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A study of dense-medium cyclone inner-wall abrasion based on ultrasonic phased array technology

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ABSTRACT

Directing at the problem that dense-medium cyclone is abraded by materials while conventional detection method can't make real-time and highly efficient detection of defects, this paper introduced working process and imaging principle of ultrasonic phased array technology in details. And then through experimental research of dense-medium cyclone model, it drew the conclusion that ultrasonic phased array technology could conduct real-time imaging display of dense-medium cyclone inner-wall abrasion defects and the error was within 8%.

1. Introduction

With increasingly improved dense-medium coal preparation process and technology, as the principal equipment, dense-medium cyclone has been extensively generalized and applied in many coal preparation plants. Dense-medium cyclone is a kind of coal preparation unit with simple structure and high separation efficiency and without moving parts, its main structure adopts carbon structural steel and its liner uses aluminum oxide ceramics [1]. When operating, it will pump solid-liquid mixed ore pulp into cyclone along the vessel wall in tangent line under certain pressure, ore pulp will conduct high-speed revolution inside cyclone and use strong centrifugal force field to realize separation of coal and gangue [2]. Large block coal and gangue will be tossed to vessel wall under the effect of centrifugal force, consequently, cyclone liner will experience brittle rupture and exfoliation under the effect of strong impact load, then materials will directly abrade cyclone inner wall [3], as a result, internal flow fields of cyclone will be in chaos, and then separation efficiency and service life are reduced. Hence, a convenient and highly efficient nondestructive testing method is adopted to timely master abrasion situation of cyclone inner wall, which is of great significance to giving full play to its performance and guaranteeing continuous production of coal preparation plant.

At present, common NDT methods are radiographic testing, ultrasonic testing, magnetic particle testing and liquid permeation testing. Working environment of dense-medium cyclone is quite complicated, conventional testing means have problems of low efficiency and precision and harming human body, etc, and they can't obtain real-time and rapid testing results. Hence, this paper attempted to use branch of ultrasonic testing—ultrasonic phased array technology to study inner-wall abrasion of dense-medium cyclone.

2. Working process and imaging principle of ultrasonic phased array

2.1. Working process

Main design ideas of ultrasonic phased array testing technology are Huygens-Fresnel Principle and Helmholtz Sound Pressure Integration Theorem [4]. As for phased array transducer, several independent array elements form an array according to certain sequence, each array element has independent transmitting and receiving circuits, and deflection and focusing of sound beams can be realized by controlling transmission delay time of each array element (as shown in Fig. 1), and then ultrasonic scan imaging can be completed.

The core of phased array system lies in phase regulation [5] which includes transmission and reception. When phased array is transmitting, array elements are stimulated by pulse signals of the same frequency, ultrasonic waves will be transmitted according to preset time delay rule under the control of electronic system, ultrasonic waves with different phase positions will make superposition interference in space, and then a new wave front and composite sound beam are formed; when it is receiving, time delay compensation is made according to the time difference of echo returning different array elements [6], signal synthesis is made, echo signals in undetermined direction will experience superposition enhancement, while echo signals in other directions will be weakened until they are offset. Finally, there will be a real-time display of composite signals in the form of image, and real-time imaging is what makes ultrasonic phased array testing superior to

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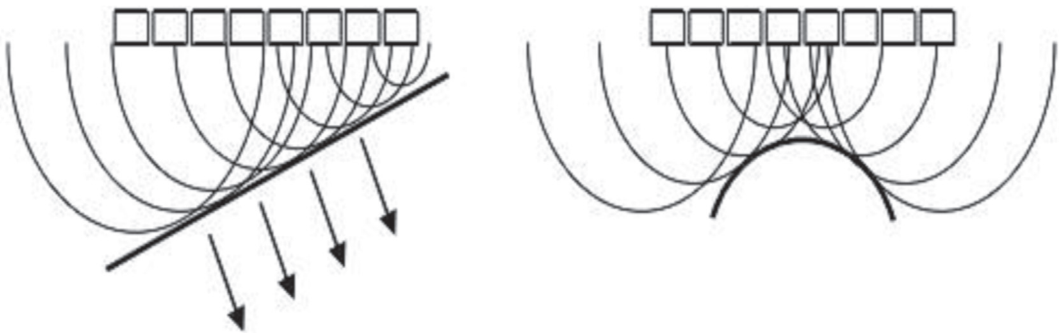

(a) deflection of sound beams (b) focusing of sound beams

Fig. 1. Schematic diagram of deflection and focusing of sound beams.

conventional testing methods.

2.2. Imaging principle

Radiated sound field of transducer is the basis of studying imaging principle of ultrasonic phased array [7], what radiated sound field describes is sound pressure at points in the sound field. In terms of single-source piston-type transducer (see in Fig. 2), vibration amplitudes and phase positions of all points on it are the same [8], and then sound pressure of an arbitrary point in the sound field can be solved through integral formula

$$p(\vec{r},t) = j\frac{k\rho_0 c_0}{2\pi}u_a e^{j(\omega t-\alpha)}\int\int_S \frac{e^{-jkR}}{R}dS, \quad (1)$$

In formula (1), the unit of sound pressure is Pa; $\vec{r}$ is spatial position of field point; ρ_0 is medium density; c_0 is sound wave velocity; k is wave number, $k = 2\pi/\lambda$; j is imaginary unit, $j^2 = -1$; R is the distance from transducer surface element to field point; $u_a e^{j(\omega t-\alpha)}$ is sound source vibration form.

It's assumed that a linear array transducer consists of N array elements, and then radiated sound field of this array transducer is [9]:

$$p(\vec{r},t) = j\frac{\rho_0 c_0}{2\pi}\sum_{i=1}^{N} k_i u_i e^{j(\omega_i t-\alpha_i)}\int\int_{S_i} \frac{e^{-jk_i r_i}}{r_i}dS, \quad (2)$$

In formula (2), the unit of sound pressure is Pa; u_i is vibration amplitude of the i-th array element surface in the array; ω_i is angular frequency of vibration of the i-th array element surface in the array; α_i is initial phase of vibration of the i-th array element surface in the array; k_i is wave number of i-th array element in the array; j is imaginary unit, $j^2 = -1$; r_i is the distance from surface element of the i-th array element in the array to the field point; S_i is the area of the i-th array element in the array.

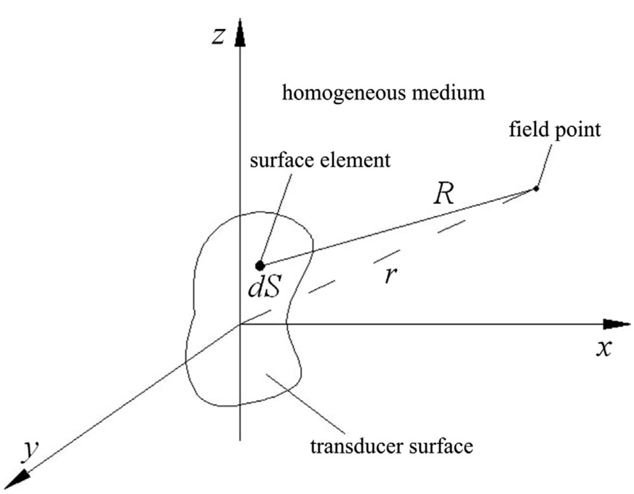

Fig. 2. Single-source transducer and its coordinate system.

Under normal circumstances, all array elements in the same array make same-frequency and uniform vibration in the same medium, namely: all ω_i and all k_i are the same. Sound pressures at points in the sound field can be obtained according to formula (1) and formula (2), different colors are used to represent sound pressures in all scanning regions, and ultrasonic phased array detection technology uses this principle to realize real-time imaging.

3. Detection test of cyclone model

Abrasion problem of dense-medium cyclone existing on industrial scene is mainly about brittle rupture and exfoliation of ceramic liner and inner-wall abrasion and reduction in liner exfoliation region. Hence, detection test is divided into three circumstances: normal cyclone liner stickup, liner exfoliation and inner-wall abrasion and reduction.

3.1. Test specimen

Cyclone model used in the test was a segment of large-diameter steel round tube as shown in Fig. 3, length of the sound tube was 500 mm, outer diameter was 700 mm and wall thickness was 7.5 mm. Three artificial defects were engraved in internal surface of cyclone model, respectively being a long strip defect and two round defects, whereby the length of long strip defect was 170 mm and its width was 8 mm with deep middle and two shallow sides, and depth variation range was 0–3 mm, the orientation of the long strip defect is the relative inner wall to the cyclone liner; diameters of two round defects were 15 mm, and depths were respectively 2 mm and 3 mm. In addition, local region of this cyclone model was pasted with aluminum oxide ceramic chip (thickness was 8 mm), which was identical with actual liner material of dense-medium cyclone.

3.2. Test instrument

Ultrasonic phased array detector used in this test was OmniScan MX2 matched with 5L64-A12 linear array probe and SA12-0L straight wedge block as shown in Fig. 4.

Region to be tested of outer wall of cyclone model was polished before the test, lubricant agent was used as coupling agent which was uniformly wiped between probe and wedge block and between wedge block and workpiece to realize favorable coupling. Parameter setting was completed step by step in accordance with guide instructions, and setting of main testing parameters was as shown in Table 1.

Outer wall of cyclone model went through circumferential and axial scanning during the test, firstly it was roughly scanned to determine