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Defect Location Analysis of Tank Bottom Based on Acoustic Emission with Different Location Algorithms

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Abstract: Acoustic emission technology used in the state testing of the tank bottom has become a new hot spot for researchers and designers. Two location algorithms, such as three-point locating method and multi-point locating method are applied in this paper using multi-channel acoustic emission system for detection of tank bottom. The location result of the broken lead calibration shows that a larger error will be produced for different algorithm. The effects of the arrangement form of sensors on locating corrosion defect have been analyzed through experiments with two algorithms. The typical arrangement form of sensors has been discussed to study the effects on corrosion-pitting location. The test results show that two algorithms both have the capacity of locating defects and multipoint positioning algorithm is more accurate. It is not clear that the sensors distribution forms affect corrosion-pitting location. But the circumferential distribution of sensors along the bottom is better to test the state of tank with the consideration of feasibility, accuracy and rationality of signal source region. It is of practical engineering significance. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Acoustic emission testing, Multipoint locating method, Sensor, Nondestructive test, Signal analysis.

1. Introduction

All sorts of damage of the vertical steel tanks are inevitably appeared sometimes in the condition of oil delivery and natural environment for years. It is affected by a variety of adverse factors. It is very necessary to test the state of storage tank with consideration of operation safety. The test way, is usually divided into open testing and on-line detection according to whether test affect the tank operation [1, 2]. Bottom plates are the most corrosion parts of tanks. Corrosion is the major cause of structural degradation. The oil leakage caused by bottom corrosion often cause serious disaster, environment pollution and economic loss. Open testing has larger workload due to bottom position hidden and observation difficult. Acoustic emission testing technology [3], as a nondestructive test, could inspect and test effectively to obtain the technical state of test object data and avoid or lessen the loss by stopping operation because the process of corrosion itself often brings in acoustic emission. Acoustic emission testing [4] is a cost-effective detecting-defect method that common testing could not detect them precisely used in metal materials. Acoustic emission detector [5] is used to judge the state by signal characteristic of bottom by signal message detecting, collecting, transmission,

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analyzing and processing. As we known, it is not a single way for acoustic wave propagation. It maybe leads to larger errors for locating sound source [6-8]. Based on the different location algorithms, the location precision is different for the same corrosion defects. The objectives of the present paper are: (i) to establish a simulated tank instead of storage tank; (ii) to contrast the broken lead calibration precision between the three-point location and multi-point location method; (iii) to compare the corrosion-pitting location precision caused by the different sensor distribution based on two algorithms; (iv) to analyze and evaluate the results between the testing location and practical corrosion location of tank bottom.

2. Location Algorithms

The location principle of acoustic emission in the bottom testing could be shown in Fig. 1. The sound signals, generated by the tank bottom defects, could be detected by sensor located at the bottom plate. If signals can be received by three or more sensors, the sound source location can be detected by time difference and stress wave velocity.

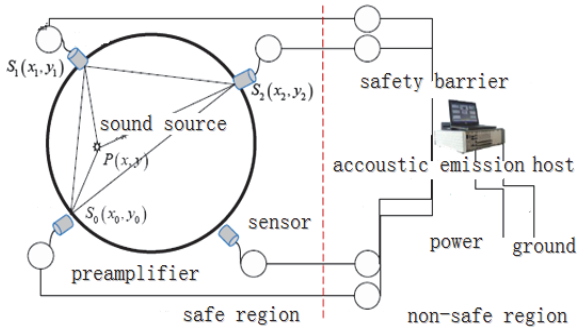

Fig. 1. Acoustic emission location principle.

2.1. Three-point Algorithm

The sensor is located in the same plane, and any three sensors can constitute a triangle. The sound source can be detected by three-point location and time difference [9]. $S_0(0,0)$, $S_1(x_1,y_1)$ and $S_2(x_2,y_2)$ are sensors, and $P(x,y)$ is unknown signal source as shown in Fig. 1. The calculation process is as shown in the following.

$$\delta_{10} = r_1 - r_0 = (t_1 - t_0)v \tag{1}$$

$$\delta_{20} = r_2 - r_0 = (t_2 - t_0)v \tag{2}$$

$$x^2 + y^2 = r^2 \tag{3}$$

$$(x - x_1)^2 + (y - y_1)^2 = (r + \delta_{10})^2 \tag{4}$$

$$(x - x_2)^2 + (y - y_2)^2 = (r + \delta_{20})^2, \tag{5}$$

where r_0, r_1, r_2 are the distances of PS_0, PS_1 and PS_2 respectively; t_0, t_1, t_2 are the times that signals propagate to three sensors respectively; v is the stress wave velocity.

Put $x = r\cos\theta$ and $y = r\sin\theta$, and formula (3) can be put into formula (4) and (5),

$$2r(x_1\cos\theta + y_1\sin\theta + \delta_1) = x_1^2 + y_1^2 - \delta_{10}^2 \tag{6}$$

$$2r(x_2\cos\theta + y_2\sin\theta + \delta_2) = x_2^2 + y_2^2 - \delta_{20}^2 \tag{7}$$

Put $A_1 = x_1^2 + y_1^2 - \delta_{10}^2$
and $A_2 = x_2^2 + y_2^2 - \delta_{20}^2$.
If $x_1\cos\theta + y_1\sin\theta + \delta_{10} \neq 0$
and $x_2\cos\theta + y_2\sin\theta + \delta_{20} \neq 0$.

$$r = \frac{A_1}{2(x_1\cos\theta + y_1\sin\theta + \delta_{10})} = \frac{A_2}{2(x_2\cos\theta + y_2\sin\theta + \delta_{20})} \tag{8}$$

$$(A_1x_2 - A_2x_1)\cos\theta + (A_1y_2 - A_2y_1)\sin\theta = A_2\delta_{10} - A_1\delta_{20} \tag{9}$$

Put $B = [(A_1x_2 - A_2x_1)^2 + (A_1y_2 - A_2y_1)^2]^{0.5}$
Combined formula (9),

$$\frac{(A_1x_2 - A_2x_1)\cos\theta}{B} + \frac{(A_1y_2 - A_2y_1)\sin\theta}{B} = \frac{A_2\delta_{10} - A_1\delta_{20}}{B}$$
$$\cos = (\theta - \phi) = k, \tag{10}$$

where $k = \dfrac{A_2\delta_{10} - A_1\delta_{20}}{B}$ and $\tan\phi = \dfrac{A_1y_2 - A_2y_1}{A_1x_2 - A_2x_1}$.

The $\tan\phi$ can be obtained by location of sensors, propagation velocity and time difference that acoustic emission signals received. B is assumed positive value, θ has two solutions in $[-\pi, \pi]$. But there is one solution to satisfy the positive value that r get. Therefore, the sound source can be detected by three-point algorithm.

2.2. Multi-point Algorithm

The sound source can be detected by multi-point location and time difference [10]. $S_0(0,0)$ is origin of the polar coordinates. $S_i(r_i, q_i)$ is denoted coordinates of $(i-1)^{\text{th}}$ sensor; t_i is time difference that signals received $(i-1)^{\text{th}}$ sensor compared with signals received $S_0(0,0)$. The calculation process is as shown in the following.

Equation (11) can be constituted according to TOBIAS algorithm.

$$2Rvt_i + v^2 t_i^2 + 2Rr_i \cos q_i \cos q + 2Rr_i \sin q_i \sin q = r_i^2, \quad (11)$$

where R is the radius of tank bottom, and $i = 1, 2, ..., m-1$.

$$\begin{pmatrix} t_1 & r_1 \cos q_1 & r_1 \sin q_1 \\ t_2 & r_2 \cos q_2 & r_1 \sin q_1 \\ \cdots & \cdots & \cdots \\ t_{m-1} & r_{m-1} \cos q_{m-1} & r_{m-1} \sin q_{m-1} \end{pmatrix} \begin{pmatrix} 2R\upsilon \\ 2R \cos q \\ 2R \sin q \end{pmatrix} = \begin{pmatrix} r_1^2 \\ r_2^2 \\ \cdots \\ r_{m-1}^2 \end{pmatrix} - \begin{pmatrix} t_1^2 \\ t_2^2 \\ \cdots \\ t_{m-1}^2 \end{pmatrix} \upsilon^2, \quad (12)$$

where $A = \begin{pmatrix} t_1 & r_1 \cos q_1 & r_1 \sin q_1 \\ t_2 & r_2 \cos q_2 & r_1 \sin q_1 \\ \cdots & \cdots & \cdots \\ t_{m-1} & r_{m-1} \cos q_{m-1} & r_{m-1} \sin q_{m-1} \end{pmatrix}$

When m=4, equation (11) can be transformed into the following equation

$$\begin{pmatrix} 2R\upsilon \\ 2R \cos q \\ 2R \sin q \end{pmatrix} = A^{-1} \begin{pmatrix} r_1^2 \\ r_2^2 \\ \cdots \\ r_{m-1}^2 \end{pmatrix} - A^{-1} \begin{pmatrix} t_1^2 \\ t_2^2 \\ \cdots \\ t_{m-1}^2 \end{pmatrix} \upsilon^2 = \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix} - \begin{pmatrix} b_1 \\ b_2 \\ b_3 \end{pmatrix} \upsilon^2 \quad (13)$$

When m>4, equation (11) can be transformed into the following equation.

$$\begin{pmatrix} 2R\upsilon \\ 2R \cos q \\ 2R \sin q \end{pmatrix} = B \begin{pmatrix} r_1^2 \\ r_2^2 \\ \cdots \\ r_{m-1}^2 \end{pmatrix} - B \begin{pmatrix} t_1^2 \\ t_2^2 \\ \cdots \\ t_{m-1}^2 \end{pmatrix} \upsilon^2 = \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix} - \begin{pmatrix} b_1 \\ b_2 \\ b_3 \end{pmatrix} \upsilon^2, \quad (14)$$

where $B = (A^T A)^{-1} A^T$, and A^T is the transposed matrix of A.

$$(R\upsilon)^2 = ((R \cos q)^2 + (R \sin q)^2)\upsilon^2, \quad (15)$$

A simple cubic equation can be got if $x = v^2$.

$$ax^3 + bx^2 + cx + d = 0, \quad (16)$$

where $\begin{pmatrix} a \\ b \\ c \\ d \end{pmatrix} = \begin{pmatrix} b_2^2 + b_3^2 \\ -(2a_2 b_2 + 2a_3 b_3 + b_1^2) \\ a_2^2 + a_3^2 + 2a_1 b_1 \\ -a_1^2 \end{pmatrix}$

There are three solutions of equation (16). Put the solution into equation (13) and (14), considering $v > 0, r \geq 0$ for their physical significance, r and θ can be calculated as a real number solution.

3. Broken Lead Calibration Using Different Localization Algorithms

The testing instrument this paper adopted is multi-channel acoustic emission collection system. The parameters are : sensors type SR40M, signal propagation attenuation loss less than 1 dB/30 m, cable length less than 150 m, sample frequency 2 MHz, threshold value 30 dB, filter frequency 25-300 kHz, defected steel plate size 1500×1200×10 mm.

To analyze the effect of location algorithm on precision of broken lead calibration, the sensors have been arranged in steel plate as Fig. 2 shown. The number 1-6 is denoted sensors.

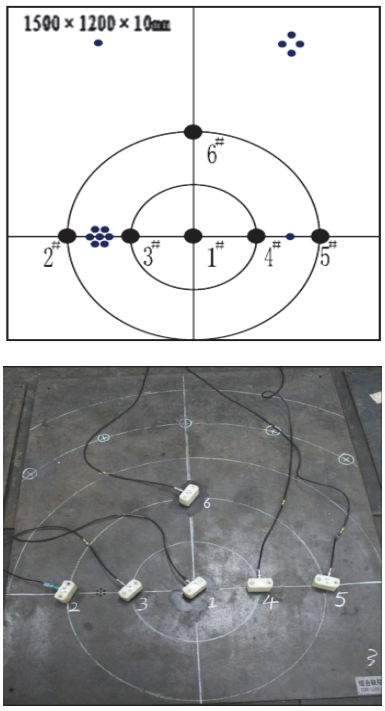

Fig. 2. Defect steel plate and sensor location.

Stress wave is induced by 3~5 mm pencil lead according to acoustic emission standards. The broken lead model is simulated as Fig. 3 shown. Lead broke in accordance with the order of 1 to 6, and the data is collected and stored in the computer.

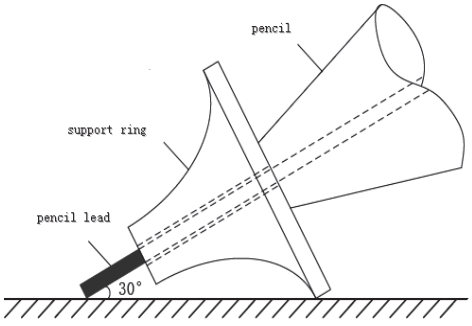

Fig. 3. Sound source simulation.

Through acoustic emission software analysis, the location results of broken lead signals based on different algorithms can be shown in Fig. 4. Solid blue dots are denoted a non-iterative multipoint location result, and hollow green dots are denoted three-point location result. The number 11-16 in the location figure is denoted the host channel number. Channel number 11-16 is corresponding with sensor number 1-6 respectively. The results of broken lead calibration show that the multi-point locating algorithm is more precise than three-point locating algorithm in condition of minor time difference. Defect location cannot be detected without hydraulic pressure. The experiment also shows that locating defects need be stimulated by external load.

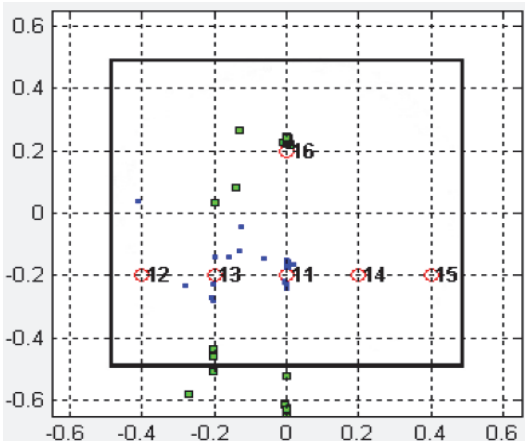

Fig. 4 (a). Broken lead calibration at location 1.

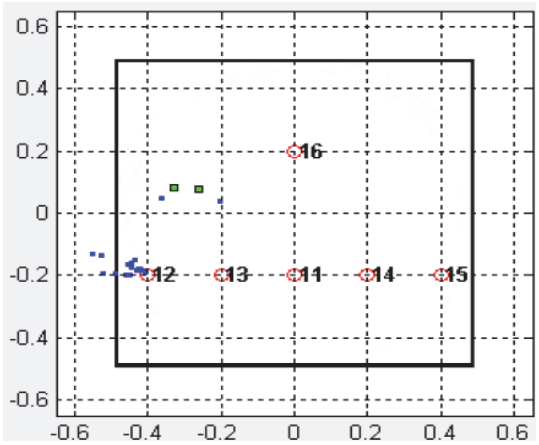

Fig. 4 (b). Broken lead calibration at location 2.

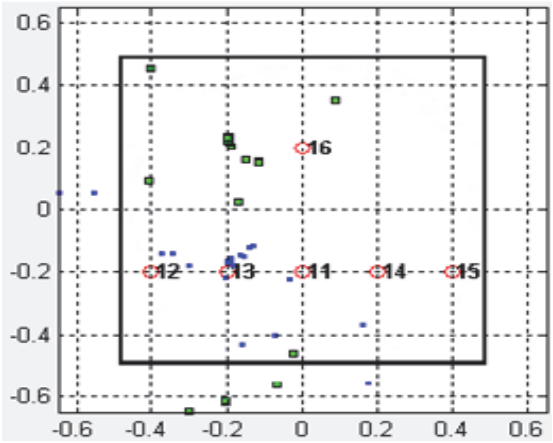

Fig. 4 (c). Broken lead calibration at location 3.

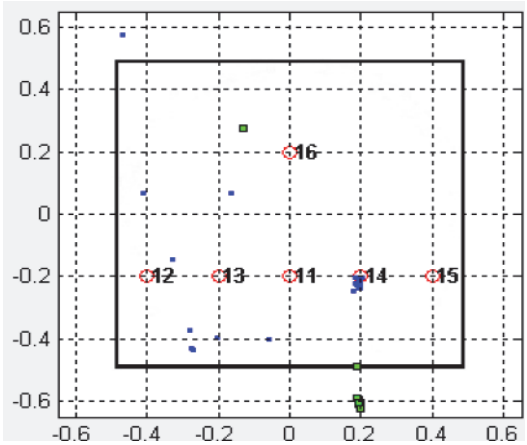

Fig. 4 (d). Broken lead calibration at location 4.

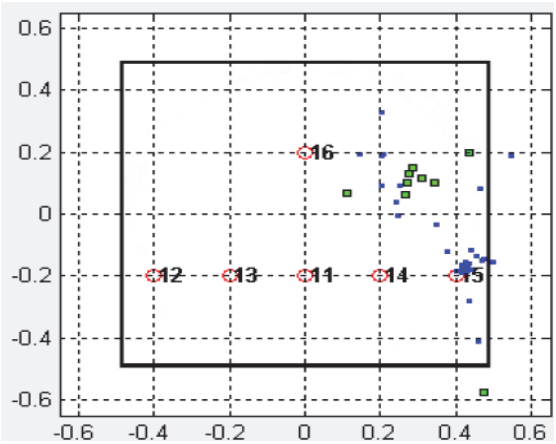

Fig.4 (e). Broken lead calibration at location 5.

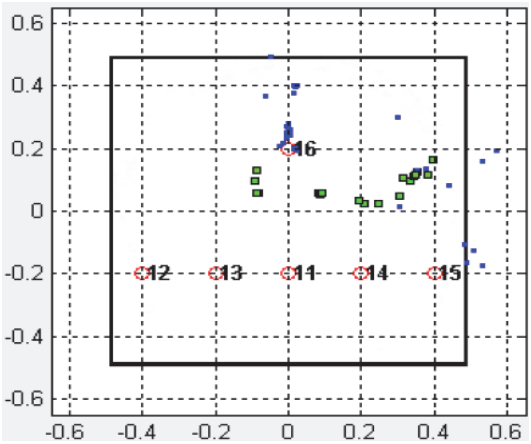

Fig. 4 (f). Broken lead calibration at location 6.

4. Effects of Sensor Arrangement Form on Defects Location

Considering the result above is detected without hydraulic pressure, tank simulator need be established to simulate bottom corrosion of storage tank as shown in Fig. 5. Sizes and data of simulated tank have: inner diameter 600 mm, tank wall height 600 mm, liquid level height 510 mm, density of diluted hydrochloric acid 5 %. Simulated bottom is two pieces of plate without welding and pitting corrosion. The cut plates are cut from the real tank bottom. Their sizes are both 1000×800×8 mm. In order to contrast the location precision, the location of corrosion-pitting should be designed in the fixed position. A slender glass tube is stickup to simulated bottom by glass cement. The length of glass tube is 1.2 m. location of corrosion pitting is dependent on the glass tube lower end, and size of is dependent on quantity of diluted hydrochloric acid. Corrosion-pittings of two plates are 150 mm distant from bottom center. The locations of the corrosion-pitting are as shown in Fig. 6, and coordinates of it are (140,-54) mm and (0,-150) mm respectively.

Sensors arrangement form is designed as linear distribution and circumferential distribution. Each form is located by two algorithms. To make comparable with the two methods, the corrosion location and corrosion time are the same in order to obtain the same corrosion characteristics liquid. Also liquid levels are both 510 mm.

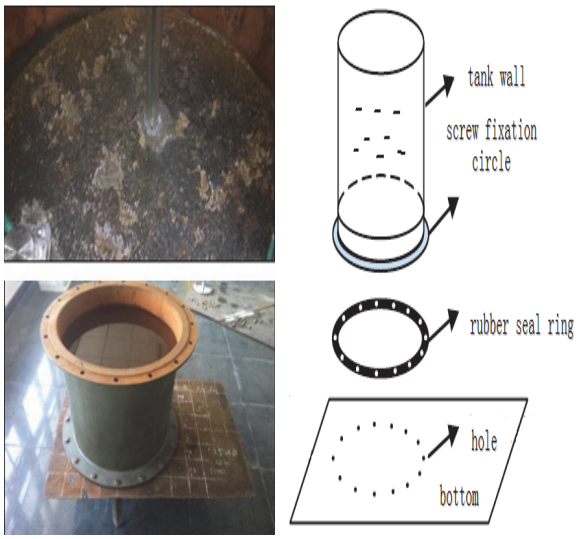

Fig. 5. Tank simulator for corrosion test.

The location results in Fig. 7 show that signal of pitting corrosion can be precisely detected by two arrangement forms of sensors; detected signals are approximately linear distribution caused by the linear distribution sensors and detected signals are approximately circular area in a certain radius around the corrosion-pitting caused by the circumferential distribution sensors; for each arrangement form, corrosion defects can be precisely located by two algorithms, and multi-point location method is more precise than three-point location method.

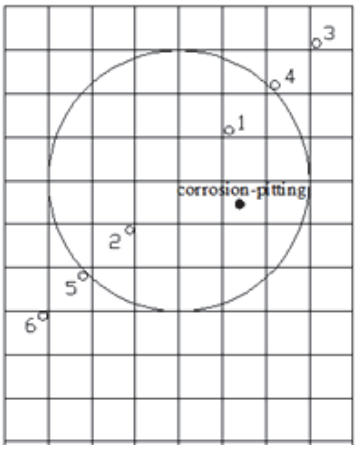

Fig. 6 (a). Location of sensors and corrosion-pitting – linear distributed sensors.

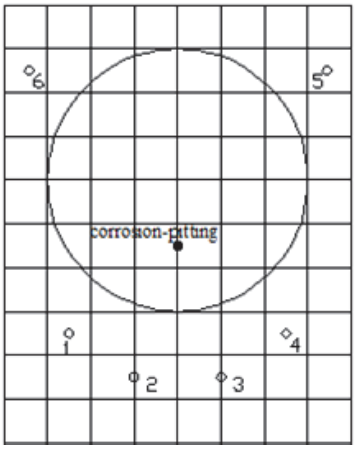

Fig. 6 (b). Location of sensors and corrosion-pitting – circumferential distributed sensors.

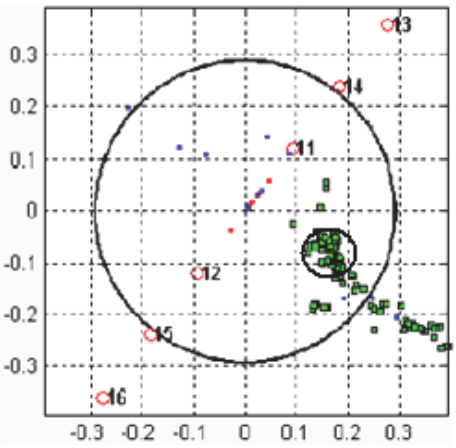

Fig. 7 (a). Corrosion-pitting location with two different algorithms under hydraulic press – linear distribution location.

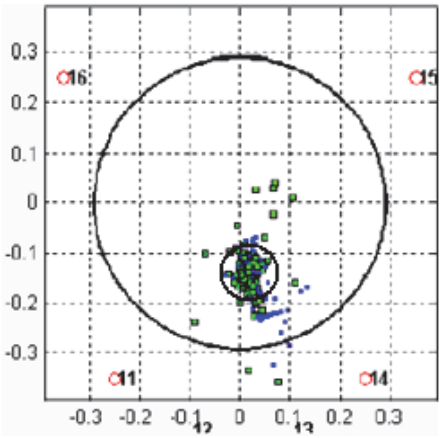

Fig. 7 (b). Corrosion-pitting location with two different algorithms under hydraulic press – circumferential distribution location.

5. Conclusions

Discussion on acoustic emission test of tank bottom based on different algorithms can be summarized as follows.

The two locating algorithms both precisely detect the corrosion defects of tank bottom. The multi-point location algorithm is more accurate than three-point algorithm. But a proposal that two algorithms should be located the signal at the same time with the consideration of possibility that the signal cannot be detected by three sensors in the same time.

The two different arrangement forms of sensors both precisely detect the corrosion defects. The location of sound source with the method of circumferential distribution form is more prone to practice. A proposal that corrosion defects detection should be better arranged in circumferential distribution along the bottom of tank with the consideration of feasibility and accuracy of acoustic emission test.

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