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# Transient and Steady State Response Formulas

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# List of 19 Transient and Steady State Response Formulas

## Transient and Steady State Response

### Second Order System

#### 1) Delay Time

$$\text{fx } t_d = \frac{1 + (0.7 \cdot \zeta)}{\omega_n}$$

[Open Calculator !\[\]\(de95854c7ee024cfadc48187bbb781b2\_img.jpg\)](#)

$$\text{ex } 0.046522\text{s} = \frac{1 + (0.7 \cdot 0.1)}{23\text{Hz}}$$

#### 2) First Peak Overshoot

$$\text{fx } M_o = e^{-\frac{\pi \cdot \zeta}{\sqrt{1-\zeta^2}}}$$

[Open Calculator !\[\]\(6a9b39b98eb945faa14c645ec99e4eaa\_img.jpg\)](#)

$$\text{ex } 0.729248 = e^{-\frac{\pi \cdot 0.1}{\sqrt{1-(0.1)^2}}}$$


#### 3) First Peak Undershoot

$$\text{fx } M_u = e^{-\frac{2 \cdot \zeta \cdot \pi}{\sqrt{1-\zeta^2}}}$$

[Open Calculator !\[\]\(f1c5da15572e3e09d343161be98f508d\_img.jpg\)](#)

$$\text{ex } 0.531802 = e^{-\frac{2 \cdot 0.1 \cdot \pi}{\sqrt{1-(0.1)^2}}}$$



4) Number of Oscillations 

$$fx \quad n = \frac{t_s \cdot \omega_d}{2 \cdot \pi}$$

Open Calculator 

$$ex \quad 6.365281Hz = \frac{1.748s \cdot 22.88Hz}{2 \cdot \pi}$$

5) Peak Time 

$$fx \quad t_p = \frac{\pi}{\omega_d}$$

Open Calculator 

$$ex \quad 0.137307s = \frac{\pi}{22.88Hz}$$

6) Peak Time given Damping Ratio 

$$fx \quad t_p = \frac{\pi}{\omega_n \cdot \sqrt{1 - \zeta^2}}$$

Open Calculator 

$$ex \quad 0.137279s = \frac{\pi}{23Hz \cdot \sqrt{1 - (0.1)^2}}$$

7) Rise Time given Damped Natural Frequency 

$$fx \quad t_r = \frac{\pi - \Phi}{\omega_d}$$

Open Calculator 

$$ex \quad 0.125507s = \frac{\pi - 0.27rad}{22.88Hz}$$



8) Rise Time given Damping Ratio Open Calculator 


$$fx \quad t_r = \frac{\pi - \left(\Phi \cdot \frac{\pi}{180}\right)}{\omega_n \cdot \sqrt{1 - \zeta^2}}$$

$$ex \quad 0.137073s = \frac{\pi - \left(0.27\text{rad} \cdot \frac{\pi}{180}\right)}{23\text{Hz} \cdot \sqrt{1 - (0.1)^2}}$$

9) Rise Time given Delay Time Open Calculator 

$$fx \quad t_r = 1.5 \cdot t_d$$

$$ex \quad 0.06s = 1.5 \cdot 0.04s$$

10) Setting Time when Tolerance is 2 Percent Open Calculator 

$$fx \quad t_s = \frac{4}{\zeta \cdot \omega_d}$$

$$ex \quad 1.748252s = \frac{4}{0.1 \cdot 22.88\text{Hz}}$$

11) Setting Time when Tolerance is 5 Percent Open Calculator 

$$fx \quad t_s = \frac{3}{\zeta \cdot \omega_d}$$

$$ex \quad 1.311189s = \frac{3}{0.1 \cdot 22.88\text{Hz}}$$



## 12) Time of Peak Overshoot in Second Order System

$$fx \quad T_{po} = \frac{(2 \cdot k - 1) \cdot \pi}{\omega_d}$$

[Open Calculator !\[\]\(e2376d476d06eb31946dc01a69a4403a\_img.jpg\)](#)

$$ex \quad 1.235766s = \frac{(2 \cdot 5 - 1) \cdot \pi}{22.88Hz}$$

## 13) Time Period of Oscillations

$$fx \quad T = \frac{2 \cdot \pi}{\omega_d}$$

[Open Calculator !\[\]\(0b5e7e25e8775f7e7e80906ada4f0021\_img.jpg\)](#)

$$ex \quad 0.274615s = \frac{2 \cdot \pi}{22.88Hz}$$

## 14) Time Response in Overdamped Case

**fx**
[Open Calculator !\[\]\(bd3b31712ad9bab5a241210fa6925cdd\_img.jpg\)](#)

$$C_t = 1 - \left( \frac{e^{-\left(\zeta_{over} - \left(\sqrt{\left(\zeta_{over}^2\right) - 1}\right)\right) \cdot (\omega_n \cdot T)}}{2 \cdot \sqrt{\left(\zeta_{over}^2\right) - 1} \cdot \left(\zeta_{over} - \sqrt{\left(\zeta_{over}^2\right) - 1}\right)} \right)$$

**ex**

$$0.807466 = 1 - \left( \frac{e^{-\left(1.12 - \left(\sqrt{\left((1.12)^2\right) - 1}\right)\right) \cdot (23Hz \cdot 0.15s)}}{2 \cdot \sqrt{\left((1.12)^2\right) - 1} \cdot \left(1.12 - \sqrt{\left((1.12)^2\right) - 1}\right)} \right)$$



15) Time Response in Undamped Case 

$$fx \quad C_t = 1 - \cos(\omega_n \cdot T)$$

[Open Calculator !\[\]\(d3fb9f94af8b26d1c844efa9a98805b0\_img.jpg\)](#)


$$ex \quad 1.952818 = 1 - \cos(23\text{Hz} \cdot 0.15\text{s})$$

16) Time Response of Critically Damped System 

$$fx \quad C_t = 1 - e^{-\omega_n \cdot T} - \left( e^{-\omega_n \cdot T} \cdot \omega_n \cdot T \right)$$

[Open Calculator !\[\]\(e1d6102fe77919492c04879c8450f1f5\_img.jpg\)](#)


$$ex \quad 0.858732 = 1 - e^{-23\text{Hz} \cdot 0.15\text{s}} - \left( e^{-23\text{Hz} \cdot 0.15\text{s}} \cdot 23\text{Hz} \cdot 0.15\text{s} \right)$$

Steady State Error 17) Steady State Error for Type 1 System 

$$fx \quad e_{ss} = \frac{A}{K_v}$$

[Open Calculator !\[\]\(104fbf564e2e5a8fbd84f31656d114c7\_img.jpg\)](#)

$$ex \quad 0.064516 = \frac{2}{31}$$

18) Steady State Error for Type 2 System 

$$fx \quad e_{ss} = \frac{A}{K_a}$$

[Open Calculator !\[\]\(21226b58c700e5231ab98d27101bac58\_img.jpg\)](#)

$$ex \quad 0.060606 = \frac{2}{33}$$



## 19) Steady State Error for Type Zero System

[Open Calculator !\[\]\(feabb98897b440bc8695a03336a6e2df\_img.jpg\)](#)

$$\text{fx } e_{ss} = \frac{A}{1 + K_p}$$

$$\text{ex } 0.060606 = \frac{2}{1 + 32}$$






## Variables Used

- **A** Coefficient Value
- **C<sub>t</sub>** Time Response for Second Order System
- **e<sub>SS</sub>** Steady State Error
- **k** Kth Value
- **K<sub>a</sub>** Acceleration Error Constant
- **K<sub>p</sub>** Position of Error Constant
- **K<sub>v</sub>** Velocity Error Constant
- **M<sub>o</sub>** Peak Overshoot
- **M<sub>u</sub>** Peak Undershoot
- **n** Number of Oscillations (*Hertz*)
- **T** Time Period for Oscillations (*Second*)
- **t<sub>d</sub>** Delay Time (*Second*)
- **t<sub>p</sub>** Peak Time (*Second*)
- **T<sub>po</sub>** Time of Peak Overshoot (*Second*)
- **t<sub>r</sub>** Rise Time (*Second*)
- **t<sub>s</sub>** Setting Time (*Second*)
- **ζ** Damping Ratio
- **ζ<sub>over</sub>** Overdamping Ratio
- **Φ** Phase Shift (*Radian*)
- **ω<sub>d</sub>** Damped Natural Frequency (*Hertz*)
- **ω<sub>n</sub>** Natural Frequency of Oscillation (*Hertz*)





## Constants, Functions, Measurements used

- **Constant:** **pi**, 3.14159265358979323846264338327950288  
*Archimedes' constant*
- **Constant:** **e**, 2.71828182845904523536028747135266249  
*Napier's constant*
- **Function:** **cos**,  $\cos(\text{Angle})$   
*Cosine of an angle is the ratio of the side adjacent to the angle to the hypotenuse of the triangle.*
- **Function:** **sqrt**,  $\text{sqrt}(\text{Number})$   
*A square root function is a function that takes a non-negative number as an input and returns the square root of the given input number.*
- **Measurement:** **Time** in Second (s)  
*Time Unit Conversion* 
- **Measurement:** **Angle** in Radian (rad)  
*Angle Unit Conversion* 
- **Measurement:** **Frequency** in Hertz (Hz)  
*Frequency Unit Conversion* 



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