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# Study on Simulation of Guided Wave Propagation in Pipes

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**Abstract:** In this paper, we researched visualization of guided wave propagation in pipe with defect. The characteristic of three-dimensional sound field is simulated by finite element method. First, the characteristics of many modes of guided wave propagation in pipe and the interaction of guided wave with defect is studied. Then, the model of scattering sound field for defect exist is builded when guided wave propagation. The interaction of guided wave with defect is rebuilded by the model we build. At last, visualization process is simulated by building the model of pipe with defect and loading guided wave by using the soft of ANSYS. This research will make it easily to numerical and intuitionistic understand the location of defect and the characteristic of guide wave propagation in pipe. The research will make it easily to apply nondestructive testing technology in engineering based on guided wave.
**Keywords**: visualization, guided wave, propagation, pipe.

## 1. Introduction

The application of guided wave detect pipe interests many researchers for it can propagation long distance and high speed and it can detect the whole thickness of the wall[1-5]. For the expression vector of the guided wave propagation in pipe is complex and verbose so it is difficult to realize the interaction with defect and feature of guided wave propagation. If the feature of guided wave propagation and interaction with defect in pipe can be disentangled and researched intuitionistic, the theory of guided wave propagation and mode convertion will be profound comprehend. It will make important significance to apply non-destruction testing technique in pipe by using guided wave theory.

There are researchers simulated guided wave propagation in pipe by using software [6-7]. The software of ANSYS is a kind of large universal software include structure, thermodynamics, acoustic,liquid and electromagnetic analysis[8].It can solve simple linear static and complex nonlinear dynamic question. In this paper we simulate visualization of guided wave propagation in pipe by using software of ANSYS.

## 2. Equation of guided wave propagation in pipes

The dynamics equation of Elastic wave propagation in solid media is:

$$(\lambda+2\mu)\nabla(\nabla\cdot U)+\mu\nabla\times(\nabla\times U)=\rho\frac{\partial^2 U}{\partial t^2} \tag{1}$$

$U$ present displace, $\rho$ is material density , $\lambda$ and $\mu$ is lamb constant.The first item in equation(1) is expand proportion and the second item in equation is circumrotate proportion .According to the theory of elastic dynamics and guided wave [9] ,for a anisotropic cylinder hollow pipe with outer diameter a and inner diameter b. The root of the equation (1) can be assumed as fellow:

$$u_{(r,\theta,z,t)} = u_r \exp(jn\theta)\exp[j(\omega t + zt)] \tag{2}$$

$$u_r = U_r(r)\cos(n\theta)\cos(\omega t + kz) \tag{3}$$

$$u_\theta = U_\theta(r)\sin(n\theta)\cos(\omega t + kz) \tag{4}$$

$$u_z = U_z(r)\cos(n\theta)\sin(\omega t + kz) \tag{5}$$

$u_r, u_\theta, u_z$ are radical displacement , circumferential displacement and axial displacement respectively. $U_r(r), U_\theta(r), U_z(r)$ are amplitudes formed by Bessel function respectively.

There are three modes for guided wave propagation in pipe.They are longitudinal mode L(0,m),torsinal mode T(0,m) and flexural mode F(n,m). To solve the equation of guided wave in pipe is to solve following dispersion equation.

$$D = \begin{vmatrix} c_{11} & c_{12} & \cdots & c_{16} \\ c_{21} & c_{22} & \cdots & c_{26} \\ \vdots & \vdots & & \vdots \\ c_{61} & c_{62} & \cdots & c_{66} \end{vmatrix} = 0 \tag{6}$$

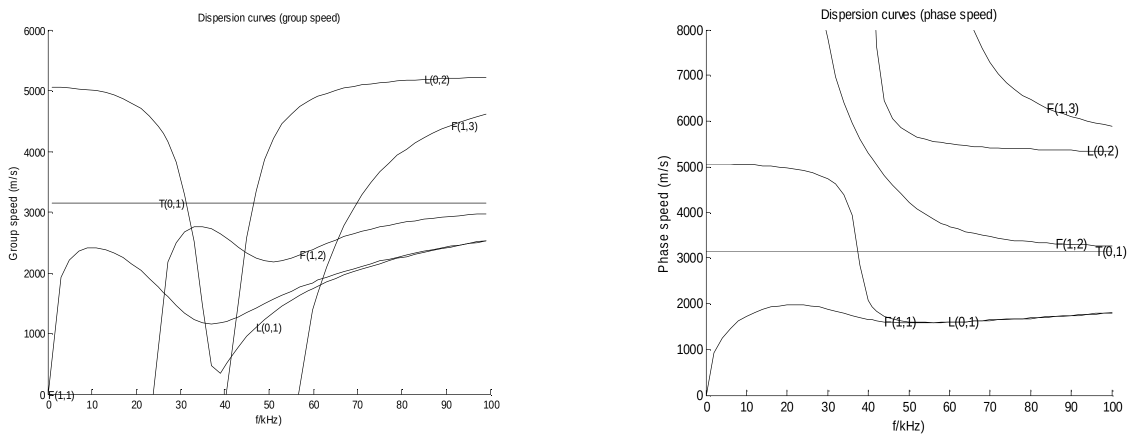
Guided wave mode is symmetrical for n=0, then the disperse equation can be disassembled as following:

$$D = D_1 \cdot D_2 = 0$$

$$D_1 = \begin{vmatrix} C_{11} & C_{12} & C_{14} & C_{15} \\ C_{31} & C_{32} & C_{34} & C_{35} \\ C_{41} & C_{42} & C_{44} & C_{45} \\ C_{61} & C_{62} & C_{64} & C_{65} \end{vmatrix}, \quad D_2 = \begin{vmatrix} C_{23} & C_{26} \\ C_{53} & C_{56} \end{vmatrix} \tag{7}$$

$D_1 = 0$ and $D_2 = 0$ are mode L(0,m) and mode T(0,m) respectively.

To calculate the disperse curve for a pipe with outer diameter 46mm and inner diameter 38mm.The free stress boundary condition is r=a,r=b : $\sigma_{rr} = \sigma_{rz} = \sigma_{r\theta} = 0$ .The dispersion curve is calculated as FIGURE 1.




（ a ）Dispersion curve of group speed　　　　（ b ）Dispersion curve of phase speed

Fig.1 Disperse curve of pipe with outer diameter 46mm and thickness 4mm

Dispersion is exist in the progress of guided wave propagation. From the FIGURE 1(a) there is only mode L(0,1) when the excitation frequency is near by 20kHz and the dispersion is little. So 20kHz is choosen as the excitation frequency.

# 3.Modeling and solution

In China there is researcher made the pipe model by using the element shell163 to simulate the propagation of guided wave in pipe with rack[10]. In this paper we build a model of steel pipe through define characteristic parameter of material by using element of solid164.The length of the steel pipe is 2 meters with outer diameter 46mm and thickness 4m.There is a through hole in the middle of the pipe with diameter 7mm.The pipe is meshed by sweep gridding with element length 5mm.There are 9900 elements and 19455 nodes .The steep pipe model being meshed is as following FIGURE 2:

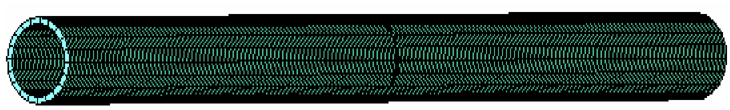


Fig.2 Model of steel pipe

We choose three-cycle 20kHz toneburst in a Hanning window and the expression is $F(t) = 15(1 - \cos(2\pi f_c/3))\sin(2\pi f_c)$.The excitation frequency $f_c$ is 20kHz.The excitation signal is as FIGURE 3. The parameter of load-time array is as following TABLE 1.

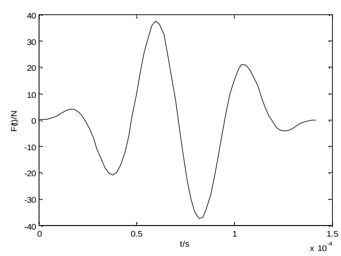


Fig.3 Excitation signal

Tab.1 Array of load-time

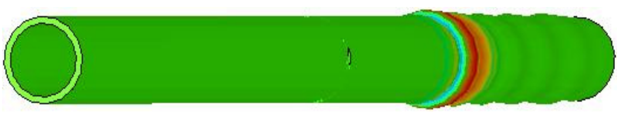
| Load step | Time (ms) | Load ( N ) |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 0.018 | 3.13275 |
| 3 | 0.038 | -15.75705 |
| 4 | 0.05 | 0 |
| 5 | 0.064 | 27.932025 |
| 6 | 0.076 | -3.758325 |
| 7 | 0.086 | -27.932025 |
| 8 | 0.1 | 0 |
| 9 | 0.11 | 15.75705 |
| 10 | 0.126 | -0.872625 |
| 11 | 0.132 | -3.132525 |
| 12 | 0.15 | 0 |

Set the analysis time is 0.00165 second and the output steps is 100.Then the solve progress can be started. When the solution is done we can read the result from the general processor. The wave form of special time also can be observed.

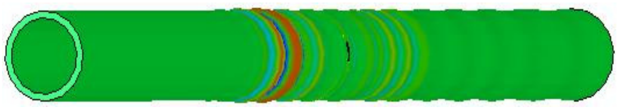
## 4.Results and discussion

The recording time of one echo is t=0.0008003. We can calculate the velocity of the longitudinal guided wave is $v = \frac{l}{t} = \frac{2\times 2}{0.0008003} = 4998.1m/s$ .It is agree well with the velocity from the disperse curve of mode L(0,1) at 20kHz which is 5000m/s.

From the general prepress processor the wave propagation can be observed by choosing special node as well as special time.The following FIGURE 4 is the state of wave propagation when t =0.00013195 s, t =0.0002805 s .



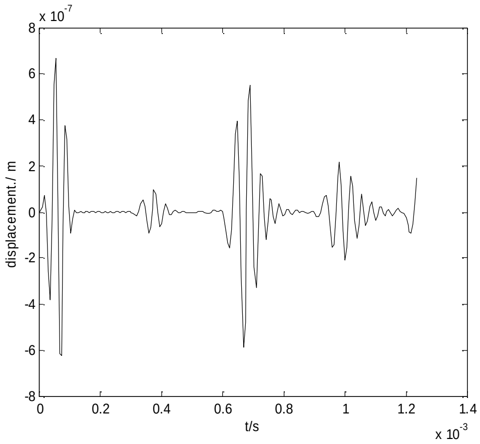
t =0.00013195 s



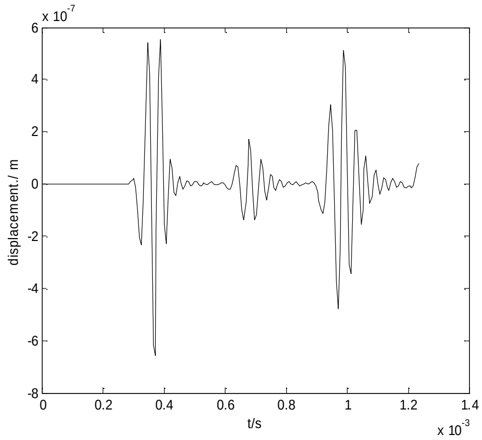
t =0.0002805 s

Fig.4 Longitudinal guided wave propagating in pipes

The model of guide wave in pipe and calculated result can be opened by loading the data file in processor. The results such as curve of time-displace course and curve of time-acceleration course can be drawed by using main menu. This example the curve of time-displace course for particles of node 3928 local at x=0m, y=0.023m and z=0.03980m and node 6779 local at x=0.00710739m, y=0.0218743m and z=1.9602m.The curves of displacement-time are as following FIGURE 5.



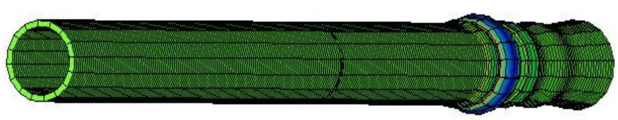

(a) Curve of the course of displacement –time for node 3928



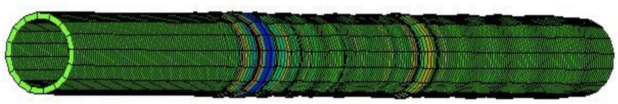

(b)Curve of the course of displacement–time for node 6779

Fig.5 Curve of the course of displacement –time for nodes

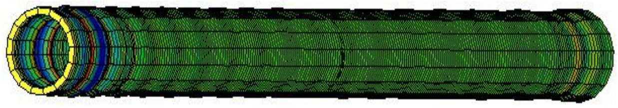
The animation of guided wave propagation in pipe can be made. The state of the wave propagation in pipe when time at t=0.00098943s，t=0.00029696 s，t=0.00042897 s，t=0.0005775 s are as FIGURE 6.



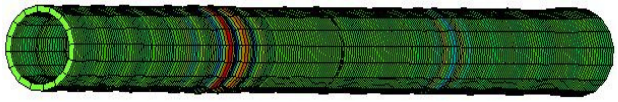
t=0.00098943s



t=0.00029696 s



t=0.00042897 s



t=0.0005775 s

Fig.6 Animation of longitudinal guided wave propagation

From the FIGURE 5 we can find the amplitude of first wave crest is large then the amplitude of echo become smaller. In FIGURE 5(a) the amplitude of the second reflect echo from the hole become larger and the width of the echo become wider which is agree well with the attenuation of actual guided wave testing. It can reflection there is little dispersion in the L(0,1) wave propagation at the frequency of 20kHz. The animation of guided wave propagation in pipe from figure 6 can reflect the reflection and transmission when it meet defect and pipe end which is agree very well with the state of guided wave propagation in actual pipe.

## 5.Conclusions

The velocity of the lognitudinal guided wave propagation in steel pipe is calculated from the echo obtained through build the finite element model of pipe and apply lognitudinal high frequency force to the pipe end to excitation guided wave.The calculated velocity is agree well with the velocity get from the dispersion curve which is got from the calculate software. The wave get from the observe point can reflect the reflection and the attenuation of guided wave propagation in pipe. The animation of the guided wave propagation is simulated vivid.

## References


[1] Y. M Cheong, D, H Lee, S. S. Kim, H. K. Jung, 2003, "Analysis of circumferential guided wave for axial crack detection in a feeder pipe.", 11th APCNDT, Jeju island, Korea. Nov,pp. 3-7.

[2] P. Cawley., M.J.S Lowe, D.N. Alleyne ,B. Pavlakovic and P. Ilcox, 2003, "Practical long range guided wave testing : Application to pipes and rails. " Materials Evaluation, Vol.61, pp.66-74

[3 ] J. J. Ditri, 1994, " Utilization of guided elastic waves for the characterization of circumferential cracks in hollow cylinders." J.Acoust. Soc. Am. 96, pp. 3769-3775.

[4] Alleyne,D.N,Lowe,M.J.S.,and Crawley,P, 1996 ,'The inspection of chemical plant pipework using Lamb waves:Defect sensitivity and field experience." Review of progress in Quantitative NDE,Vol.15,D.O Thompson and D, E Chimenti,Plenum Press,New York,pp.1859-1866.

[5] Wang Yue-min,Kang Yi-hua,Wu Xin-jun. 2005, "Application of ultrasonic guided wave nondestructive testing of pipes."[J].Journal of Naval University of Engineering,China,17(5):pp.34-37.

[6] Wenhao zhu,2002, "An FEM Simulation for Guided Elastic Wave Generation and Reflection in Hollow Cylinders With Corrosion Defects." ASME.J mem. 124,pp.108-116.

[7] Jooh-soo Park ,Hyung–ju Yu, Sung Song ,Young H.Kim, yong Moo Cheng, Hyun-Kyn Jung ,2006, "Analysis of ultrasonic guided wave dispersion in pipes using 3-D FEM and 2-D FFT." Review of Quantitative Nondestructive Evaluation. American Institute of Physics., 24: 219-225.

[8] Li Ni-ming. Practicality course of finite element method analyze for soft of ANSYS.Ting hua university Press,2005.

[9] J.L. Rose, Ultrasonic waves in solid media. University Press, Cambridge, 1999.

[10] Cheng Zai-bin,Wang Zhi-hua,Zhang Li-jun ,Ma Hong-wei, 2004, "Numerical simulate detect crack using longitudinal guided wave in pipe." [J]Chinese journal of applied mechanics.,21(4):76-79.