17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China

The Design of High Strength Bolts Scanning Testing Imaging System Based on the Eddy Current Array Probe

Min-Zhu LOU, Yun GUO
(Shanghai research institute of materials, 99 Handan, Shanghai 200437, China)
ndt@shcdc.com.cn

Abstract

High strength bolt is the important fastener of automobile and steel structure which quality directly affects the safety and reliability of the automobile and steel structure. After treatment process such as quenching and tempering, cracks occur in bolt. In the process of installation and using, bolt undertakes complicated stress. So the cracks (especially cracks in bolt root) will finally cause failure and fracture of bolt , which have serious consequence in use. In this paper, a bolts scanning testing imaging system based on the eddy current array probe is introduced, which specializes in high strength bolt root crack detection. The system can effectively detect the cracks in bolt root so as to prevent the accidents happen. Compared to traditional mechanical rotary bolt eddy current testing system, this system can detect the circumferential crack quickly in lower mistaken rate, and with larger scan coverage, the system has more simple mechanical device. In this paper, using real time scanning testing imaging system is also a good solution to mass parts detection.

Key words: Eddy current array probe; High strength bolt; Scanning imaging; Crack detection

High strength bolt is the important fastener of automobile, train and steel structure. In manufacturing process, high strength bolt has cracks after being heat treatment such as quenching and tempering. Quenching cracks are more likely to appears in the bolt boot which has complex structure and alternating stress inside. In industrial applications, particularly in cars, motorcycles and other dynamic use of high strength bolts, any more forging cracks and quenching cracks are not allowed. For all these reason, the inspection of cracks in high strength bolts boot become an important issue to research.

The conventional method of high strength bolts testing is magnetic particle testing(MT), which has limitations as follows:

(1) low testing speed

(2) high labor intensity

(3) insensitive to the cracks in bolt boot

(4) human error

All the limitation above can be conquered by eddy current testing(ET). Since conventional eddy current dynamic testing has the complex mechanical device and cause probe rapid wear, it is difficult for application.

A bolts scanning testing imaging system using eddy current array probe[1,2] effectively achieve the array probe static scanning instead of single probe dynamic scanning. It not only electrically control the probe exciting and signal receiving but also display the cracks by C-scan

image. The system reduce the complexity of mechanical device and decrease the testing time.

1. Eddy current array probe testing method

Eddy current array probe is constructed by lots of coils which is ordered in special structure. When arrayed probe works, its coil units are time-sharing switched according to the logically program which is electrically set. When eddy current responsive signal is received by the instrument, a testing cycle is finished. Once array probe testing scan is equal to single probe several times back and forth scan.

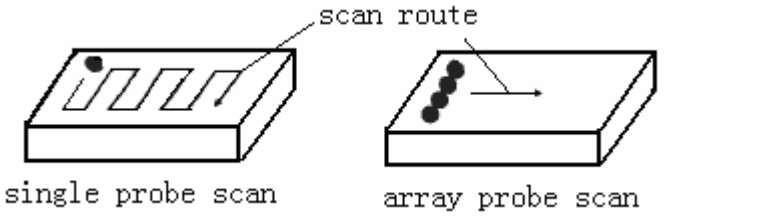

Fig 1 Schematic of single probe and array probe scan

Since the eddy current signal has very short response time, the exciting signal can be quickly switched between different coil units and so array probe scan much quicker than the conventional single probe. Logical switch circuit inside the probe or instrument is designed to realize all that. The system main features listed below:

(1) Scan the object surface quicker with larger coverage area
(2) Have the same sensitivity as the single probe and don't have blind area such as long cracks and cracks in special direction
(3) Can be applied in all kinds of fixed shape object, such as: pipe, bar and plate etc
(4) Probe array can be easily change to fit the different requirement. Multi-frequency and frequency-mixing technology can be used for interference suppression and improve SNR.
(5) C-scan imaging method display cracks size and shape more clearly.

2. Eddy current 16-channel array probe scanning imaging system

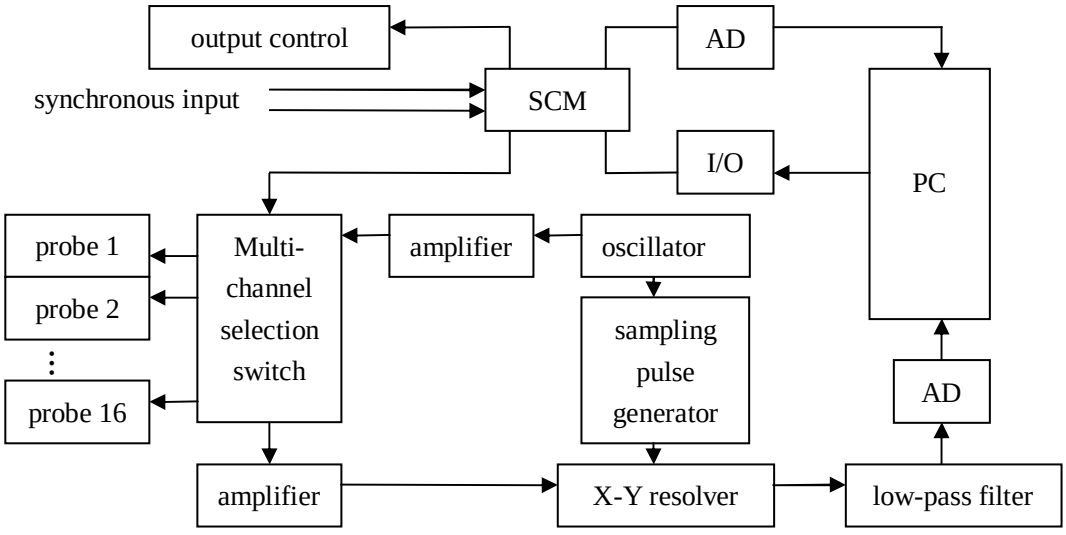

Fig 2 Block diagram of system

When SCM receives synchronous input signal from the computer, it sends 10-cycle

frequency sine wave to power amplifier. Exciting signal is switched to the probes by electric switch circuit . Response signal from the array probes is send through amplifier to x-y resolver. After a low-pass filter, the analog signal is conversed to the digital signal by AD data acquisition and finally sent to PC.PC receives the outside synchronous signal, scan signal and probe switch signal and shows the scan result of each probe in monitor in impedance graph, XY value graph, 16 channel wave graph and 16 channel scan image. Through digital image processing, full area scan image is built and displayed. PC also send control signal to SCM for alarming and selection.

- Analog to Digital Data Acquisition

The main feature of data acquisition adapter are:

(1) Provides 16 A/D channels and the resolution is 12 bits.
(2) 400KHz acquisition frequency with sample and hold circuitry inside.
(3) Input impedance>100MHz, max input voltage: <+12V/-12V, difference common mode rejection ratio>80dB.
(4) Input voltage range: 0V to5V or 0V to 10V for unipolar, and from -5V to 5V or -10V to 10V for bipolar.
(5) Two acquisition mode: Parallel Sampling/Scan Sampling

- X-Y resolver

For the purpose of analysis of Eddy current, it's important to acquire the 2D information of the signal. X-Y resolver is the circuitry designed to resolver the eddy current signal which contain the two impedance components: R and ωL . The schematic is:

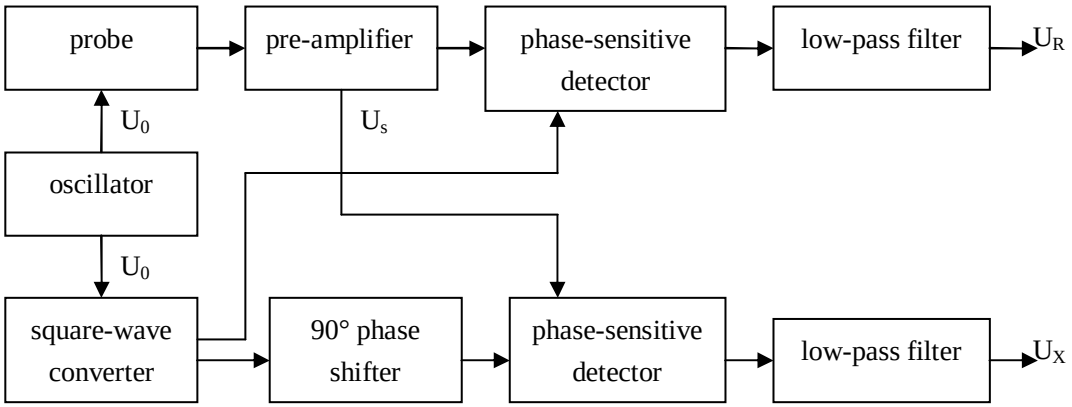

Fig 3 Schematic of X-R resolver

Oscillator output the signal: $U_0 = B\sin\omega t$. In one way, U_0 exciting the probes, probes create the eddy current signal which is amplified by the pre-amplifier: $U_s = A\sin(\omega t - \varphi)$. U_s is sent to the two phase-sensitive detectors as the testing signal. In other way, U_0 is transform to the square wave with duty cycle to the 90° phase shifter. The original square wave and 90° phase shifted wave are sent to the two phase-sensitive detectors to multiplied with the testing signal. And then after low-pass filter two way signals become: $U_R = \frac{1}{T}\int_0^{\frac{T}{2}} U_s dt = \frac{A}{\pi}\cos\varphi G_R$ and $U_X = \frac{1}{T}\int_{0-\frac{\pi}{2}}^{\frac{T}{2}-\frac{\pi}{2}} U_s dt = \frac{A}{\pi}\sin\varphi G_x$ which can be directed adopted by AD card.

3. ET imaging software

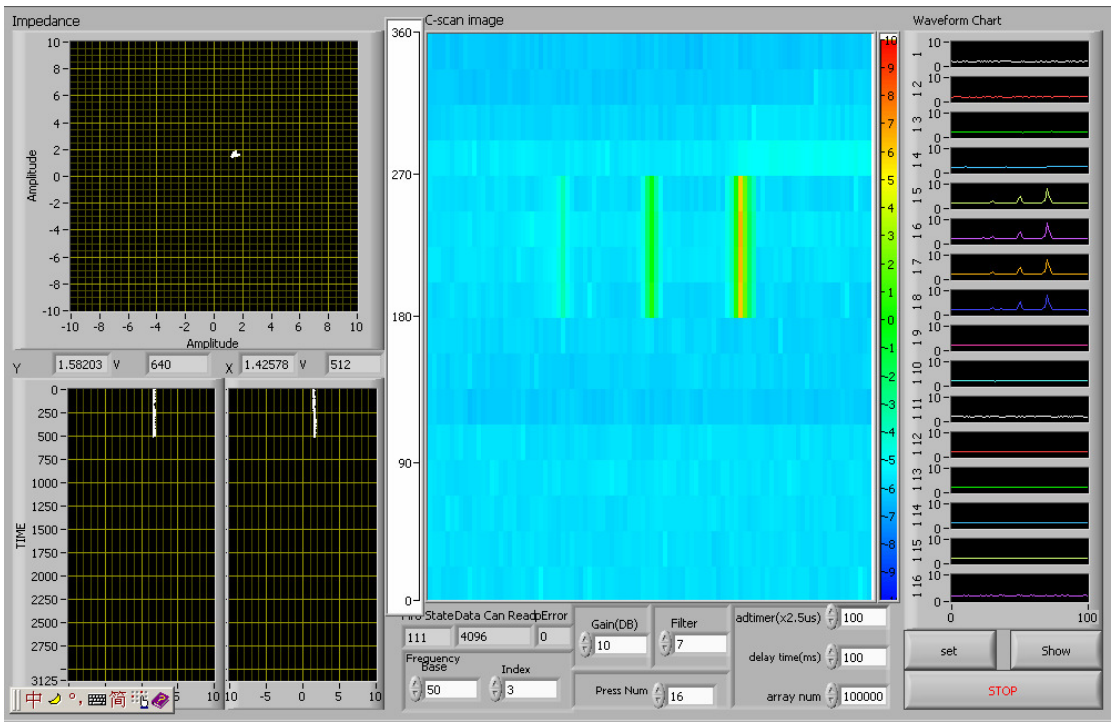

Fig 4 Software main interface

The ET imaging software based on NI LabVIEW Professional Development System. 16 Channel Eddy current voltage values are acquired and sent to PC through PCI bus. Software read the data by loading the IO DLL. After signal process, software displays the impedance graph, XY value graph, 16-Channel value chart and C-scan color chart. Fig 5 is the Software flaw chart:

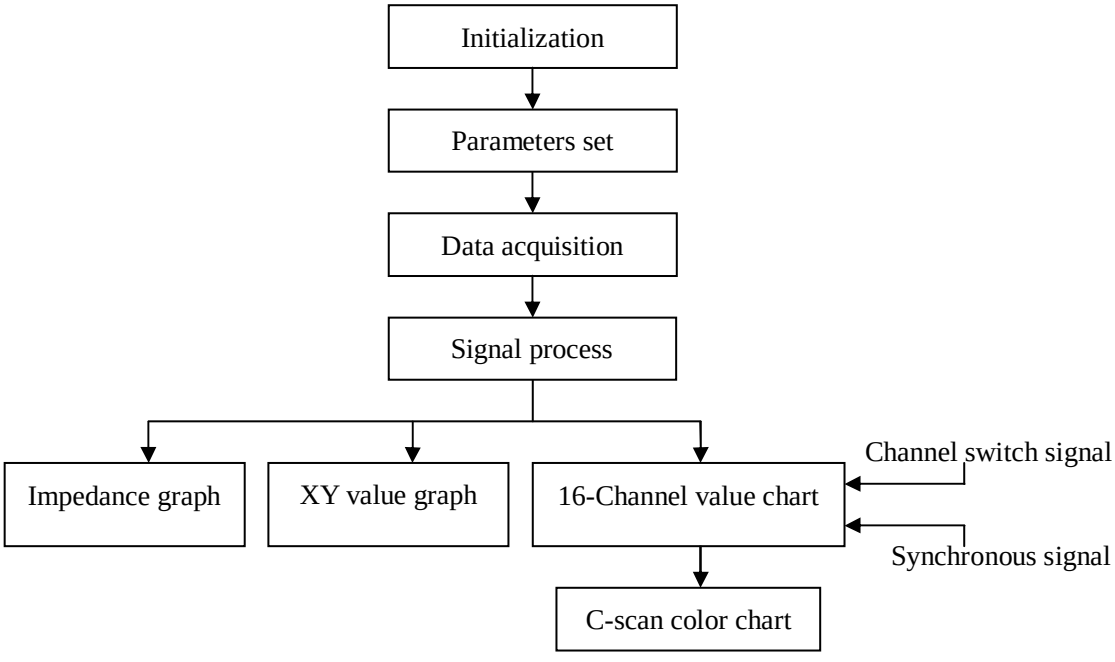

Fig 5 Software flaw chart

Main functions of the software is listed as follows:

(1) 16-Channel parameters real time set
(2) Impedance graph real time display
(3) X and Y value real time display
(4) 16-Channel scan value display
(5) Object testing C-scan color imaging
(6) Image interpolation process

4. Experiment

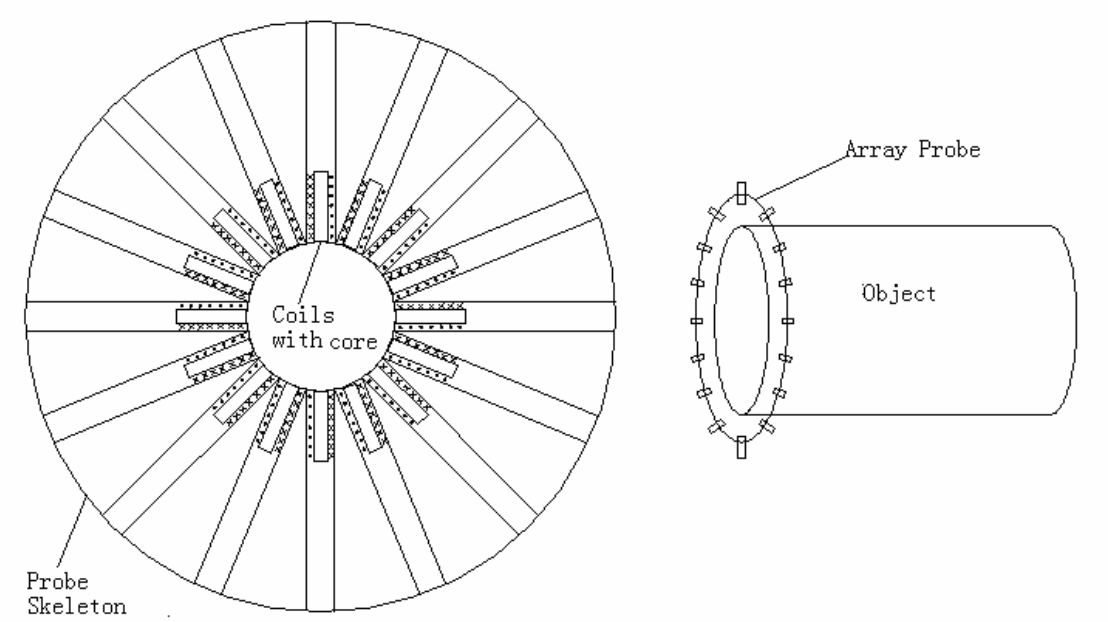

Fig 6 Schematic of array probe

16-Channel array probe with 16 coils evenly distributed inside, circle surrounds the object. After the object through the array probe ,the instrument finishes scanning and shows the testing results in C-scan imaging chart. The size of the probe judged by the size of the object.

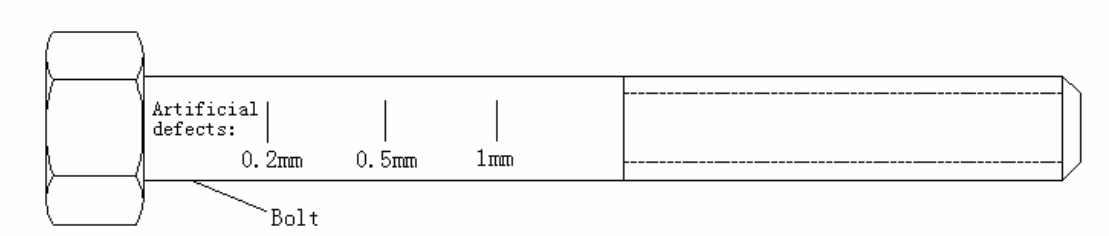

Fig 7 Schematic of artificial defects

The sample object is bolt with three artificial defects in depth: 0.2mm, 0.5mm and 1mm Three defects have the same length and distribute with same distance.

16-Channel array probe scan the bolt boot, scanning image of the bolt cylindrical surface is unwrapped to plane. The vertical direction of image is equal to the circumferential direction of the bolt and the horizontal direction of image is equal to the axial direction of bolt. Vertical resolution of scanning image is determined by the number of coils. We have 16 coils in the array probe. So the vertical resolution is 16. The horizontal resolution of scanning image is determined by scan step size. We have 100 scan steps in the bolt rod between head and thread. Actually, aspect ratio of the image should be equal to the aspect ratio of unwrapped cylindrical surface of bolt rod. So we

add points to the image in the vertical direction.

Fig 8 shows the C-scan color imaging result, The exciting frequency is 50kH.

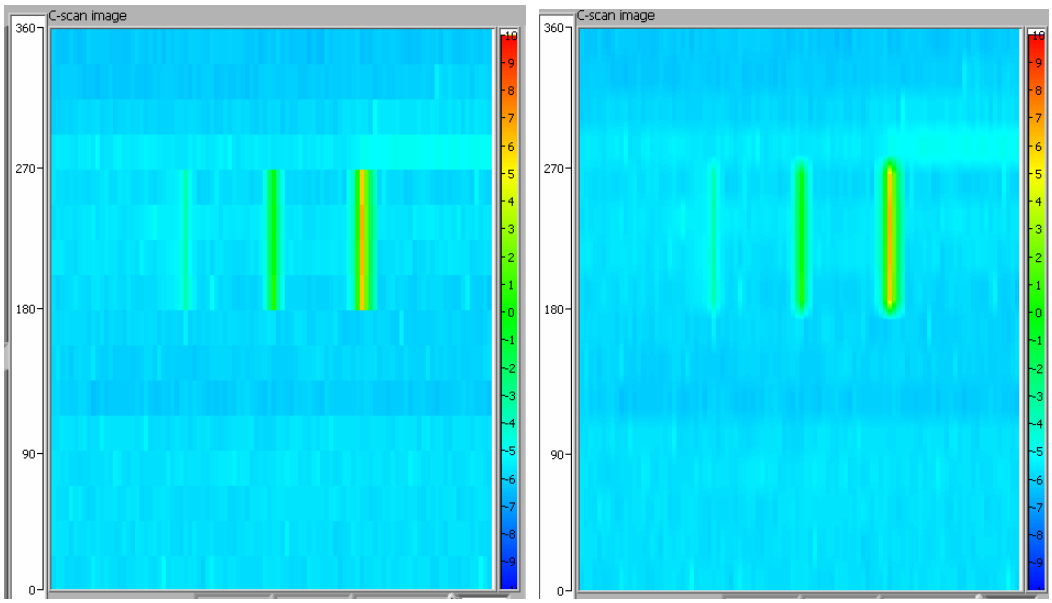

Fig 8 C-scan color imaging result

Left picture in Fig 8 shows the image added with original points. Right picture in Fig shows the image added with interpolation points.

From the left picture of Fig 8, we see three defects clearly. The defects image shows the defects shape and the color indicates the defects depth. For the reason of probe coils size, the size of defects is larger than the real defects.

From the left picture of Fig 8, after the image interpolation process, we see not only the whole picture with more smooth color image, but also defects image having more smooth edge than the right picture.

5. Conclusion

- High strength scan imaging system supported with array probe realizes quick static scanning and imaging. It has the same testing accuracy to single probe testing.
- C-scan color image shows the shape and size of defects effectively, which helps inspectors better acknowledge of the defects.
- Experiment show that the imaging picture's accuracy is limited by numbers of coils and difference between coils. So the quality of the imaging should be improved in the method such as digital filter and digital imaging processing.
- The system supported with other array probe can be applied in other metal components and parts. So it has board prospects of application.

References

[1] Leclerc R, Samson R. Eddy current array probe for corrosion mapping on ageing aircraft. Review of progress in quantitative nondestructive evaluation. AIP, vol. 19A.; 1999. p. 489–496.

[2] Kurokawa M, Miyauchi R, Enami K, Matsumoto M. New eddy current probe for NDE of steam generator tubes. Electromagnetic nondestructive evaluation (III). IOS Press; 1999. p. 57–64.