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Implementation of Small Term Reduction in Taylor Series in Analytical Physics Problem

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Abstact: *This research is motivated by the low ability of students to apply mathematical solving methods to analytic physics. The purpose of this research is to show the implementation of small term reduction in Taylor series on analytic physics problems. The analytical physics material described in this study is the pendulum oscillation material, heat conduction and the perturbation quantum state function. This research method involves a mathematical derivation of the Taylor series formation. The epicenter of the idea of reducing the Taylor series in this study is the use of very small terms in the Taylor series to reduce terms with values reaching towards zero, namely the third term and the fourth term. This small term reduction method is spread into problems of mechanics, oscillations, heat, electricity, magnetism and quantum mechanics. The results of this study show that after using the small term reduction principle, the equations to be solved are like first-order and second-order differential equations. By solving these equations we get a variable physical quantity.*

Keywords: *Analytic physics, physics problems, small term, small term reduction, Taylor series*

Implementasi Reduksi Suku Kecil dalam Deret Taylor pada Masalah Fisika Analitik

Abstrak: Penelitian ini dilatarbelakangi oleh rendahnya kemampuan siswa dalam menerapkan metode penyelesaian matematis pada fisika analitik. Tujuan penelitian ini adalah untuk menunjukkan penerapan reduksi suku kecil deret Taylor pada permasalahan fisika analitik. Materi fisika analitik yang dijelaskan pada penelitian ini adalah materi osilasi pendulum, konduksi panas dan fungsi keadaan kuantum perturbasi. Metode penelitian ini melibatkan derivasi matematis dari pembentukan deret Taylor. Episentrum gagasan reduksi deret Taylor pada penelitian ini adalah penggunaan suku-suku yang sangat kecil pada deret Taylor untuk mereduksi suku-suku yang nilainya mendekati nol, yaitu suku ketiga dan suku keempat. Metode reduksi jangka kecil ini merambah ke permasalahan mekanika, osilasi, panas, listrik, magnet, dan mekanika kuantum. Hasil penelitian ini menunjukkan bahwa setelah menggunakan prinsip reduksi jangka kecil, persamaan-persamaan dapat diselesaikan seperti persamaan diferensial orde pertama dan orde kedua. Dengan menyelesaikan persamaan ini kita memperoleh kuantitas besaran variabel fisika.

Kata Kunci: Deret Taylor, fisika analitik, *reduksi suku kecil*, soal fisika, suku kecil

INTRODUCTION

Application physics (applied physics) is the application of physics to analytical and engineering problems. Where problems at this level require analytical methods such as mathematical analysis. Analytical mathematics such as calculus and algebra are needed to solve applied physics problems. Applied physics questions related to analytical mathematics relate to very small changes in physical variables as well as periodic questions. The background of this research is that in learning applied physics, students often face solving problems related to applied mathematics (Simangunsong & Trisna, 2021). In fact, there is a close relationship between physics and mathematics so that mathematical abilities are needed to understand the concepts physics in mathematical models (Kereh et al., 2014). The Taylor Series is a complicated mathematical structure when combined with several concepts. Therefore, it may be very difficult for students to begin to understand it when using this method. Analysis Preliminary studies reveal that many patterns Students' reasoning is based on certain elements and actions performed on mathematical elements that underlie the Taylor series structure.

Why the Taylor series is so important in applied physics. The Taylor series itself is an analysis method that allows us to represent various functions as a sum of simpler terms with very small changes in function (Chen, 2006). This is very useful in various fields of physics, such as mechanics, electromagnetism, and quantum mechanics (Antera, 2021). In classical mechanics, for example, the Taylor series can be used to express the motion of a particle as the sum of simpler harmonic motions. This can be very helpful in understanding the behavior of oscillating systems, such as pendulums or springs. In electromagnetism, the Taylor series can be used to represent the behavior of electromagnetic waves as the sum of simpler harmonic waves. This can be very helpful in understanding the behavior of electromagnetic radiation, such as light or radio waves. In quantum mechanics, Taylor series can be used to represent the behavior of quantum states as simpler sums of states. This can be very helpful in understanding the behavior of quantum systems, such as atoms or particles. Overall, the Taylor series is a powerful tool in physics because it allows us to represent complex phenomena in a simple and easy to understand way. This can lead to a deeper understanding of the underlying physics and make it easier to solve problems and make predictions (Simangunsong, 2022). This means that the small terms in physics and engineering are a problem in themselves.

The Taylor series is a series of expansions of a function at a point (Kouki & Griffiths, 2020). Taylor series are infinite series of a certain kind. The accuracy and precision of the Taylor series approximation of a function depends on how many terms we have in the series . In most cases, we can get arbitrary precision (as high as we want), but we balance this with the difficulty of scaling down and computing more terms (Chen et al., 2019). Life becomes simpler if we can replace it with something easier to do. We'll start by reviewing the linear approximation of a function. We will learn how to form a Taylor series representation of a function starting from a central point, and we will discuss the errors that occur in approximating the function in this way. Suppose we have a function variable x with a value very close to a certain value h. Then the gradient of the function around point h is:

$$\frac{f(x) - f(a)}{(x - a)} = f'(a) \tag{1.1}$$

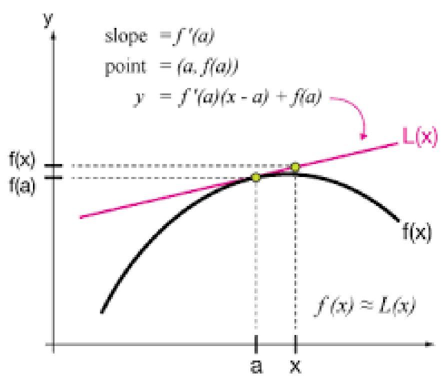

Figure 1. Function $f(x)$ with closy to x

Using a linear algebra approach, the above equation can be written as:

$$f(x) = f(a) + (x-a)f'(a) \tag{1.2}$$

The equation above can be made into a power series, so we write the Taylor series in general form, namely:

$$f(x) = f(a) + (x-a)f'(a) + \frac{(x-a)^2}{2!}f''(a) + \frac{(x-a)^3}{3!}f'''(a) + \cdots + \frac{(x-a)^n}{n!}f^n(a) \tag{1.3}$$

For the value $a = 0$, the Taylor series equation above is called the Macclaurin series. So the Macclaurin series is called the Taylor series with a special case. So several functions can be created in the Macclaurin circuit as below:

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \frac{x^4}{4!} + \cdots. \tag{1.4}$$

$$\sin x = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \cdots. \tag{1.5}$$

$$\cos x = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + \cdots. \tag{1.6}$$

However, in the problem of determining basic values, the small change terms in the Taylor series above are often ignored. This is done to determine the boundary value problem of a physical problem. Therefore, the problem for students in applying the Taylor series method is first, understanding the Taylor series function is for the problem of determining the value of a finite function, second is determining.

RESEARCH METHOD

This research is qualitative research. This research is based on the emergence of several analytical physics learning problems whose solutions are close to mathematical methods. The data sources in this research were obtained through several journals and books regarding the application of the Taylor series method in analytical physics problems. The Taylor series used in this research is one dimensional with a simple differential format. The applications of the Taylor series described in this research are in oscillating materials, thermal conduction and Quantum perturbation theory. The place of this research was carried out at the TD Pardede Institute of Science and Technology where the researcher worked as a lecturer. This research was conducted for ten months.

RESULTS AND DISCUSSIONS

One of the pedagogical aspects of knowledge reduction to the smallest term is a critical thinking skills attitude. A critical thinking attitude is an element that adds aspects of thinking experience to increasing a person's ability to analyze which is a solution (Ariani, 2020). In other words, a critical thinking attitude can increase students' understanding and reduce difficulties in learning. In many solution methods, the generalization of the Fourier series contributes to the solution of many problems including nonlinear function equations (Öɫrekçi, 2015). In other words we obtain recurrence relations of complex nonlinear functions such as exponential, logarithm, and trigonometric functions.

A simple pendulum is an ideal object consisting of an object of mass m suspended on a light string ℓ, where the length of this string cannot increase or stretch. The practice of pendulums is used for several solutions in answering physical quantities such as the period of the pendulum and the gravitational acceleration of the earth's surface. In the world of geological engineering, the method of determining the Earth's gravitational acceleration is also used to determine rock mass density. We will carry out a theoretical test of the implementation of the Taylor series on a pendulum. A string pendulum with a mass m attached to its end is deflected at an angle θ. For this case, a small deviation is taken so that the deviation angle is also small. This is why pendulum motion with small deviations is called simple harmonic motion. If the deviation is large, the motion of the pendulum will experience disturbances, this disturbance can be in the form of friction. Of course, estimating this value is a challenge. One of the challenges in using Taylor series is estimating high-order derivative terms in the algebra of the series (Paudel et al., 2022). These higher order terms start with the second derivative term. We can see the forces acting on the pendulum in Figure 2. When it vibrates (swings) the centripetal force keeps the object m on the string.

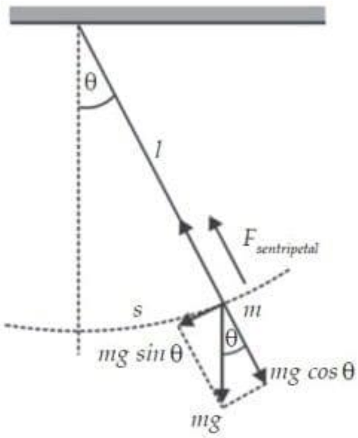

Figure 2. A pendulum of length l and mass m is at the end of the string

According to the restoring force acting on the pendulum, the equation applies:

$$\sum F_p = -mg\sin\theta \tag{3.1}$$

According to the restoring force acting on the pendulum, the equation applies:

$$ma = -mg\sin\theta \tag{3.2}$$

According to the restoring force acting on the pendulum, the equation applies:

$$\sin\theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \frac{\theta^7}{7!} + \cdots \tag{3.3}$$

For very small θ we can reduce the term $\frac{\theta^3}{3!}$ and the next term becomes zero. This is because the value of this term has become very small. To obtain higher accuracy we must assume that the solution to the equation is convergent for all values of the series (He, 2020). This means that if the series is convergent, the solution obtained is exact. Here we use the approximate relationship for very small angles from the Taylor series reduction above, namely:

$$\sin\theta \approx \theta$$

So the equation above becomes:

$$a = -g\theta \qquad (3.4)$$

When the object m swings, the object makes a circular motion so that the path it takes is in accordance with the equation below:

$$s = \theta . l$$

$$\frac{ds^2}{dt^2} + \frac{g}{l}s = 0 \qquad (3.5)$$

We can solve the equation above using several methods, either the variable separation method or by assuming $\frac{g}{l} = \omega^2$so that we get a solution for the period magnitude:

$$T = 2\pi\sqrt{\frac{l}{g}} \qquad (3.6)$$

Where l l is the length of the pendulum.

A plate with an extended surface (combined conduction-convection system) is a solid body in which heat transfer by conduction is assumed to occur in one-dimensional direction, while heat is also transferred by convection (and/or radiation) from the surface in a direction transverse to the direction of conduction. If heat is transferred from a surface to a fluid by convection, what the surface condition is is determined by the law of conservation of energy. Fourier's law of heat conduction states that the flow of heat through a material is proportional to the temperature gradient. This law is based on the assumption of a classical system, where heat flow is continuous and instantaneous. This theory also introduces the concept of time dilation, where time appears to move more slowly to an observer moving relative to another observer. In classical systems, heat flow is instantaneous, but in systems where time dilation is present, heat flow may not be instantaneous, which would conflict with Fourier's law (Djesse et al., 2023). However, it is important to note that Fourier's law is still a useful and accurate description of heat conduction in most everyday situations, and is consistent with the theory of relativity when applied within appropriate limits.

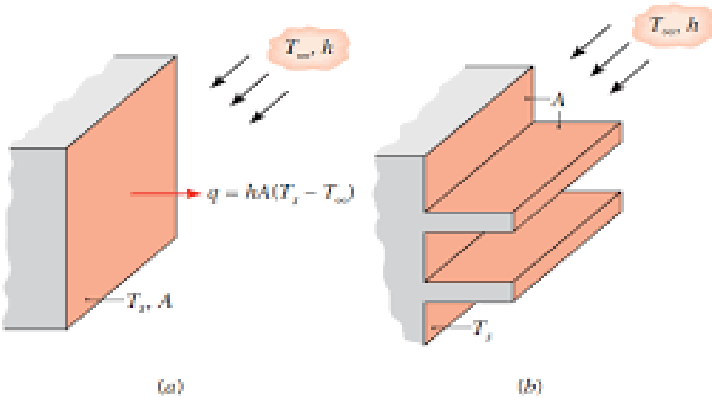

Figure 3. Metal plate with wing surface

By applying differential conservation of energy to the movement of heat in the plate is

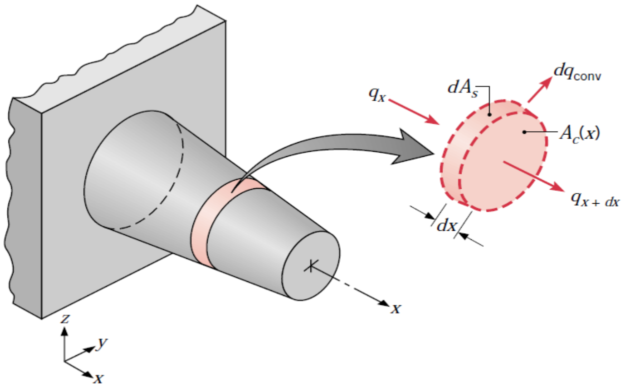

Figure 4. Differentiation of heat conduction with length dx

$$q_x = q_{x+dx} + dq_{conv} \tag{3.7}$$

And Fourier's law of heat conduction:

$$q_x = -kA_c \frac{dT}{dx} \tag{3.8}$$

By applying the Taylor series expansion the above equation becomes:

$$q_{x+dx} = q_x + \frac{dq_x}{dx}dx + \frac{1}{2!}\frac{d^2q_x}{dx^2}dx^2 + \frac{1}{3!}\frac{d^3q_x}{dx^3}dx^3 + \cdots \tag{3.9}$$

From the very small dx approach then $\frac{dT}{dx} \approx 0$ So that we can reduce the value of the Taylor series the third term and so on will be considered to be very small so that the equation above becomes:

$$q_{x+dx} = q_x + \frac{dq_x}{dx}dx$$

$$q_{x+dx} = -kA_c\frac{dT}{dx} - k\frac{d}{dx}\left(A_c\frac{dT}{dx}\right)dx \tag{3.10}$$

By applying heat conduction for convection $dq_{conv} = hdA_s(T - T_\infty)$ so the above equation can be written:

$$\frac{d}{dx}\left(A_c\frac{dT}{dx}\right) - \frac{h}{k}\frac{dA_s}{dx}(T - T_\infty) = 0$$

$$\frac{d^2T}{dx^2} - \frac{hP}{kA_c}(T - T_\infty) = 0 \tag{3.11}$$

The equation above is a harmonic equation with a solution that is solved by:

$$dA_c/_{dx} = P(fin\ perimeter)$$

The perturbation method (Perturbation theory) is a general method for analyzing complex quantum systems in the form of simpler variants. This method relies on expectation values, matrix elements, and overlapping integrals. The perturbation method assumes that the perturbation is a linear algebra with the perturbation itself which can be written as follows:

$$E_n = E_n^{(0)} + \lambda E_n^{(1)} + \lambda^2 E_n^{(2)} + \lambda^3 E_n^{(3)} + \lambda^3 E_n^{(3)} + \cdots \tag{3.12}$$

$$\Psi_n = \Psi_n^{(0)} + \lambda \Psi_n^{(1)} + \lambda^2 \Psi_n^{(2)} + \lambda^3 \Psi_n^{(3)} + \lambda^3 E_n^{(3)} + \cdots \tag{3.13}$$

We can derive a general solution to the Schrodinger equation with a constant Hamiltonian:

$$\frac{\partial}{\partial t}\Psi(t) = -iH\Psi(t) \tag{3.14}$$

After that we can approximate the Taylor series function with t = 0 that:

$$\Psi(t) = \Psi(0) + \left.\frac{\partial \Psi(t)}{\partial t}\right|_{t=0} t + \frac{1}{2}\left.\frac{\partial^2 \Psi(t)}{\partial t^2}\right|_{t=0} t^2 + \frac{1}{6}\left.\frac{\partial^3 \Psi(t)}{\partial t^3}\right|_{t=0} t^3 + \cdots$$

With:

$$\left.\frac{\partial \Psi(t)}{\partial t}\right|_{t=0} = -iH\Psi(t)|_{t=0} = (-iH)\Psi(0) \tag{3.15}$$

$$\left.\frac{\partial^2 \Psi(t)}{\partial t^2}\right|_{t=0} = \left.\frac{\partial\left(-iH\Psi(t)\right)}{\partial t}\right|_{t=0} = (-iH)\left.\frac{\partial^2 \Psi(t)}{\partial t^2}\right|_{t=0} = (-iH)^2\Psi(0)$$

$$\left.\frac{\partial^3 \Psi(t)}{\partial t^3}\right|_{t=0} = \cdots (-iH)^3\Psi(0) \tag{3.16}$$

By entering the equation above, we get the equation:

$$\Psi(t) = \Psi(0) + (-iHt)\Psi(0) + \frac{1}{2}(-iHt)^2\Psi(0) + \frac{1}{6}(-iH)^3\Psi(0) + \cdots$$

$$\Psi(t) = \left[\sum_0^\infty \frac{(-iHt)^n}{n!}\right]\Psi(0) \tag{3.17}$$

To determine the solution to the perturbation method function, we enter a term with a very small perturbation value $(\lambda^2 \approx 0)$ to produce the third term and so on to produce a function value that can be reduced. If we do not limit the perturbation of the third term then there will be inefficiency in the measuring effect of the perturbation (Truchet & Leconte, 2019). This is because this inefficiency causes the value of the function to diverge and have many interpretations. For a particle (m) in a one-dimensional box of length L we define the first perturbation term as the barrier potential V_0 so that the particle energy solution for the first perturbation term is:

$$E_n = E_n^{(0)} + \lambda E_n^{(1)} + \lambda^2 E_n^{(2)} + \lambda^3 E_n^{(3)} + \lambda^3 E_n^{(3)} + \cdots \quad (3.18)$$

$$E_n \approx E_n^{(0)} + E_n^{(1)} \approx \frac{h^2}{8mL^2} n^2 + V_0 \quad (3.19)$$

The implications of this small term reduction provide definite results. The wave function for second order terms and so on can be reduced from the Taylor series.

Taylor series is a function expansion to determine the value of a function around a point. The Taylor series is important because the Taylor series makes it possible to integrate functions that cannot be solved before by expressing them as a power series first, then integrating the series term by term. From the discussion above we can solve analytical physics problems regarding pendulum periods, heat conduction and representation of quantum state functions through perturbation theory. In the case of pendulum motion, oscillatory motion for small deviations $(\theta \approx very\ small)$ is used so that disturbances in the form of friction and damping can be ignored. By applying the θ term to the Taylor series equation (3.3) so that the remaining terms in the series are only the first term and the second term. By relying on this small term, it is used to solve the differential equation (3.5) to find the oscillation period of the pendulum. It is found that the pendulum period for the second term of the Taylor series depends on the length of the pendulum and the strength of the gravitational field, and not on mass. In the case of thermal (heat) conduction, heat flows through a flat metal by fulfilling the zeroth law of thermodynamics and Black's principle. Euler's thermal law is used for heat transfer by conduction. Heat transfer is calculated on an expanded metal plate as in Figure 3. So in this case heat transfer occurs by conduction and convection. The heat transfer function is derived in the Taylor series function (3.9). By taking the principle that heat transfer goes to zero for the heat transfer rate in the third term and so on for the terms of the series, we get the remainder of the Taylor series, namely the first term and the second term.

From the reduction of the smallest term, it is obtained that the equation for the rate of change of temperature over the length of the extension field satisfies the second order harmonic differential equation. From here, the variable separation method equation solution is used to solve the equation. In the case of perturbation theory, we get the quantum state function through the idea of how the function is created within the perturbation parameters. The disturbance functions (3.12) and (3.13) are created in Taylor series so that we can reduce the third term of the series for very small disturbances (Mohiuddin & Saha, 2023). This means that the perturbation function only has physical values in the first and second terms because the third term has a value that is identical to zero.

CONCLUSION AND SUGGESTION

Taylor series is a method of solving problems by expanding a function around a point. The linear combination of Taylor series functions exposes the approximate values of the nth term with the lim $\Delta x \approx 0$ approximation. This results in the third term of the Taylor series having a value so small that it can be ignored. This small term reduction approximation is adopted to solve analytical physics problems. This small term reduction method is spread into problems of mechanics, oscillations, heat, electricity, magnetism and quantum mechanics. The solution in the form of an equation or value from the Taylor series method produces a definite value for a special category. From the results of the analysis of pendulum oscillation problems, thermal conductivity and perturbation quantum state functions, we obtain special solutions for very small reduction term values. Very good for making Taylor series analysis in two-dimensional functions. Whether the resulting solution is exact or not, a parameter approach should be taken.

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