International Journal of Scientific Research in Physics and Applied Sciences
Vol.11, Issue.2, pp.10-14, April 2023
E-ISSN: 2348-3423
Available online at: www.isroset.org

Research Paper

Response of Undamped Oscillators Exposed to Rectangular Pulse Force

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Received: 25/Feb/2023; **Accepted**: 22/Mar/2023; **Published**: 30/Apr/2023

Abstract— In the paper, the response of an undamped or non-damped mechanical oscillator as well as a non-damped electrical oscillator exposed to a rectangular pulse force is obtained by the integral Gupta transform (GT). Generally, this problem has been treated by methods like Calculus or Laplace transforms. Also, some operational properties of the integral GT are discussed. A rectangular pulse force is usually hired for shock loading of short duration. This paper tenders a far-out way for fixing the response of a non-damped mechanical oscillator as well as a non-damped electrical oscillator exposed to a rectangular pulse force and reveals that GT is an effective tool for dealing with such problems

Keywords— Response, Gupta transform, non-damped oscillator, Rectangular pulse.

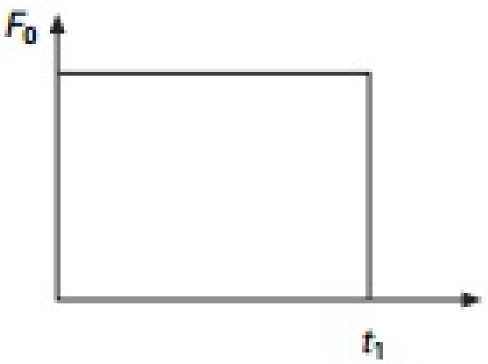
1. Introduction

The rectangular pulse force [1] is written as:

$F(t) = F_o \; for \; t < t_1$

$= 0 \; for \; t \geq t_1.$

The load F_o is immediately put in to the structure and is instantly taken out after a limited time duration t_1 as shown in the figure below.



The integral GT has been submitted by Rahul Gupta and Rohit Gupta in contemporary years and put in to unfold the problems in engineering [2], [3]. This paper tenders a far-out way for fixing the response of a non-damped mechanical oscillator as well as a non-damped electrical oscillator exposed to a rectangular pulse force. In a general sense, methods like the Convolution method [4], integral Laplace transforms [5], Rohit transforms [6], integral Mohand transforms [7], Matrix method [8], integral Aboodh transforms [9], etc. are put in to unfold the problems in engineering. This paper shows beyond doubt the materiality of the for fixing the response of a non-damped mechanical oscillator as well as a non-damped electrical oscillator exposed to a rectangular pulse force. It reveals that GT is an effective tool for fixing the response of a non-damped mechanical oscillator as well as a non-damped electrical oscillator exposed to a rectangular pulse force.

The GT [2] of g(t), t ≥ 0 is specified as $\dot{R}\{g(t)\} = G(p) = \frac{1}{p^3}\int_0^\infty e^{-pt} g(t)dt$. Here, p is a real or complex constant.

The GT of certain chief [3] functions is as follows

- $\dot{R}\{t^n\} = \frac{n!}{p^{n+4}}$, *where* $n = 0,1,2,3 \ldots\ldots\ldots$
- $\dot{R}\{sinat\} = \frac{a}{p^3(p^2+a^2)}, \quad p > 0$
- $\dot{R}\{cosat\} = \frac{1}{p^2(p^2+a^2)}, \quad p > 0$

A unit step function [10] is written as $U(t-d) = 0\ for\ t < d\ and\ 1\ for\ t \geq d$. The GT of a unit step function is specified as

$$\dot{R}\{U(t-d)\} = \frac{1}{p^3}\int_0^{\infty} e^{-pt}U(t-d)dt$$

$$\dot{R}\{U(t-d)\} = \frac{1}{p^3}\int_d^{\infty} e^{-pt}dt$$

$$\dot{R}\{U(t-d)\} = \frac{1}{p^4}e^{-pd}$$

Shifting property of Gupta transform:
If $\dot{R}\{g(t)\} = G(p)$, then $\dot{R}[g(t-d)U(t-d) = e^{-pd}G(p)$.
Proof:

$$\dot{R}[g(t-d)U(t-d)] = \frac{1}{p^3}\int_0^{\infty} e^{-pt}g(t-d)U(t-d)dt$$

$$\dot{R}[g(t-d)U(t-d)] = \frac{1}{p^3}\int_d^{\infty} e^{-pt}g(t-d)dt$$

$$\dot{R}[g(t-d)U(t-d)] = \frac{1}{p^3}\int_0^{\infty} e^{-p(v+d)}g(v)dv,$$

$$where\ v = t-d$$

$$\dot{R}[g(t-d)U(t-d)] = e^{-p(d)}\frac{1}{p^3}\int_0^{\infty} e^{-p(v)}g(v)dv$$

$$\dot{R}[g(t-d)U(t-d)] = e^{-p(d)}\frac{1}{p^3}\int_0^{\infty} e^{-p(t)}g(t)dt$$

$$\dot{R}[g(t-d)U(t-d)] = e^{-pd}G(p)$$

The GT of the first derivative of $g(t)$ is given by

$$\dot{R}\left\{\frac{\partial g(t)}{\partial t}\right\} = \frac{1}{s^3}\int_0^{\infty} e^{-st}\frac{\partial g(t)}{\partial t}dt$$

Here, s is a real or complex constant.

Integrating by parts and applying limits, we get

$$\dot{R}\left\{\frac{\partial g(t)}{\partial t}\right\} = \frac{1}{s^3}\{-g(0) - \int_0^{\infty} -se^{-st}g(t)dt\}$$

$$\dot{R}\left\{\frac{\partial g(t)}{\partial t}\right\} = \frac{1}{s^3}\{-g(0) + s\int_0^{\infty} e^{-st}g(t)dt\}$$

$$\dot{R}\left\{\frac{\partial g(t)}{\partial t}\right\} = sG(s) - \frac{1}{s^3}g(0)$$

Now, replacing $g(t)$ by $\frac{\partial g(t)}{\partial t}$ and $\frac{\partial g(t)}{\partial t}$ by $\frac{\partial^2 g(t)}{\partial t^2}$, we have

$$\dot{R}\left\{\frac{\partial^2 g(t)}{\partial t^2}\right\} = s\dot{R}\left\{\frac{\partial g(t)}{\partial t}\right\} - \frac{1}{s^3}g'(0)$$

$$\dot{R}\left\{\frac{\partial^2 g(t)}{\partial t^2}\right\} = s\left\{s\dot{R}\{g(t)\} - \frac{1}{s^3}g(0)\right\} - \frac{1}{s^3}g'(0)$$

$$\dot{R}\left\{\frac{\partial^2 g(t)}{\partial t^2}\right\} = s^2\dot{R}\{g(t)\} - \frac{1}{s^2}g(0) - \frac{1}{s^3}g'(0)$$

$$\dot{R}\left\{\frac{\partial^2 g(t)}{\partial t^2}\right\} = s^2G(s) - \frac{1}{s^2}g(0) - \frac{1}{s^3}g'(0)$$

and so on.

Hence the GT of some derivatives of g(t) is given by

$$\dot{R}\{g'(t)\} = sG(s) - \frac{1}{s^3}g(0),$$

$\dot{R}\{g''(t)\} = s^2G(s) - \frac{1}{s^2}g(0) - \frac{1}{s^3}g'(0)$ and so on.

2. Methodology

The article is outlined as: First, a brief inception of the RT is laid out. Second, the enactment of the RT to Mechanically Non-damped Oscillator as well as Electrically Non-damped Oscillator is explained. Finally, the argumentation and the deduction are furnished.

2.1 *Mechanically Non-damped Oscillator*

A non-damped mechanical oscillator [10], [11], [12] exposed to a rectangular pulse force is specified by the equation:

$$m\ddot{y}(t) + k\,y(t) = F(t)$$

Or

$$\ddot{y}(t) + \omega_0{}^2 y(t) = \frac{F(t)}{m} \qquad (1)$$

$where\ \omega_0 = \sqrt{\frac{k}{m}}$, $F(t)$ is a rectangular pulse force, y (0) = 0

and $\dot{y}(0) = 0$.

The GT of (1) provides

$$q^2\bar{y}(q) - \frac{1}{q^2}y(0) - \frac{1}{q^3}\dot{y}(0) + \omega_0{}^2\bar{y}(q) = \frac{1}{m}\frac{1}{q^3}\int_0^{\infty} e^{-qt}F(t)\,dt$$

$$\Rightarrow q^2\bar{y}(q) - \frac{1}{q^2}y(0) - \frac{1}{q^3}\dot{y}(0) + \omega_0{}^2\bar{y}(q) = \frac{F_o}{m}\frac{1}{q^3}\int_0^{t_1} e^{-qt}\,dt + \frac{1}{m}\frac{1}{q^3}\int_{t_1}^{\infty} e^{-qt}(0)dt$$

$$\Rightarrow q^2\bar{y}(q) - \frac{1}{q^2}y(0) - \frac{1}{q^3}\dot{y}(0) + \omega_0{}^2\bar{y}(q) = \frac{F_o}{m}\frac{1}{q^3}\int_0^{t_1} e^{-qt}\,dt \qquad (2)$$

Here $\bar{y}(q)$ is the GT of $y(t)$, $y(0) = 0$ and $\dot{y}(0) = 0$.

$$\Rightarrow q^2\bar{y}(q) + \omega_0{}^2\bar{y}(q) = \frac{F_o}{m}\frac{1}{q^3}\int_0^{t_1} e^{-qt}\,dt$$

$$\Rightarrow q^2\bar{y}(q) + \omega_0{}^2\bar{y}(q) = -\frac{1}{q^4}\frac{F_o}{m}[e^{-qt_1} - 1]$$

$$\Rightarrow q^2\bar{y}(q) + \omega_0{}^2\bar{y}(q) = \frac{F_o}{m}\{\frac{1}{q^4} - \frac{1}{q^4}e^{-qt_1}\}$$

$$\Rightarrow \bar{y}(q) = \frac{1}{q^4}\frac{F_o}{m}\{\frac{1}{(q^2+\omega_0{}^2)} - \frac{1}{(q^2+\omega_0{}^2)}e^{-qt_1}\}$$

$$\Rightarrow \bar{y}(q) = \frac{1}{q^2}\frac{F_o}{m}\{\frac{1}{q^2(q^2+\omega_0{}^2)} - \frac{1}{q^2(q^2+\omega_0{}^2)}e^{-qt_1}\}$$

$$\Rightarrow \bar{y}(q) = \frac{1}{q^2}\frac{F_o}{m}\{\frac{1}{(\omega_0{}^2)q^2} - \frac{1}{(\omega_0{}^2)(q^2+\omega_0{}^2)}$$

$$-\frac{1}{(\omega_0^{\,2})\,q^2}+\frac{1}{(\omega_0^{\,2})(q^2+\omega_0^{\,2})}e^{-qt_1}\}$$

$$\Rightarrow \bar{y}(q)=\frac{F_o}{m}\{\frac{1}{(\omega_0^{\,2})\,q^4}-\frac{1}{(\omega_0^{\,2})\,q^2(q^2+\omega_0^{\,2})}-\frac{1}{(\omega_0^{\,2})\,q^4}+\frac{1}{(\omega_0^{\,2})\,q^2(q^2+\omega_0^{\,2})}e^{-qt_1}\}$$

Taking inverse GT, we have

$$y(t)=\frac{F_o}{m}\{\frac{1}{(\omega_0^{\,2})}-\frac{\cos\omega_0 t}{(\omega_0^{\,2})}-\frac{1}{(\omega_0^{\,2})}U(t-t_1)+\frac{\cos\omega_0(t-t_1)}{(\omega_0^{\,2})}U(t-t_1)\}$$

$$\Rightarrow y(t)=\frac{F_o}{m(\omega_0^{\,2})}\left\{\begin{matrix}1-\cos\omega_0 t-U(t-t_1)\\ +\cos\omega_0 t\,U(t-t_1)\end{matrix}\right\}$$

$$\Rightarrow y(t)=\frac{F_o}{k}\left\{\begin{matrix}1-\cos\omega_0 t-U(t-t_1)\\ +\cos\omega_0 t\,U(t-t_1)\end{matrix}\right\} \qquad (3)$$

For t < t_1,

$$y(t)=\frac{F_o}{k}\{1-\cos\omega_0 t\} \qquad (4a)$$

Taking F_o = 1000N, k = 10000N/m and ω_0=314rad/s, the graphs of (4a) is shown in the figure 1.

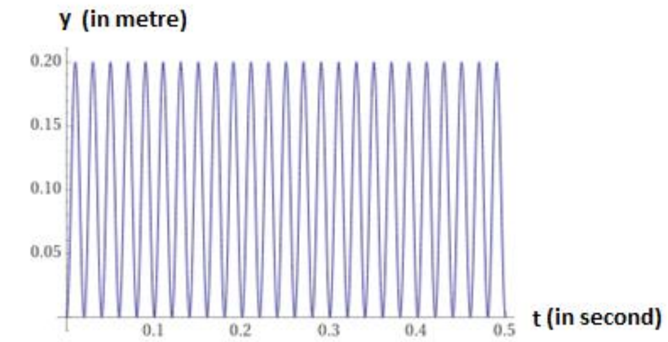


Figure 1

For t > t_1,

$$y(t)=\frac{F_o}{k}\{-\cos\omega_0 t+\cos\omega_0(t-t_1)\} \qquad (4b)$$

Taking F_o = 1000N, k = 10000N/m, t_1 = 0.5s and ω_0=314rad/s, the graphs of (4b) is shown in the figure 2.

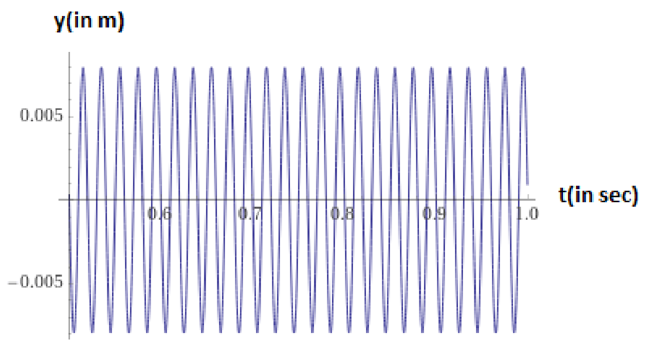


Figure 2

2.2 *Electrically Non-damped Oscillator*

The non-damped electrical oscillator exposed to a rectangular pulse potential [13], [14], [15] is specified by the equation:

$$L\ddot{Q}(t)+\frac{1}{C}Q(t)=V(t)$$

Or

$$\ddot{Q}(t)+\omega_0^{\,2}Q(t)=\frac{V(t)}{L} \qquad (5)$$

$where\ \omega_0=\sqrt{\frac{1}{LC}}$, V(t) is a rectangular pulse potential, Q (0) = 0 and $\dot{Q}(0)=0$.

The GT of (1) provides

$$q^2\bar{Q}(q)-\frac{1}{q^2}Q(0)-\frac{1}{q^3}\dot{Q}(0)+\omega_0^{\,2}\bar{Q}(q)=\frac{1}{L}\frac{1}{q^3}\int_0^\infty e^{-qt}\,V(t)\,dt$$

$$\Rightarrow q^2\bar{Q}(q)-\frac{1}{q^2}Q(0)-\frac{1}{q^3}\dot{Q}(0)+\omega_0^{\,2}\bar{Q}(q)=\frac{V_o}{L}\frac{1}{q^3}\int_0^{t_1}e^{-qt}\,dt+\frac{1}{L}\frac{1}{q^3}\int_{t_1}^\infty e^{-qt}\,(0)dt$$

$$\Rightarrow q^2\bar{Q}(q)-\frac{1}{q^2}Q(0)-\frac{1}{q^3}\dot{Q}(0)+\omega_0^{\,2}\bar{Q}(q)=\frac{V_o}{L}\frac{1}{q^3}\int_0^{t_1}e^{-qt}\,dt \qquad (6)$$

Here $\bar{Q}(q)$ is the GT of $Q(t)$ and $Q(0)=0$ and $\dot{Q}(0)=0$.

$$\Rightarrow q^2\bar{Q}(q)+\omega_0^{\,2}\bar{Q}(q)=\frac{V_o}{L}\frac{1}{q^3}\int_0^{t_1}e^{-qt}\,dt$$

$$\Rightarrow q^2\bar{Q}(q)+\omega_0^{\,2}\bar{Q}(q)=-\frac{1}{q^4}\frac{V_o}{L}[e^{-qt_1}-1]\}$$

$$\Rightarrow q^2\bar{Q}(q)+\omega_0^{\,2}\bar{Q}(q)=\frac{V_o}{L}\{\frac{1}{q^4}-\frac{1}{q^4}e^{-qt_1}\}$$

$$\Rightarrow \bar{Q}(q)=\frac{1}{q^4}\frac{V_o}{L}\{\frac{1}{(q^2+\omega_0^{\,2})}-\frac{1}{(q^2+\omega_0^{\,2})}e^{-qt_1}\}$$

$$\Rightarrow \bar{Q}(q)=\frac{1}{q^2}\frac{V_o}{L}\{\frac{1}{q^2(q^2+\omega_0^{\,2})}-\frac{1}{q^2(q^2+\omega_0^{\,2})}e^{-qt_1}\}$$

$$\Rightarrow \bar{Q}(q)=\frac{1}{q^2}\frac{V_o}{L}\{\frac{1}{(\omega_0^{\,2})\,q^2}-\frac{1}{(\omega_0^{\,2})(q^2+\omega_0^{\,2})}-\frac{1}{(\omega_0^{\,2})\,q^2}+\frac{1}{(\omega_0^{\,2})(q^2+\omega_0^{\,2})}e^{-qt_1}\}$$

$$\Rightarrow \bar{Q}(q)=\frac{V_o}{L}\{\frac{1}{(\omega_0^{\,2})\,q^4}-\frac{1}{(\omega_0^{\,2})\,q^2(q^2+\omega_0^{\,2})}-\frac{1}{(\omega_0^{\,2})\,q^4}+\frac{1}{(\omega_0^{\,2})\,q^2(q^2+\omega_0^{\,2})}e^{-qt_1}\}$$

Taking inverse GT, we have

$$Q(t)=\frac{V_o}{L}\{\frac{1}{(\omega_0^{\,2})}-\frac{\cos\omega t}{(\omega_0^{\,2})}-\frac{1}{(\omega_0^{\,2})}U(t-t_1)+\frac{\cos\omega(t-t_1)}{(\omega_0^{\,2})}U(t-t_1)\}$$

$$\Rightarrow Q(t) = \frac{V_o}{L(\omega_0{}^2)}\{1 - \cos\omega_0 t - U(t - t_1) + \cos\omega_0 (t - t_1) U(t - t_1)\}$$

$$\Rightarrow Q(t) = V_o C \left\{ \begin{array}{c} 1 - \cos\omega_0 t - U(t - t_1) \\ + \cos\omega_0 (t - t_1) U(t - t_1) \end{array} \right\} \quad (6)$$

For t < t_1,

$$Q(t) = V_o C\{1 - \cos\omega_0 t\} \quad (7a)$$

Taking V_o = 230V, C = 1000 microfarad and ω_0=314rad/s, the graph of (7a) is shown in the figure 3.

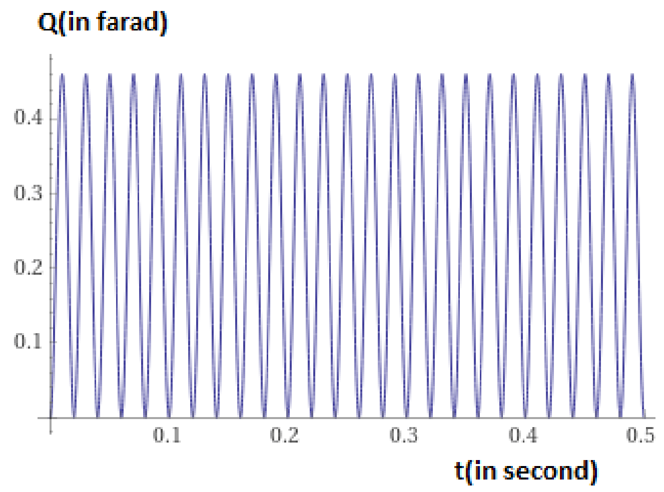


Figure 3

For t > t_1,

$$Q(t) = V_o C\{-\cos\omega_0 t + \cos\omega_0 (t - t_1)\} \quad (7b)$$

Taking V_o = 230V, C = 1 microfarad, t_1 = 0.5s and ω_0=314rad/s, the graphs of (7b) is shown in the figure 4.

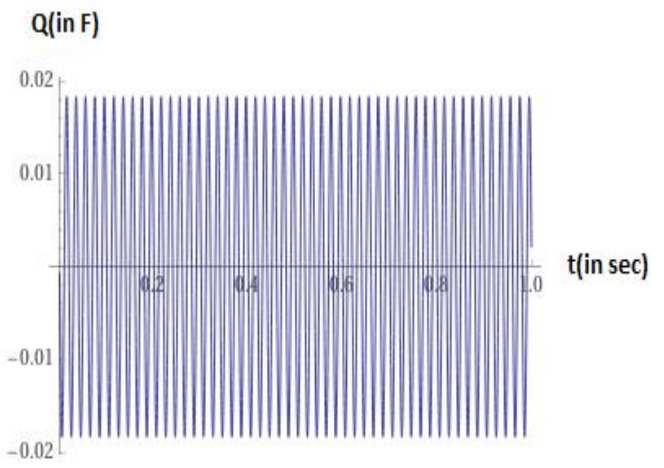


Figure 4

3. Results and Discussion

In the paper, the response of a non-damped mechanical oscillator as well as a non-damped electrical oscillator exposed to a rectangular pulse force has been fortuitously fixed by the integral Gupta transform (GT). The paper embellished the GT for fixing the response of a non-damped mechanical oscillator as well as a non-damped electrical oscillator exposed to a rectangular pulse force. In case of Mechanically Non-damped Oscillator, it is clear that before the removal of rectangular pulse, the response (displacement) of the oscillator increases and decreases periodically with constant amplitude as shown in the figure 1, but when we remove the rectangular pulse, the response becomes oscillatory with constant amplitude as shown in the figure 2. Also, in case of Electrically Non-damped Oscillator, it is clear that before the removal of rectangular pulse, the response (electric charge) of the oscillator increases and decreases periodically with constant amplitude as shown in the figure 3, but when we remove the rectangular pulse, the response becomes oscillatory with constant amplitude as shown in the figure 4. The results fixed are the same as fixed with other methods.

4. Conclusion and Future Scope

The paper has tendered a far-out way for fixing the response of a non-damped mechanical oscillator as well as a non-damped electrical oscillator exposed to a rectangular pulse force and reveals that GT is an effective tool for figuring out such problems.

Conflict of Interest
It is declared by the authors that there is no conflict of interest.

Funding Source
There is no source of funding.

Authors' Contributions
All authors reviewed and edited the manuscript and approved the final version of the manuscript.

Acknowledgments
The authors would like to thank Dr. Dinesh Verma, Professor, Department of Mathematics, NIILM University Kaithal, (Haryana) India.

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