The Future of Titanium Bar and Billet Inspection for the Commercial Aerospace Industry

Due to requirements of the Federal Aviation Administration, titanium bar and billet manufacturers have been required to tighten inspection criteria on such material.

Why do we need to detect smaller defects in the Titanium that is used in rotating aircraft engine components? It has been found that very small differences in the grain structure of titanium that is subject to high stress levels can result in structural failure. This condition is at the grain boundary level, when a hard area creates a zone that is a possible source of a crack. The processing of titanium has since been changed to minimize this condition utilizing multiple melt processes.

In 1989 a DC-10 airliner suffered a catastrophic engine failure when a fan disk cracked then split sending engine shrapnel thru the aircraft fuselage. The result was a hydraulic system that was disabled, the aircraft lost all navigational ability and subsequently crash landed. The crash investigation results showed that an engine compressor disk had cracked yielding an un-contained failure, meaning that engine component parts had left the engine compartment. Future analysis traced the problem to a hard alpha condition from the billet prior to the forging process. It was determined that billet before forging should be tested at a sensitivity that would better detect this condition. Also after the disaster, engines with the same type of disks were torn down and inspected utilizing a comprehensive ultrasonic and eddy current testing program in an attempt to avoid a re-occurrence.
As mentioned, ultrasonic inspection is the method to detect internal indications that could result in failure of a critical component.

Fundamentally, sound waves are generated and transmitted thru the part under test, the results are compared to known standards and the part is evaluated. Discontinuities in the material under test will give reflections that differ from signals received from homogenous samples.

With titanium inspection, however, there is a challenge, by nature it is noisy in ultrasonic terms. Sound waves scatter within the boundaries of the material and the test results are much harder to obtain. Sound waves and visible light waves act in the same manner in the fact that they can be focused. In photography, that uses light waves we notice that a subject in a picture may be in focus but objects in front of or behind may be blurred. Ultrasonic test probe designers and manufacturers install lens on the probes that give a fixed focal length, this focal length then can be used to give the optimal test sensitivity at a given depth in the material under test.

What has been found thru research is that to obtain a suitable sensitivity over a large sound path or material cross-section. It is necessary to use multiple transducers with different focal lengths to entirely cover the thickness of the material, while maintaining the same sensitivity throughout the volume of this material. This type of test apparatus is quite complicated and requires relatively large amounts of time for set-up and calibration. It may require as many as eight transducers (eight zones) that are approximately one inch of metal travel. Also the apparatus must track the surface movement of the bar under test to maintain normality. This tracking may require some four feet of distance that must be maintained along the length of the bar under test.

An alternate method of testing has been proposed for this inspection using a single test probe. The phased array approach, where a single
test probe made up of many small individual elements is controlled by a computer. The computer pulses the probe and when the return echo is detected, various portions of the test element are turned on and off to electronically focus the whole array. This allows the probe to while over the same spot of the material under test, to focus thru the whole range of depth. This method should prove to be a more economical method in the fact that less time will be spent in the system calibration as well as less capitol for the set-up of a working test system. Although this test system was designed for inspection of rotor grade titanium bar and billet, it would be beneficial for the inspection of other titanium bar that is of larger diameter, where greater test sensitivity is desired.

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By Albert R. Fletcher
Agenda

• Why we need to detect small defects in titanium billets
• What can happen if we do not?
• Manufacturing steps in the material.
• Fundamentals of ultrasonic inspection.
• Issues related to the testing of titanium.
• Current technology in use for inspection.
• Proposed inspection technology.
• Advantages and disadvantages of the proposed method.
• Questions and Answers
Why detect small defects?

• Question: Why would we want to detect small or very small defects in titanium billet.

• Answer: After billet are forged into aircraft engine disks, and placed under the stress’s small defects can propagate.
Fight 232 Crash
Why?
Uncontained Failure
Engine Failure

• A very small inclusion in the billet material grew in time, under the stresses of use, resulting in a crack.

• This crack caused a compressor disk to shatter and fly thru the engine housing.

• Debris from this disk cut thru hydraulic control lines, disabling the flight control system.
Location of Fan Disk
Engine Forging Production

Billet before forging

Disk after forge process
Forging Process
Forged disk
Ti Fan Disk

To be the standard by which all other testing laboratories are measured.
Disk in engine with blades
How to avoid a reoccurrence.

- Ultrasonic Inspection.
- How it works.
Fundamentals of Ultrasonic Inspection
Titanium offers challenges

- Materials such as steel and nickel alloys are relatively easily inspected to a high sensitivity level.
- Due to Titanium’s material nature (grain structure etc.), testing to a high sensitivity level can be a challenge.
Ultrasonic Wave Generation and Propagation
Depth of Field

- Large depth of field
  - Focus Point
  - 1/3
  - 2/3
- Shallow depth of field
  - Focus Point
  - Depth of Field zone

Precisely.

To be the standard by which all other testing laboratories are measured.
Beam Focusing
Material noise in Titanium

• To inspect material with high material noise, the area can be broken down into sections or (zones), covering different depths.

• Ultrasound like visible light can be focused.
Multizone Approach

- Transducers arranged with different focal depths to achieve high sensitivity at all depths tested.
Multizone System
Transducer’s Lined Up On Fixture
Alternative Method

• What if we could test with a single probe.
Phased Array Approach

• In Phased Array a single test probe composed of many individual elements is utilized.

• The signals are received by a computer controlled receiver, that focuses the test probe at all the desired depths in steps.
Phased Array Unit
Phased Array
Mechanical vs. Electronic Focus
Advantages

• Calibration of Multi-Zone channels requires each channel be calibrated individually. Each test probe must be positioned over the test block.

• Phased array is calibrated with only one basic element.

• Multi-Zone transducers are positioned in line over a relatively large span of distance.

Disadvantages

• A single phased array element has a small footprint, resulting in a shorter scan time.

• Initial costs of the two types of systems are both relatively high, but it is expected that Phased Array will be less expensive.

• Trials are not complete for phased array, although things look promising.