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Analysis The Wave Equation Of The Dispersion Term On The Wave Group Velocity

Sumihar Simangunsong[1]
Institut Sains Dan Teknologi TD Pardede Medan
E-mail: sumiharbwv79@yahoo.co.id
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ABSTRACT

Penelitian ini bertujuan untuk memperoleh persamaan dispersi untuk kecepatan kelompok gelombang dalam suatu medium. Medium dispersif adalah medium di mana, ketika gelombang memasuki area tersebut, gelombang mengalami perubahan bentuk dan energi. Tujuan penelitian ini adalah untuk menunjukkan bagaimana metode integrasi integral memperoleh persamaan dispersi. Penelitian ini bersifat kualitatif. Lokasi penelitian ini berada di Institut Sains dan Teknologi TD Pardede. Dari analisis dalam penelitian ini, ditemukan bahwa intensitas gelombang menurun menuju kedalaman medium dispersif, dengan asumsi bahwa koefisien atenuasi (μ) tetap kontinu di seluruh kedalaman material yang dilalui gelombang. Dalam kasus gelombang seismik, ketika gelombang merambat melalui suatu medium, intensitasnya menurun seiring jarak. Ketika koefisien absorpsi a = 0, gelombang tidak diserap tetapi dipantulkan, dan ketika a = 1, gelombang sepenuhnya diserap. Jika a = 0,5, 50 persen energi diserap. Energi yang diserap ini diubah menjadi panas. Dalam beberapa kasus, energi yang diserap dapat meningkatkan energi partikel suatu zat.

This study aims to obtain the dispersion equation for the group velocity of waves in a medium. A dispersive medium is a medium in which, when a wave enters the area, the wave undergoes changes in shape and energy. The purpose of this study is to demonstrate how the integral integration method obtains the dispersion equation. This research is qualitative. The location of this research is at the TD Pardede Institute of Science and Technology. From the analysis in this study, it was found that the wave intensity decreases towards the depth of the dispersive medium, assuming that the attenuation coefficient (μ) remains continuous throughout the depth of the material the wave passes through. In the case of seismic waves, when the wave travels through a medium, its intensity decreases with distance. When the absorption coefficient a = 0, the wave is not absorbed but reflected, and when a = 1, the wave is completely absorbed. If a = 0.5, 50 percent of the energy is absorbed. This absorbed energy is converted to heat. In some cases, the absorbed energy can increase the energy of the particles of a substance.

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INTRODUCTION

waveform changes when entering a medium, describing the effects of different wavelengths traveling at different speeds. Research primarily addresses wave velocity dispersion, which is based on the concept of group velocity. For now, for a rough physical overview, let's use the somewhat ambiguous term "velocity." A basic example of dispersion is light in a glass prism (or generally any medium other than a vacuum).Light as an electromagnetic wave is an entity present in the universe. One of the largest sources of light for the earth is sunlight. Sunlight is very important for the continuity of the photosynthesis process carried out by phytoplankton. Productive phytoplankton are only found in the upper layers of water, where the light intensity is sufficient for photosynthesis to take place. Light also plays a role in visualizing the environment for aquatic organisms. In many cases today the need for optical properties of light is a very important need for the development of quality of life. The use of optical properties is useful in the world of engineering such as mining, construction and in the medical field. One of the optical properties that is useful in the above fields is the problem of scattering and attenuation (Mari, J.-L, 2019).

When light travels through a material, different wavelengths travel at different speeds. Therefore, when white light enters, for example, a glass prism from air, Snell's law tells us that the different wavelength components refract in different directions. This is called chromatic dispersion. In this lecture, we will only consider waves traveling within a single material or a periodic arrangement of materials, and therefore refraction at interfaces will not play a role.

The nature of the dispersive material when illuminated shows the existence of an attenuation process in the material. The magnitude of this property can be calculated through the attenuation coefficient. The attenuation coefficient is a description of how much the incoming light is reduced or lost compared to the energy of the incoming light on the surface. This medium can be solid or liquid. The quantity of light that experiences attenuation is equivalent to the amount of light absorbed and scattered. The attenuation process also causes light penetration to only penetrate the water column to a certain depth. Therefore, knowledge of the attenuation coefficient can be used to determine the characteristics of a water column. The intensity of radiation entering a material is not the same but experiences energy loss (Lossy Energy). The intensity of radiation entering the material depends on how deep the light enters (Saydalimov, A. S, 2022).To analyze the propagating wave in the medium we use

Gaussian waves because the Gaussian wave packet is localized so that we can still determine the state function of the quantity such as mass density, attenuation or wave energy in a certain inner layer. In this study the differential equation in the dispersion medium is

$$\left(\nabla^2 + \frac{\omega^2 n^2(\omega)}{c^2}\right)\psi(x) = 0$$

$$; \quad \psi(x,t) = \psi(x)\ x\ e^{-i\omega t}$$

Where the equation above is for a medium that does not experience linear attenuation, so the simple solution can be written as

$\psi(x,t) = \psi_0\ e^{i(kx-\omega t)}$ with $\mathrm{k} = \frac{\omega\ \mathrm{n}(\omega)}{c}$

geoup velocity

$$\emptyset = kx - \omega t = k\left(x - \frac{\omega}{k}t\right)$$

$$= k\left(x - v_{phase}t\right)$$

$$v_{phase} = \frac{c}{\mathrm{n}(\omega)}$$

Suppose we assume the Gaussian wave function propagating in the x-axis is

$$\Psi(x,t_0) = Ae^{ikx-\frac{x^2}{2\sigma^2}}$$

where $A = \frac{1}{\pi^{1/4}\sqrt{\sigma}}$ with integral transformation

$$\Psi(k) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty}\Psi(x,t_0).\,e^{-ikx}dx$$

So that we get $\Psi(k) = \frac{A}{\sqrt{2\pi}}\int_{-\infty}^{\infty} e^{-\frac{x^2}{2\sigma^2}}dx$

By using the relationship

$$\int_{-\infty}^{\infty} e^{\gamma+\beta x-\alpha x^2}dx = \sqrt{\frac{\pi}{\alpha}}e^{\frac{\beta^2}{4\alpha}+\gamma}$$

So we get $\Psi(k) = \frac{\sqrt{\sigma}}{\pi^{1/4}}$

By entering the function $\Psi(k)$ into the function $\Psi(x,t)\ we\ get$

$$\Psi(x,t) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty}\Psi(k).\,e^{i\left(kx-\frac{\hbar k^2 t}{2m}\right)}dk$$

$$\Psi(x,t) = \frac{1}{\sqrt{2\pi}}\frac{\sqrt{\sigma}}{\pi^{1/4}}\int_{-\infty}^{\infty} e^{-\left(\frac{i\hbar t}{2m}\right)k^2+(ix)k}dk$$

By using the integral relationship above:

$$\Psi(x,t) = \frac{1}{\sqrt{2\pi}} \frac{\sqrt{\sigma}}{\pi^{1/4}} \sqrt{\frac{2\pi m}{i\hbar t}}\, e^{\frac{(ix)^2}{\left(\frac{i\hbar t}{2m}\right)}}$$
$$= \frac{\sqrt{\sigma} m}{\pi^{1/4} i\hbar t} e^{\frac{-mx^2}{2i\hbar t}}$$

Seismic waves are waves that propagate in the earth caused by structural deformation, pressure or tension due to the elastic properties of the earth's crust. These waves carry energy and then propagate in all directions throughout the earth and can be recorded by seismographs. Surface waves are complex waves with low frequencies and large amplitudes, which propagate due to the free surface effect, namely the difference between the elastic properties. The propagation of seismic waves below the surface will be influenced by the properties of the heterogeneous and anisotropic medium. The propagation of seismic waves below the surface will be influenced by the properties of the heterogeneous and anisotropic medium.

Heterogeneous properties are defined as the physical properties of a medium that depend on position so that they do not depend on direction, this is different from anisotropy which depends on direction. This heterogeneous property has variations in physical properties on a small scale (grain scale) while anisotropy has variations in physical properties on a large scale. This scale is determined by a standard of comparison, namely the seismic wavelength. Anisotropic velocity affects the position laterally and at depth and the focus of geological structures. The success of seismic imaging is the calculation and estimation of accurate anisotropy.

The attenuation coefficient is also useful in the recognition of solid layers (rocks). The need to determine the identification of the attenuation coefficient for solid layers (rocks), so that layers that have hard or soft soil types can be identified. If the value of the sediment or rock attenuation coefficient in an area is large, then the vulnerability of the sediment to earthquakes is high or the area is dangerous when an earthquake occurs, and conversely if the value of the sediment attenuation coefficient obtained is small, then the area is an area with a lower risk when an earthquake occurs. For the field of geology, Shear wave velocity and shear modulus are common to determine the interaction of dynamic soil properties.

RESEARCH METHOD

The method used in this research is a literature study through various references. This research begins with a fundamental analysis of the wave properties in a medium experiencing reflection and absorption. Using an infinite frequency, the inverse Fourier function is proposed by adopting the frequency of the absorption wave. The general intensity is given as a description of the shear signal with a general form in elastic waves, namely a function in real and imaginary numbers. The concept of wave absorption by the medium is initiated by a combination of the effects of material depth so that the absorption wave function also depends on the depth function. This research was conducted for one year at the TD Pardede Institute of Science and Technology.

RESULTS AND DISCUSSIONS

Wave propagation in transmission lines has been a subject of research for decades. These lines consist of periodically placed, concentrated components, such as capacitors and inductors. Transmission lines can also exhibit temporal periodicity, and this paper discusses low-pass transmission lines with both spatial and temporal periodicity. This is achieved by modulating the capacitance periodically in time. Our modeling is realistic, taking into account the absorption mechanism, the nonlinearity of the varactor that provides the temporal modulation of the capacitance, and most importantly, the effect of the modulation source on wave propagation. Spatial periodicity is known to produce a dispersion relation with a frequency gap and a periodicity in the phase shift, while temporal periodicity produces a dispersion relation that is periodic in frequency and has a phase shift gap. Indeed, our dynamic transmission line will be shown, both theoretically and experimentally, to exhibit such phase shift gaps.

The interaction of waves in a solid medium that experiences dispersion can be written in the form of the Maxwell equation (Cornille, P., Atomic, F., & Commission, E. 2011)

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The Maxwell equation itself is an electromagnetic wave equation that shows changes in magnetic fields and electric fields. The equation in the medium can be written as;

$$\nabla . (\nabla . E) - \nabla^2 E = -\frac{\partial \left(\mu\epsilon E + \mu\epsilon \frac{\partial E}{\partial t}\right)}{\partial t}$$

$$\nabla^2 E - \mu\sigma\frac{\partial E}{\partial t} - \mu\epsilon\frac{\partial^2 E}{\partial t^2} = 0$$

So as a consequence of the equation above, the wave equation can be written

$$\nabla^2 E = \mu\epsilon\frac{\partial^2 E}{\partial t^2} + \mu\sigma\frac{\partial E}{\partial t},$$

$$\nabla^2 B = \mu\epsilon\frac{\partial^2 B}{\partial t^2} + \mu\sigma\frac{\partial B}{\partial t}$$

So the solution to the above equation in the wave plane is

$E_{(z,t)} = E_0 e^{i(kz-\omega t)}$, $B_{(z,t)} = Be^{i(kz-\omega t)}$

With the wave number $\tilde{k}$ in complex form

$$\tilde{k} = k + i\kappa$$

with

$$k = \omega\sqrt{\frac{\epsilon\mu}{2}}\left[\sqrt{1 + \left(\frac{\sigma}{\epsilon\omega}\right)^2} + 1\right]^{1/2},$$

$$\kappa = \omega\sqrt{\frac{\epsilon\mu}{2}}\left[\sqrt{1 + \left(\frac{\sigma}{\epsilon\omega}\right)^2} - 1\right]^{1/2}$$

κ is the imaginary part that shows the disturbance of energy absorption in the medium which is proportional to the distance or depth the wave propagates in the medium (Cáceres, M.O,2021) The interaction of waves propagating in a medium can be shown in a Gaussian function in the axial direction, namely:

$$I_{(x)} = \left(1/\sigma\right)e^{-\left(x^2/2\sigma^2\right)}$$

$I_{(x)}$ is a wave propagation with a low attenuation level. The Gaussian integral transform of $I_{(x)}$ is

$$I_{(\omega)} = \sqrt{2\pi}e^{-\left(x^2\omega^2/2\right)}$$

The wave speed propagating in the x direction can be written in the form of the Gaussian amplitude P.

$$v_z(x,t) = \frac{Pc^2}{2\sigma}e^{\left(-(x-ct)^2/2\sigma^2\right)}$$

Here for the Gaussian value $P = 1$ then

$$v_z(x,\omega) = \frac{\omega}{2k}e^{-\frac{1}{2}\sigma^2 k^2}e^{-ikx} = \frac{\omega c}{2(\omega - i\alpha c)}e^{-\frac{1}{2}\sigma^2\left((\omega/c)^2+\alpha^2\right)}e^{-i(\omega/c)x}e^{-\alpha x}$$

Now assuming that the weak attenuation in the $\alpha \ll \frac{\omega}{c}$ layer we can eliminate the imaginary term from the above equation (Magrini, F., & Boschi, L. 2021) , so that equation became :

$$v_z(x,\omega) \cong \frac{c}{2}e^{-\frac{1}{2}\sigma^2\left((\omega/c)^2+\alpha^2\right)}e^{-i(\omega/c)x}e^{-\alpha x}$$

With the Fourier inverse the equation above becomes

$$v_z(x,t) = \frac{c^2}{2\sigma\sqrt{2\pi}}e^{\frac{-(x-ct)^2}{2\sigma^2}}e^{\frac{-\alpha^2\sigma^2}{2\sigma^2}}e^{-\alpha x}$$

In the case of seismic waves as the waves travel through a medium, their intensity decreases with distance. In idealized materials, the amplitude of the waves only decreases due to wave propagation (Donà, M., Lombardo, M., & Barone, G. 2015) However, all natural materials produce effects that further attenuate the waves. This further attenuation is due to scattering and absorption. Scattering is the reflection of waves in directions other than their original direction of propagation. Absorption is the conversion of wave energy to another form of energy. Ideal attenuation is not something that is ruled out, but linear perturbation analysis aims to capture the mathematical analysis by assuming that the deeper perturbation terms can be very small and can be neglected. By applying the first order linear perturbation value, namely $c \equiv c_0 + c_1|\omega|$, $\alpha \equiv \alpha_0 + \alpha_1|\omega|$ where $c_0 \gg c_1\omega$ and $\alpha_0 \gg \alpha_1\omega$ and the infinite series expansion of the Macclaurin series is $\frac{1}{1+\frac{c_1}{c_0}|\omega|} \cong 1 - \frac{c_1}{c_0}|\omega|$. This very small disturbance does not change the basic system of wave propagation.

$$v_z(x,\omega) \cong \frac{c_0}{2} e^{-\frac{1}{2}\sigma^2\left(\omega/c_0\right)^2} e^{-i\left(\frac{\omega}{c_0+c_1|\omega|}\right)x} e^{-\alpha_1|\omega|x}$$

$$v_z(x,\omega) \cong \frac{c_0}{2} e^{-\frac{1}{2}\sigma^2\left(\frac{\omega}{c_0}\right)^2} e^{-ix\left(\frac{\omega}{c_0}-\frac{c_1\omega^2 sign\,|\omega|}{c_0{}^2}\right)} e^{-\alpha_1|\omega|x}$$

Even in homogeneous materials, dispersion still causes the separation of different wavelengths. For example, an initially localized disturbance (wave packet) is a combination of waves with many different wavelengths. These waves will decompose, and the wave packet will gradually become wider because the different wavelength components propagate at different speeds. This effect is called group velocity dispersion and is particularly relevant, for example, in fiber optics. In long-distance fiber optics, clever techniques need to be used to overcome dispersion to maintain signal integrity. This is called dispersion management and is based on periodically switching the fiber material along the direction of propagation.

An effect of group velocity dispersion, which you can observe even at home, is water waves—more precisely, capillary water waves. When a relatively small object is dropped into water, the nearly circular waves resulting from the disturbance will spread out, and waves with shorter wavelengths will travel faster than waves with longer wavelengths. However, it should be noted that not all wave propagation is dispersive. For example, sound waves in air, fortunately, experience almost no dispersion. Therefore, music we hear five or fifty meters away from a band sounds the same (until dissipation). Dispersion is also a smoothing mechanism. Singularities can be explained by the presence of many waves with different (especially very small) wavelengths. Because these waves propagate at different speeds, the singularities decay and weaken over time.

By using the relationship $v_z(x,\omega) = i\omega u_z(x,\omega)$ and gauss band width $\frac{c_1 sign\,|\omega|}{c_0{}^2} x = 1$ that

$$u_z(x,\omega) \cong \frac{-ic_0}{2\omega} e^{-\frac{1}{2}\sigma^2\left(\frac{\omega}{c_0}\right)^2} e^{-ix\left(\frac{\omega}{c_0}-\omega^2\right)} e^{-\alpha_1|\omega|x}$$

by taking the dispersion term equation is

$$e^{-\alpha_1|\omega|x}$$

we can convert it with Fourier inversion to get the function of time for that term

$$e^{-\alpha_1|\omega|x} \begin{cases} e^{-\alpha_1|\omega|x} & x > 0 \\ e^{-\alpha_1|\omega|x} & x < 0 \end{cases}$$

By defining the inverse Fourier, we get

$$\tilde{f}(\omega) = \int_{-\infty}^{0} e^{-i|\omega|t} e^{\alpha_1|\omega|x}\, d\omega + \int_{0}^{\infty} e^{-i|\omega|t} e^{-\alpha_1|\omega|x}\, d\omega$$

By integrating the limit of infinite terms we get the result of the inversion, is

$$\tilde{f}(\omega) = \frac{1}{\alpha_1 x - it}\bigg|_{-\infty}^{0} - \frac{1}{\alpha_1 x + it}\bigg|_{0}^{\infty}$$

$$F(x,t) = \frac{2\alpha_1 x}{t^2 + (\alpha_1 x)^2}$$

With α_1 is the perturbation absorption coefficient in the layer. From this equation we can see that the wave function in dispersive materials can change depending on the depth of the material and the magnitude of the linear absorption coefficient and the perturbation absorption coefficient. In the case of seismic waves, the waves are transmitted through an elastic layer so that the waves experience attenuation. The presence of disturbances in the layer through which the waves pass causes the material shift to experience a disturbance characteristic where the wave amplitude becomes smaller. It indicates the proportion of waves that are absorbed. For example, $\alpha = 0.5$ means that half of the sound energy is absorbed. $\alpha = 0$ means that the sound waves are not absorbed at all but completely reflected. $\alpha = 1$ means that the sound is absorbed in its entirety. This is because the absorption of wave energy by the particles of the dispersive medium continues to experience attenuation.

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CONCLUSION

Dispersion is the phenomenon of waveform changes when entering a medium, describing the effects of different wavelengths traveling at different speeds. Research primarily addresses wave velocity dispersion, which is based on the concept of group velocity. . The process of changing waves is caused by the interaction of waves with the medium. This interaction can dampen the propagating waves. One aspect is seismic waves that propagate on the surface or depth of the layer. Additional aspects of the characteristics of the medium and the depth of the layer are the main factors causing the spread of the waves. In the case of seismic waves when the waves move through the medium, their intensity decreases with distance.

For example, $\alpha = 0.5$ means that half of the sound energy is absorbed. $\alpha = 0$ means that the sound waves are not absorbed at all but completely reflected. $\alpha = 1$ means that the sound is absorbed in its entirety.

In idealized materials, the wave amplitude only decreases due to wave spreading. The quantity that states the comparative constant between the magnitude of the absorbed radiation intensity and the thickness of a material or material is called the attenuation coefficient (μ). However, all natural materials produce effects that further increase the waves. This further attenuation is caused by scattering and absorption. Scattering is the reflection of waves in a direction other than the original direction of propagation. Absorption is the conversion of wave energy to another form of energy. Ideal attenuation is not something that is set aside, but linear disturbance (attenuation) analysis aims to capture mathematical analysis by assuming that there is a disturbance in the layer through which the wave passes, causing the material shift to experience a disturbance characteristic where the wave amplitude is getting smaller. This is because the absorption of wave energy by the dispersed medium particles continues to experience attenuation This absorbed energy is converted to heat. In some cases, the absorbed energy can increase the energy of the particles of a substance.

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