Immersion Multi-zone Ultrasonic Inspection System of Large-diameter Special Billets

Jianhua JIN [1], Xueying LIU [2], Maxim KRUSCHINSKI [3], Diamond HAN [4]
[1,4] GE Sensing & Inspection Technologies;
5F Hongcao Building, 421 Hongcao Road, Shanghai 200233, China
Phone: +86 21 34144620, Fax: +86 21 64857191; E-mail: jianhua.jin@ge.com
[2] Fushun Special Steel Co., Ltd; Fushun, China; E-mail: ftg.lxy@163.com
[3] GE Sensing & Inspection Technologies; Alzenau, Germany; E-mail: maxim.kruschinski@ge.com

Abstract

An immersion ultrasonic inspection system has been developed for the inspection of round billets. The diameters of the billets are up to 450mm. In order to detect the defects at different depth inside the billets with the same sensitivity, full-body testing of billets is carried out using multi-zone longitudinal wave inspection and shear wave inspection techniques. Eight transducers have been carefully designed to cover the inspection of different depths. The transducer fixture has been specially designed to adjust water distance and angle of the transducers with different diameters and focal length and keep them constant even with the harsh industrial environment. In order to improve the test speed and resolution, multi-channel parallel digital ultrasonic instrument based on VXI bus and GE-developed ultrasonic electronics, UTxx, is used as test electronics to drive ultrasonic transducers. The system software with imaging software has been designed to display real-time C-scan images with different kinds of graphical representation and evaluation ways. The detailed design of the ultrasonic inspection system will be presented. In addition, the test results of the system on large-diameter billets will also be provided.

Keywords: Ultrasonic testing, Immersion tank, Image processing, Billet

1. Introduction

The need for special forging materials (for example, Titanium alloy and high temperature alloys) is growing in recent years. Some of these materials are used to manufacture the critical components of aircraft engines. The performance demands for engine components can be quite stringent which, in turn, necessitates high-sensitivity inspection of the product forms that lead to the final engine component[1]. The special forging materials used in production of engine have to undergo ultrasonic inspection at the billet and forging stages. In response to this need, GE Inspection Technologies developed an immersion multi-zone ultrasonic inspection system, which was installed in 2008 in the works of Fushun Special Steel Co., Ltd. The system is used to inspect the billets with diameters and lengths up to 450mm and 8000mm respectively.

2. Multi-zone Inspection Technique

The conventional ultrasonic testing methods were limited in sensitivity due to material noise (especially coarse grain materials) and lack of transducer focusing. To overcome material noise and, therefore, improve detection sensitivity focused transducers are used to inspect the billet[1]. In order to detect the defects at different depth inside the billets with the same sensitivity, full-

body testing of billets is carried out using multi-zone longitudinal wave inspection and shear wave inspection techniques.

The whole billet volume is zoned into several inspection zones with different depths, as shown in Figure 1. The inspection zones are determined by the focal zone parameters of the transducers, the formulae used for the calculation of the –6 dB depth of field and the –6 dB beam diameter are as follows:

$$L = L_{-6db} \approx 4\lambda(\frac{F}{D})^2 \tag{1}$$

$$\phi = \phi_{-6db} \approx 1.03\lambda\frac{F}{D} \tag{2}$$

Where L is the –6 dB depth of field, ϕ is the –6 dB beam diameter, F is the focal length, D is the transducer diameter, and λ is the wavelength.

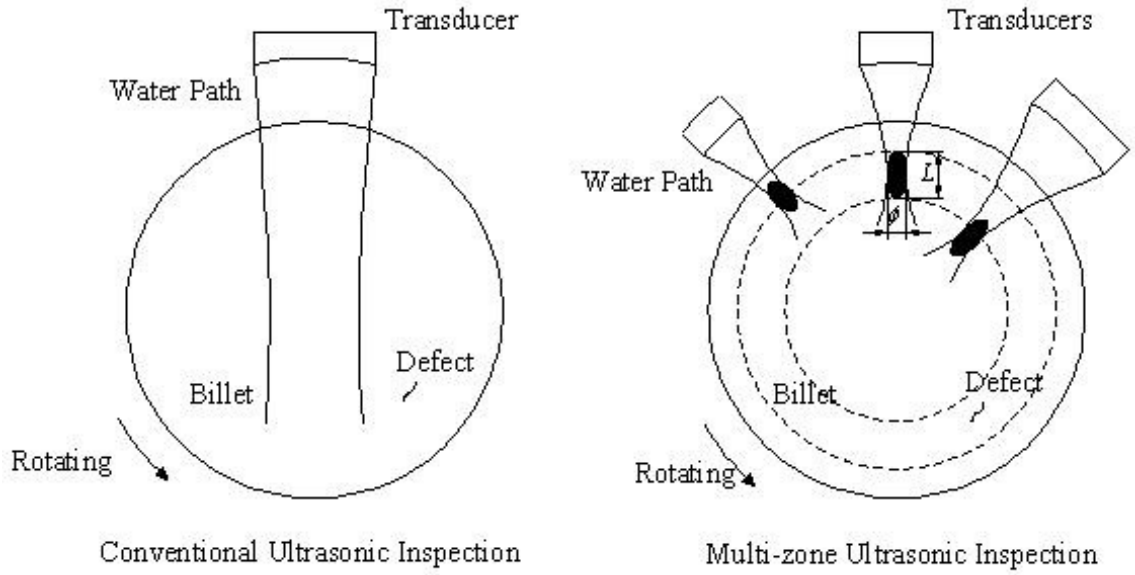


Figure 1. Conventional and multi-zone longitudinal wave inspections

Multiple transducers are used to cover these zones respectively. For this system, to cover different inspection zones the transducer unit consists of eight transducers. Seven transducers are used for multi-zone longitudinal wave inspection, the inspection by the longitudinal wave leaves an untested zone near the surface of the billet; another transducer is used for shear wave inspection, the inspection by shear wave covers untested zone in the above-mentioned area just under the surface. Therefore this transducer unit covers both the center region and the skin region perfectly.

3. Inspection System

Figure 2 shows the immersion multi-zone ultrasonic inspection system, the system consists of transducers, transducer fixture, 4-axes scanning mechanics, water tank, motion control system, ultrasonic instrument, and C-Scan imaging software.

The system also has remote service function which allows our service technicians to service and operate the machine remotely, whenever needed. This is helpful, when malfunctions or any problems during acquisition or evaluation occur.

Figure 2. Overview of immersion multi-zone ultrasonic inspection system

3.1 Transducer Fixture

The transducer fixture has been specially designed for fixing eight transducers, as shown in Figure 3.

The water distance and angle of the transducers with different diameters and focal length can be adjusted and kept constant even with the harsh industrial environment during scanning.

The transducer fixture consists of six longitudinal and two shear wave transducer holders and each holder has one manipulator. Bi-directional tilting and up-down movement of each holder are possible by the manipulator. Additionally, to adjust the incident angle the shear wave transducer holder is added a sliding movement for Y-axis.

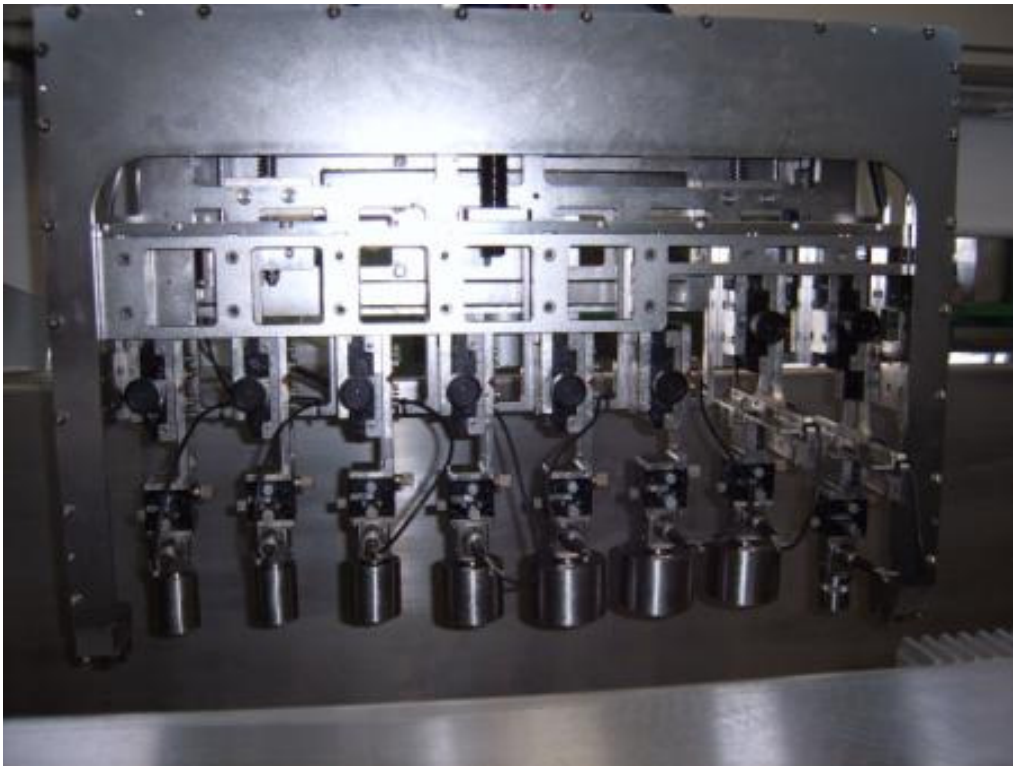


Figure 3. Transducer fixture

3.2 4-axes Scanning Mechanics

The system is equipped with 4-axes (X, Y, Z, W) scanning mechanics, as shown in Figure 4. Travel ranges of X, Y, Z-axes are 10,000 mm, 700 mm and 700 mm respectively, the maxim speed of X, Y, Z axes is 150mm/s, the maximum billet rotation speed (W-axis) is approximately 15 RPM.

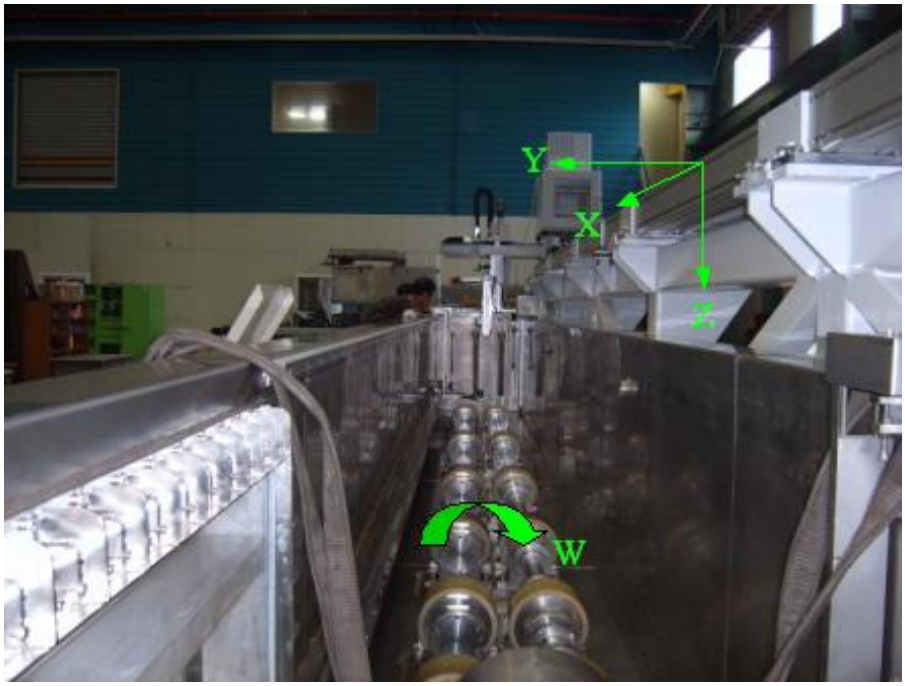


Figure 4. 4-axes scanning mechanics

3.3 Water Tank

The water tank consists of a main tank, a buffer tank and a circulation system. The water in the whole tank can be filtered one turn in one hour. The main tank contains a turning roller system for scanning and two stoppers for fixing billets. The buffer tank is equipped with a heating and filtering device.

Two sensors are mounted in the main tank and the controllers are mounted for automatic on/off control of the heating device if the water temperature is down below/higher than the setting temperature, the pre-defined temperature can be set in the operation interface.

3.4 Motion Control

For the X, Y, Z, W-axes, four DC servomotors with high quality shielded motor cables are used to minimize electric noise. Each motor is equipped with an optical encoder for positioning feedback. Figure 5 shows the main function of Motion Control Interface installed on control PC, to satisfy the whole inspection process 4 core control tasks are defined as follows:

(1) Motion control of 4-axes: Linear axis X/Y/Z for point-to-pint movement; Rotating axis W for indexing rotation.

(2) Communication with NuScan software installed on evaluation PC in real-time mode through TCP/IP network according to specified protocol.

(3) Control of water circulation and heating systems.

(4) Hand panel with joystick and several buttons for manual movement.

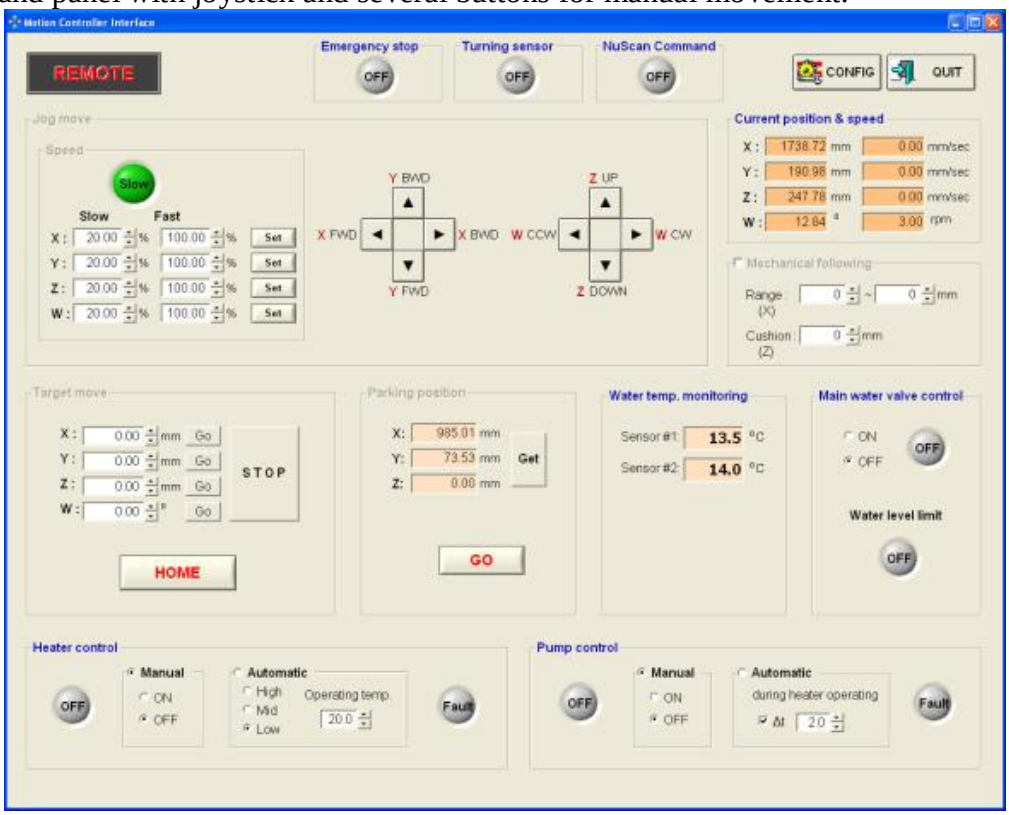


Figure 5. Motion Control Interface

3.5 Ultrasonic Instrument

Eight-channel parallel digital ultrasonic instrument based on VXI bus, UTxx71.00, is used as test electronics to drive eight ultrasonic transducers, as shown in Figure 6.

UTxx71.00 is designed for fully parallel operation of numerous channels simultaneously and at high evaluation speed. A-Scan digitization and raw data processing are performed on-board inside each UTxx71.00 module through a Digital Signal Processor (DSP).

Interfacing between UTxx71.00/VXI frame and evaluation PC is provided with optical fiber. This is the most stable and insensitive data transfer in industrial environment.

Figure 6. Eight-channel parallel digital ultrasonic instrument, UTxx71.00

3.6 C-Scan Imaging Software

For acquisition and evaluation of the data the software NuScan is used, Figure 7 shows the main interface of NuScan. Both amplitude and time-of-flight C-scans can be produced which are displayed in real time while scanning, window and full screen display modes are selectable.

After or during the inspection this data can be analyzed on the same computer in parallel with the scanning process. All data can also be stored and printed.

After acquisition, various ways of presentation and evaluation of scan data are supported, such as:

- C-Scan image;
- Zooming, real time "magnification glass";
- Filtering, (smoothing, median, edge enhancement etc.);
- Various statistics such as total value of measured data, mean value and standard deviation;
- Enclosing a defect with a set of vectors using the mouse automatically performs defect area calculations. The result in mm^2 is displayed;
- Defect distance calculation by marking adjacent defects;
- Statistical defect characteristics retrieved from the image (defect area percentage, defect size, depth, peak and average amplitude, etc.);
- Display of max., min., mean, standard deviation, histogram of the display area ;
- Automated defect detection, segmentation of found defects, automated defect statistics report;
- Documentation of all relevant inspection parameters.

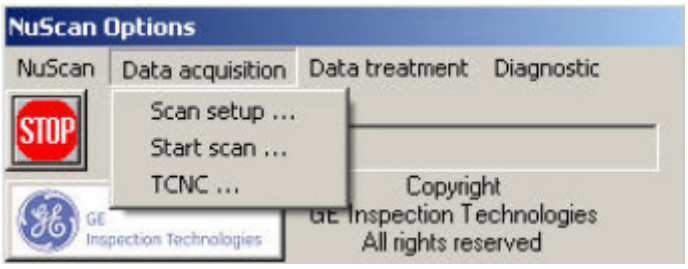


Figure 7. C-Scan imaging software, NuScan

4. Test Results

The final acceptance and performance tests have been carried out on static test and dynamic test in Fushun Special Steel Co., Ltd. The test results are as follows.

4.1 Results for Static Test

The static tests were carried out on three static test blocks with diameter 120mm, 330mm and 450mm. The test block with diameter 120mm is zoned into three zones, 0.8mm FBH is drilled in each zone. The test block with diameter 330mm is zoned into seven zones, 2.0mm FBH is drilled in each zone, Table 1 shows the zoning method on the billet with diameter 330mm. The test block with diameter 450mm is zoned into four zones, 2.0mm FBH is drilled in each zone. Figure

8-10 shows the test results on static test blocks with diameter 120mm, 330mm and 450mm respectively.

Table 1 Inspection Zones for billet with diameter 330mm

Zone	Zone Start (mm)	Zone End (mm)	Gate Start	Gate End
1	5.1	25	5.1	38
2	25	51	13	63
3	51	76	38	89
4	76	102	63	114
5	102	127	89	140
6	127	152	114	165
7	152	178	140	191

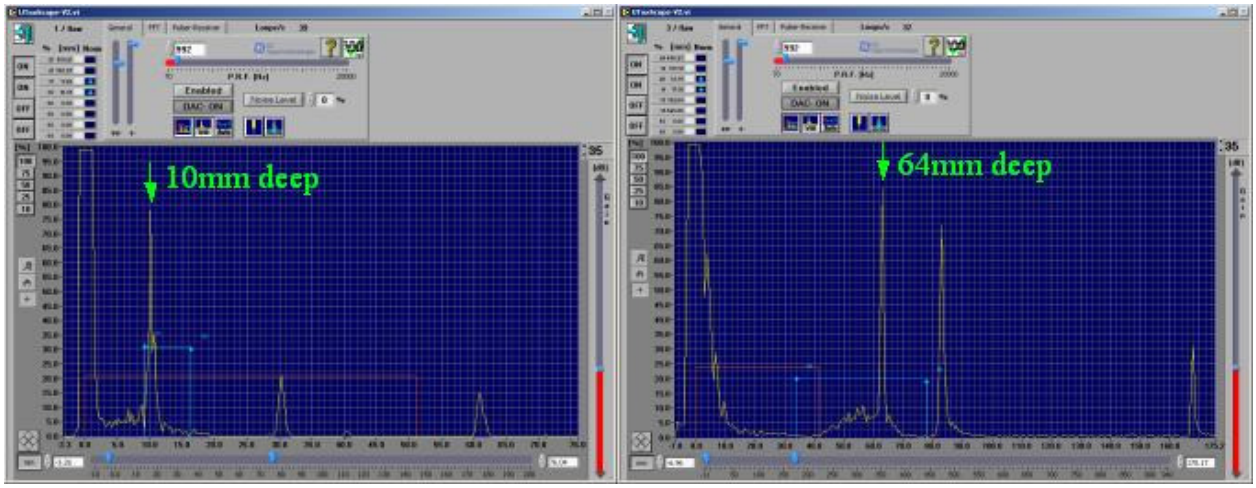


Figure 8. Test results on static test block with diameter 120mm

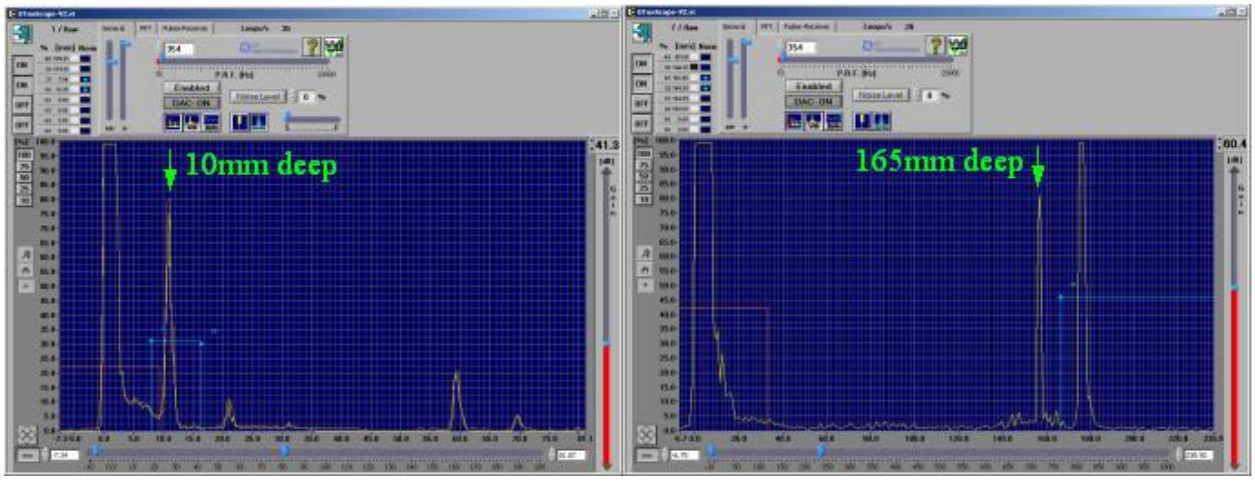


Figure 9. Test results on static test block with diameter 330mm

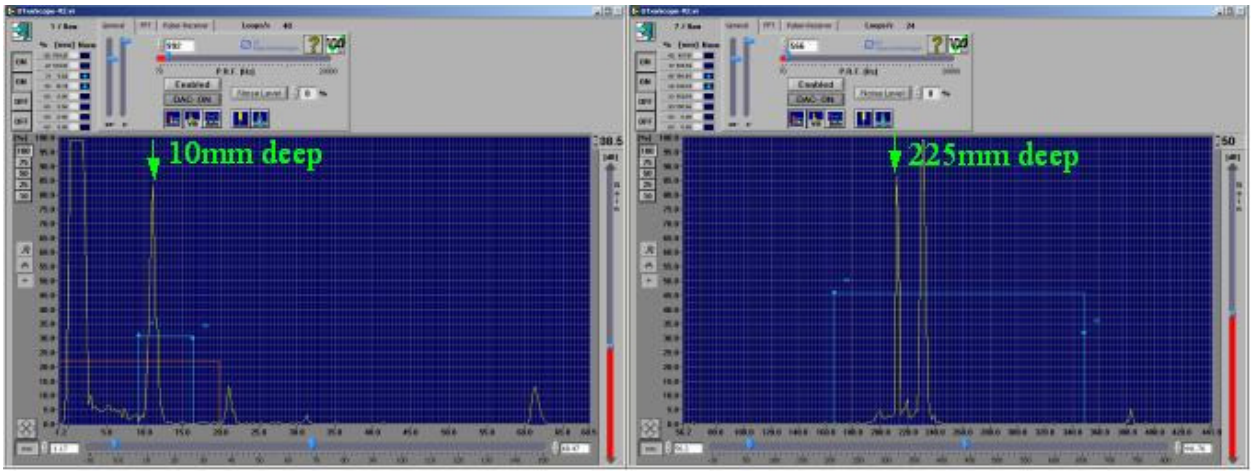


Figure 10. Test results on static test block with diameter 450mm

4.2 Results for Dynamic Test

The dynamic tests were carried out on 2 billets with diameter 300mm and 440mm, length 5000mm and 4000mm. The billets were provided by Fushun Special Steel Co., Ltd. Two natural flaws were found near the center (in zone 4) on billet with diameter 440mm, as shown in Figure 11, the left is the original image; the right is the zoomed image. No flaw was found on billet with diameter 300mm. Figure 12 shows the automatic inspection reports of flaws #1 and #2. The test results were validated by manual test using portable ultrasonic instrument.

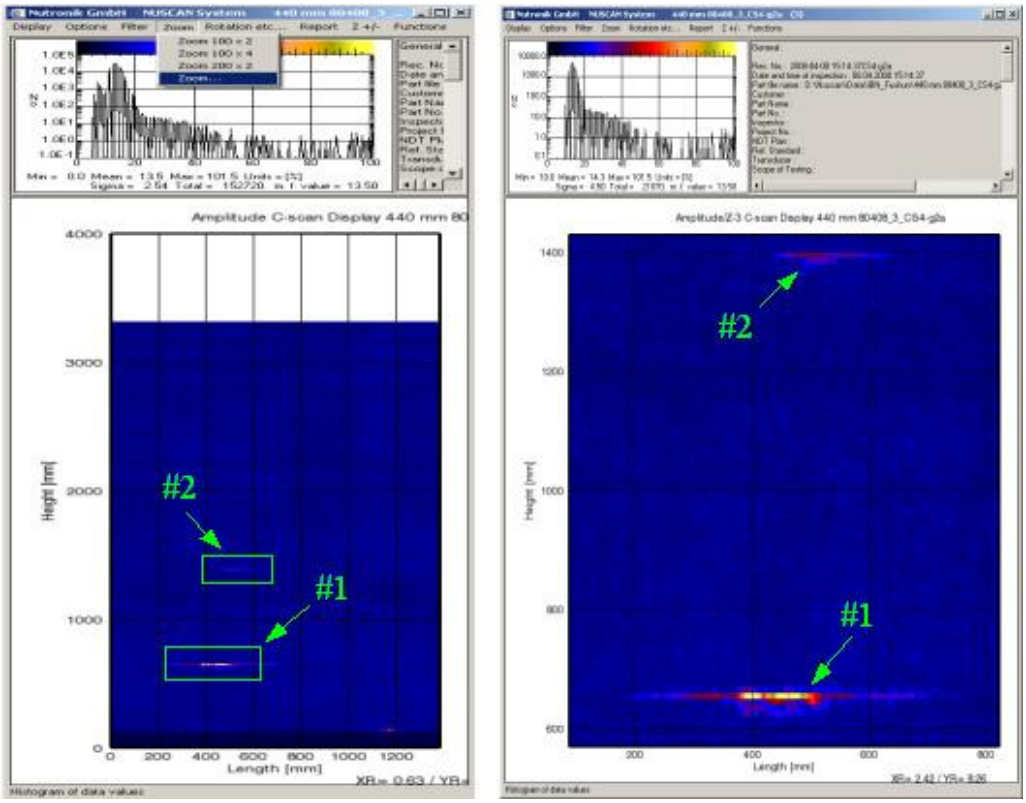
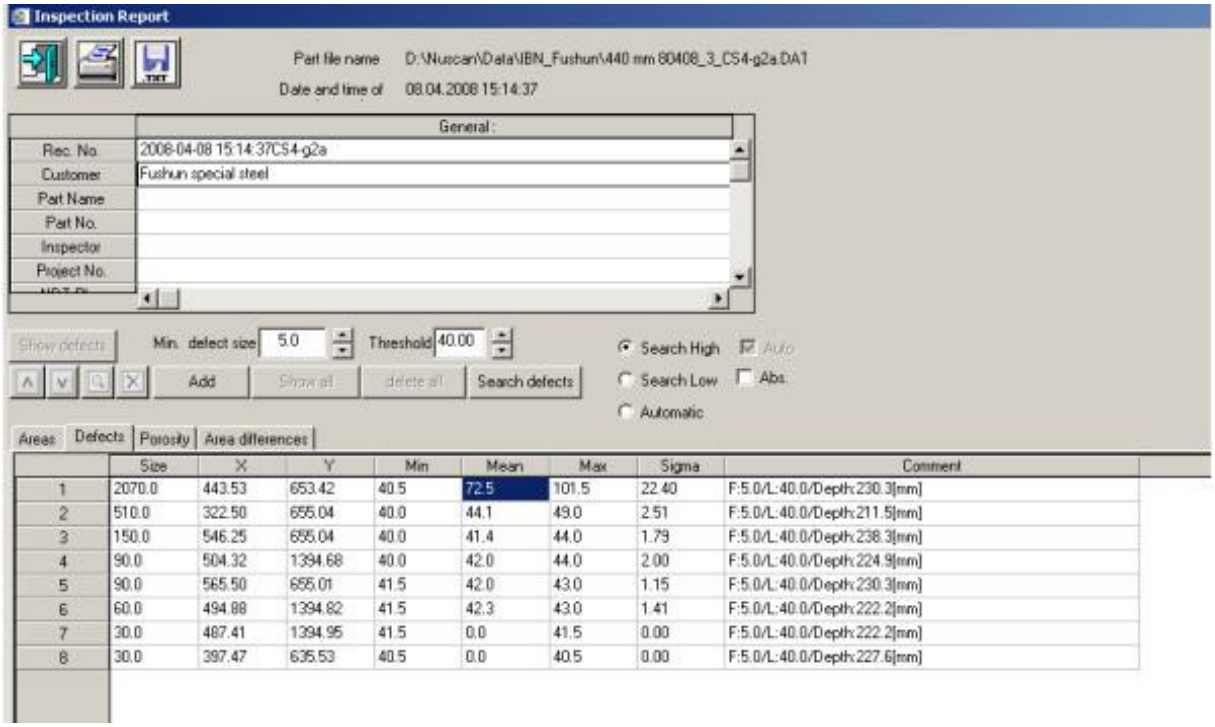


Figure 11. C-Scan images of billet with diameter 440mm



	Size	X	Y	Min	Mean	Max	Sigma	Comment
1	2070.0	443.53	653.42	40.5	72.5	101.5	22.40	F:5.0/L:40.0/Depth:230.3[mm]
2	510.0	322.50	655.04	40.0	44.1	49.0	2.51	F:5.0/L:40.0/Depth:211.5[mm]
3	150.0	546.25	655.04	40.0	41.4	44.0	1.79	F:5.0/L:40.0/Depth:238.3[mm]
4	90.0	504.32	1394.68	40.0	42.0	44.0	2.00	F:5.0/L:40.0/Depth:224.9[mm]
5	90.0	565.50	655.01	41.5	42.0	43.0	1.15	F:5.0/L:40.0/Depth:230.3[mm]
6	60.0	494.88	1394.82	41.5	42.3	43.0	1.41	F:5.0/L:40.0/Depth:222.2[mm]
7	30.0	487.41	1394.95	41.5	0.0	41.5	0.00	F:5.0/L:40.0/Depth:222.2[mm]
8	30.0	397.47	635.53	40.5	0.0	40.5	0.00	F:5.0/L:40.0/Depth:227.6[mm]

Figure 12. Automatic inspection reports

5. Conclusion

An immersion multi-zone ultrasonic inspection system has been developed for the inspection of large-diameter special billets; it meets the requirements of GE AE specification. Full-body testing of billets is carried out using multi-zone longitudinal wave inspection and shear wave inspection techniques. The system provides uniform sensitivity inspection at all depths.

References

[1] Mike Keller, Thadd Patton, et al, “Inspection Development for Titanium Billet - Engine Titanium Consortium Phase II”, FAA report DOT/FAA/AR-05/30, 2005.