam.

There is a second feature of current ultrasonic inspection which limits the benefits of near net shape fabrication techniques; conventional ultrasonic systems have limited near-surface resolution, i.e. the ability to detect defects near the surface is reduced. The reason that this occurs is simply related to the drastic difference between the amplitude of transmitted ultrasonic signal and the amplitude of the received defect signal. To observe the low amplitude defect signals, both signals must be highly amplified, and if the transmitted signal does not fall off sharply (as shown in Figure 4b), but trails off (as shown in Figure 4a), the transmitted signal will mask defect signals closely following it. The more the transmitted signal trails off, the worse the near-surface resolution will be. In many conventional systems, the near-surface zone of poor resolution can extend to a depth of 0.150" or more below the surface.

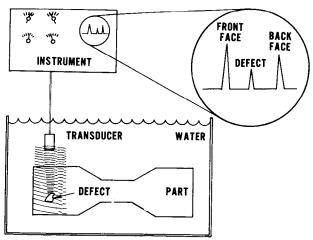


Figure 2. A schematic representation of a conventional ultrasonic inspection system. The signals shown on the instrument screen are a consequence of acoustical impedance changes at interfaces in the path of the second beam.

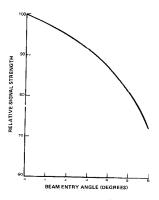


Figure 3. The variation of the amplitude of an ultrasonic beam as it deviates from a normal impingement on an interface. Sensitivity to beam entry angle requires the beam to be maintained normal to the surface under inspection.

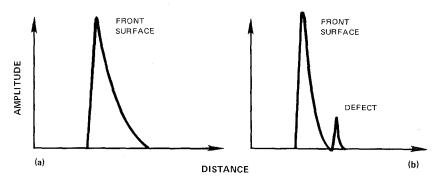


Figure 4a & 4b. A schematic showing the importance of ultrasonic instrumentation and transducers upon the resolution of defects near the front surface. The poor response of the instrumentation in (a) cause the near surface defect resolved by (b) to be obscured.

A Solution To A Problem

The major inspection shape requirement which limits the adaptation of nearnet shape fabrication can be eliminated by the use of an inspection system with the capacity to sense and follow irregularly shaped geometries maintaining the optimum inspection geometry. The liberation from shape restrictions is possible by the availability of the feedback control and calculation ability of modern inexpensive minicomputers. Inspection overstock requirements can be reduced to 0.50" or less by the use of high-sensitivity, low-noise instrumentation made possible by modern solid state electrical components.

Figure 5 is a schematic representation of an automatic contour following inspection system being developed for the inspection of near-net shape turbine disks. This system is under the control of a minicomputer and is capable of sensing the contour of a disk and, with the aid of a limited preknowledge of the nominal near-net shape, will automatically follow the near-net shape disk geometry, keeping the appropriate separation and inspection angle. For special problem areas, the system can be entirely controlled by the computer. The system design provides for two transducer manipulators for greater flexibility in performing disk inspection and for conducting defect analysis. The manipulators are mounted on a turntable which is capable of 350° of rotation. The primary contour-following transducer is located on the turntable axis of rotation. The secondary manipulator is moveable and can be made to stand off a variable distance from the primary manipulator. The manipulators have three degrees of freedom: vertical displacement, rotation and a gimbal movement. All three degrees of freedom are under direct computer control. Normalization of the contour-following transducer to the surface under inspection is controlled by the computer by sensing and maximizing the front face reflection.

The ultrasonic instrumentation has been designed to meet several important goals. First, it must be capable of resolving a No. 1 (1/64") flat bottom hole at 0.050 and 3.0 inches of metal travel with the same instrument settings if it is to have the sensitivity required to detect those small defects of interest in powder processed Ni alloys. The near-surface resolution part of this goal will permit the use of almost negligible inspection envelopes, while the high resolution at depth will permit a thorough inspection of highly-stressed thick sections such as the bore area of a turbine disk. Second, the ultrasonic subsystem must be capable of selecting the two largest indications that exist in the thickness under inspection. This requirement is necessary, not because we expect to find multiple defects (we expect to find very few since material processing is designed to eliminate them), but to insure that a real indication

is not lost if a back surface reflection were to appear suddenly and unexpectedly in the defect gate. Last, the critical controls of the ultrasonic subsystem must be under the supervision of the computer.

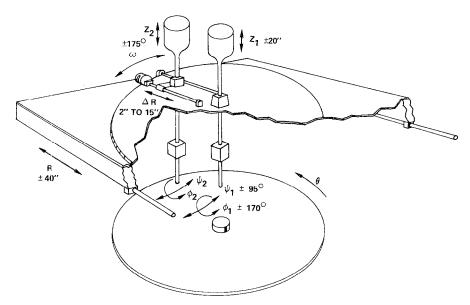


Figure 5. A schematic representation of the mechanical motions of the contour following system for the inspection of near net shape turbine disks.

Each of the degrees of freedom shown is controlled by the computer in order to contour follow and inspect a near net shape.

A block diagram of the ultrasonic instrumentation of the inspection system is shown in Figure 6. The main features include a high-rise-time pulser which can be connected to either of two transducers through a computer controlled switch. The subsystem includes two broadband receivers and two defect gates, each of which can select and indicate the position and magnitude of the two largest indications in the gate. There is only one front face and back face gate; these are assigned to the prime or contour-following transducer, since in most cases the secondary transducer will be oblique to the surface and will not see either of these reflections.

Data links are being provided between the ultrasonic subsystem and the computer to collect inspection data. All defect and position information are available to the computer on demand. Figure 7 shows how information is transmitted between inspection system elements and the computer. The inspection system is designed to be used by two levels of operators: an inspection operator who actually inspects a component and an inspection designer who decides how the inspection will be performed. The inspection designer describes the inspection system in a straightforward manner the type of inspection (shear, longitudinal or delta) and the inspection threshold for any given zone of the component. He only needs to indicate the beginning and the end point of this zone since the system can contour follow between these points. The inspection designer need not specify these points exactly, since the inspection system can account for the fabrication tolerance between components. The inspection operator has the responsibility of loading components and starting the inspection. He also interactively provides specific component information such as part number to the inspection system. The system inspects the part and notifies the operator of any abnormalities.

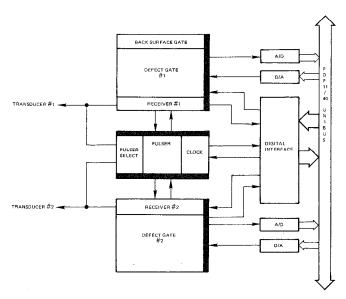


Figure 6. Block diagram of the ultrasonic instrumentation for near net inspection of turbine disks. The major components of the ultrasonic instrumentation consist of a single pulser and two independent receivers. The instrumentation is under computer control.

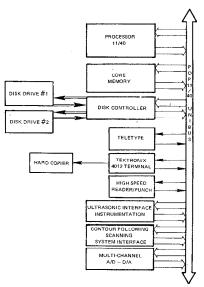


Figure 7. Block diagram of near-net shape ultrasonic inspection system.

Major components of the inspection system are the contourfollowing subsystem, ultrasonic instrumentation, and the
computer.

What are the Constraints

Although the inspection system just described will make it possible to inspect near-net shaped components, there are some shape constraints on these components. Currently, the system can contour follow on surfaces where the minimum radius is 3/8 inch. Surface roughness also affects the inspection sensitivity. Surface finishes of 160 micro inches or better are necessary for best sensitivity.

Additional Benefits

There are numerous features and options which become available with the advent of computer-controlled inspection. We have designed specific features into our inspection system to take advantage of these benefits.

- (1) Inspection records of all parts can be stored on a computer for future access and therefore any component can be "reinspected" at an arbitrary threshold (via a computer program) at any future date. The reinspection is possible since these records contain all signals above the noise level. This ability becomes extremely useful when tracing the origin of in service failures and provides a mechanism for the selective removal of all parts in the field with a similar difficulty.
- (2) Detailed stress analysis of rotating components, coupled with fracture mechanics analysis, has shown that the quality requirements in a component are not uniform throughout, but vary from point to point within the structure. With the implementation of computerized NDE techniques, it would be relatively easy to compare inspection results with zoned quality requirements for the particular part under inspection. The result would be to minimize rejections, quality review, and scrappage.
- (3) In the act of contour sensing and following the inspection system is determining the exact shape of the component under inspection. This shape data can be compared by the computer to the anticipated and final shape to determine if the preform is within tolerance or if the final shape can be machined from it. A near-net shape inspection system provides a positive feedback about process shape within a short time after the part is produced: extreme or variable dimensions discovered during the inspection can result in process modification to optimize the efficiency of the process.
- (4) A multiple transducer inspection system will permit simultaneous use of seven inspection techniques as well as provide the capacity for defect shape and orientation analysis. The latter information is derived from the angular variation in defect signal amplitude and is of great importance in clarifying the criticality of defects. The return of re-radiated energy sent by the primary transducer is detected by the second transducer and is analyzed by the computer to provide a more accurate picture of defect shape and orientation. Thus, the system provides more detailed information about the criticality of defects than is now possible.

In Conclusion

The advent of high resolution contour-following ultrasonic inspection systems will remove a significant restriction to the use of powder metallurgical processing techniques for making near-net shapes. What has been accomplished is to pass the shape determining factors from inspection to other features of the manufacturing process such as machining, fabrication shape control, heat treat distortion, etc. Figure 8 illustrates how these factors will interact to determine the optimum near-net shape for minimum cost.

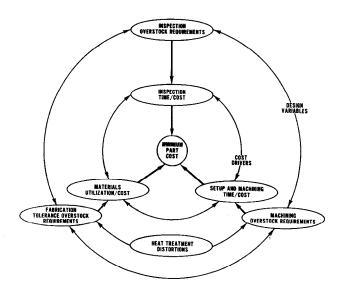


Figure 8. A schematic representation of how the important near net shape production constraints balance to affect part cost. With the development of a near-net shape inspection system the inspection shape requirements are relaxed; now other factors in the fabrication process become important in detailing actual production shapes.

Acknowledgements

The development of an inspection system for the NDE of near net is a major undertaking. Important contributions have been made by B. Yee, K. Kunselman at General Dynamics, Fort Worth, S. Matay at TRW, Cleveland, and by G. Biddle, J. Becker, and W. Adams at FWA.

The contour following technology was developed by General Dynamics under AFML Contract No. F33615-72-C-1828. The high resolution ultrasonic instrumentation being used was developed by TRW under AFML Contract No. F33615-71-C-1712. The construction of the near-net shape inspection system is being funded by the Air Force Materials Lab (AFML) under Contract No. F33615-75-C-5193.