

Numerical Methods for Engineers (7th Edition)

Chapter 1, Problem 18P

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Step-by-step solution

Step 1 of 8

The velocity is specified as the equal to rate of change in distance $x(m)$. The equation P1.19 in the problem is specified as:

$$\frac{dx}{dt} = v(t)$$

Now substituting equation 1.10 into equation P1.19, which is given as:

$$v(t) = \frac{gm}{c} \left(1 - e^{-(c/m)t} \right)$$

After substituting the above equation in P1.19, the equation can be manipulate as:

$$\frac{dx}{dt} = \frac{gm}{c} \left(1 - e^{-(c/m)t} \right)$$

Now, following process solve it analytically:

$$\frac{dx}{dt} = \frac{gm}{c} \left(1 - e^{-(c/m)t} \right)$$
$$\int_0^{10} dx = \frac{gm}{c} \int_0^{10} \left(1 - e^{-(c/m)t} \right) dt$$
$$x = \frac{gm}{c} \left[t + \frac{m}{c} e^{-(c/m)t} \right]_{t=0}^{t=10}$$

Further, it can be written as:

$$x = \frac{gm}{c} \left[t + \frac{m}{c} e^{-(c/m)t} - \frac{m}{c} \right]$$
$$x = \frac{gm}{c} \left[t + \frac{m}{c} \left(e^{-(c/m)t} - 1 \right) \right]$$

Comment

Step 2 of 8

For the problem specification, consider the following equation 1.9 and solve it as an example 1.2:

$$\frac{dv}{dt} = g - \frac{c}{m} v$$

Now apply the Euler's approach to solve the first step for $t=0$ (starting from zero) and for next steps employ the time size two:

$$\frac{dv}{dt}(0) = g - \frac{c}{m} v$$
$$= 9.8 - \frac{12.5}{68.1} 0$$
$$= 9.8$$
$$\frac{dx}{dt}(0) = v$$
$$= 0$$

Now,

$$v(2) = v(0) + \frac{dv}{dt}(0) \Delta t$$
$$= 0 + 9.8(2)$$
$$= 19.6$$
$$x(2) = x(0) + \frac{dx}{dt}(0) \Delta t$$
$$= 0 + 0(2)$$
$$= 0$$

Now apply the Euler's approach to solve the second step:

$$\frac{dv}{dt}(2) = g - \frac{c}{m} v$$
$$= 9.8 - \frac{12.5}{68.1} 19.6$$
$$= 6.2023$$
$$\frac{dx}{dt}(2) = 19.6$$

Now,

$$v(4) = 19.6 + 6.2023(2)$$
$$= 32.0047$$
$$x(4) = 0 + 19.6(2)$$
$$= 39.2$$

Thus, it can be solved using Euler's method in similar fashion till the time = 10. The complete solution can be summarized in the below table:

Time (t)	x	v	dx/dt	dv/dt
0	0	0	0.0	9.8
2	0	19.6	19.6	6.2
4	39.2	32.0	32.0	3.9
6	103.2	39.8	39.8	2.4
8	182.9	44.8	44.8	1.57
10	272.5	47.9	47.9	0.99

The Matlab code for the above generated table is written as:

```
% initialize the variable value
v=0;
x=0;
g=9.8;
```

Comment

Step 3 of 8

```
c=12.5;
m=68.1;
dv=9.8;
dx=0;

% define the time step size
time_step=2;

% initialize the time size
time=10;
dist=zeros(1,10);

% calculate the computation numbers
number_of_computations=time/time_step;
for i=1:number_of_computations
    % calculate the v
    v=v+(g-c*v/m)*time_step;
    % calculate dv
    dv=(g-c*v/m);
    % calculate the distance
    x=x+v*time_step;
    % calculate the dx
    dx=v;

    % print the result
    v,dx,dx
end
```

Comment

Step 4 of 8

The analytical solution can be done using the following procedure. First, solve velocity with respect to time.

Solve velocity with respect to time:

$$\frac{dv}{dt} = g - \frac{c}{m} v$$
$$\int_{-\infty}^t \frac{dv}{g - \frac{c}{m} v} = \int_{-\infty}^t dt$$
$$\left[-\frac{m}{c} \log \left(g - \frac{c}{m} v \right) \right]_{-\infty}^t = t$$
$$-\frac{m}{c} \left(\log \left(1 - \frac{c}{mg} v \right) \right) = t$$
$$1 - \frac{c}{mg} v = e^{-\left(\frac{c}{m} t \right)}$$
$$v = g - \frac{mg}{c} e^{-\left(\frac{c}{m} t \right)}$$

For first step (t=0):

$$v(0) = g - \frac{mg}{c} e^{-\left(\frac{c}{m} t \right)}$$
$$= 9.8 - \frac{68.1}{12.5} 12.5 e^{-\left(\frac{12.5}{68.1} t \right)}$$
$$= 0$$

For Second Step (t=2):

$$v(2) = g - \frac{mg}{c} e^{-\left(\frac{c}{m} t \right)}$$
$$= 9.8 - \frac{68.1}{12.5} 12.5 e^{-\left(\frac{12.5}{68.1} t \right)}$$
$$= 16.4$$

Comment

Step 5 of 8

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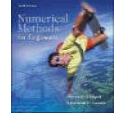
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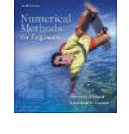
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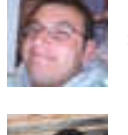
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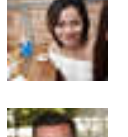
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$$\begin{aligned} \frac{dx}{dt} &= v \\ \frac{dx}{dt} &= \frac{gm}{c} - \frac{gm}{c} e^{-\left(\frac{c}{m}\right)t} \\ \int dx &= \int \left(\frac{gm}{c} - \frac{gm}{c} e^{-\left(\frac{c}{m}\right)t} \right) dt \\ x &= \frac{gm}{c} t - \frac{gm^2}{c^2} \left(1 - e^{-\left(\frac{c}{m}\right)t} \right) \end{aligned}$$

For first step (t=0):

$$\begin{aligned} xu(0) &= \frac{gm}{c} t - \frac{gm^2}{c^2} \left(1 - e^{-\left(\frac{c}{m}\right)t} \right) \\ &= \frac{9.8 \times 68.1 \times 0}{12.5} - \frac{9.8 \times 68.1 \times 68.1}{12.5 \times 12.5} \left(1 - e^{-\left(\frac{12.5}{68.1}\right)0} \right) \\ &= 0 \end{aligned}$$

For first step (t=2):

$$\begin{aligned} xu(2) &= \frac{gm}{c} t - \frac{gm^2}{c^2} \left(1 - e^{-\left(\frac{c}{m}\right)t} \right) \\ &= \frac{9.8 \times 68.1 \times 2}{12.5} - \frac{9.8 \times 68.1 \times 68.1}{12.5 \times 12.5} \left(1 - e^{-\left(\frac{12.5}{68.1}\right)2} \right) \\ &= 17.4 \end{aligned}$$

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Step 6 of 8

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Step 7 of 8

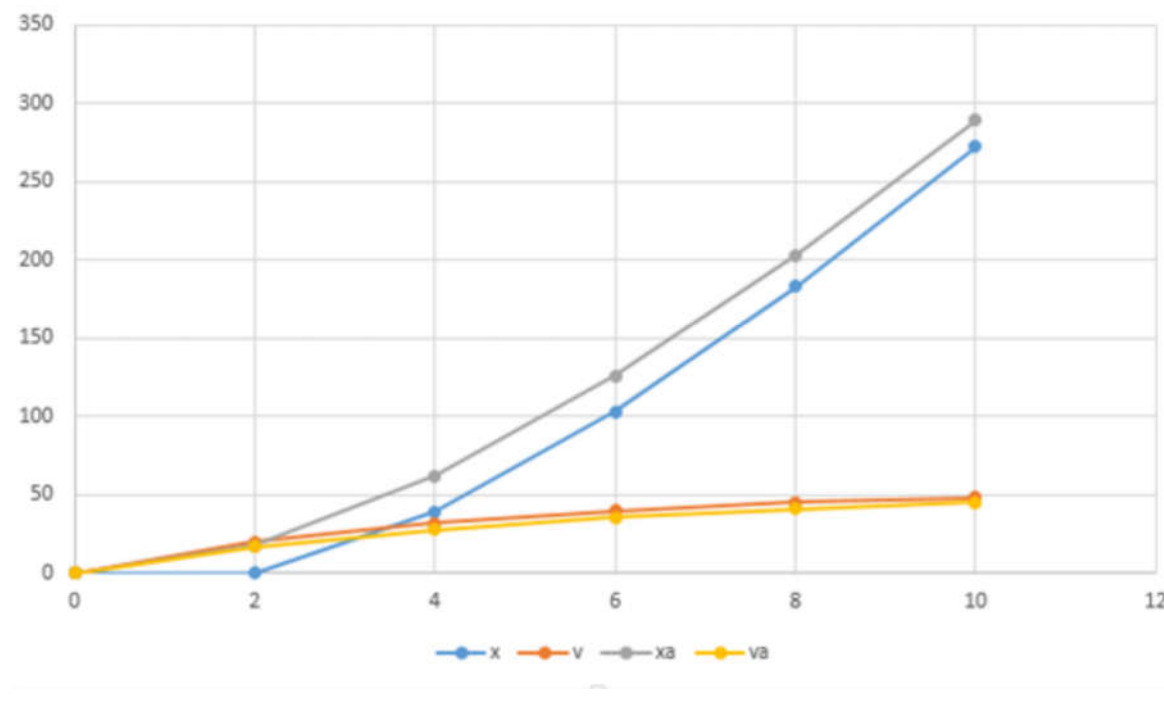
Thus, Analytical solution can be calculated in similar fashion till the time (t) = 10 for xa and va. The complete solution can be summarized in the below table:

Time (t)	x	v	dx/dt	dv/dt	xa	va
0	0	0	0.0	9.8	0.0	0.0
2	0	19.6	19.6	6.2	17.4	16.4
4	39.2	32.0	32.0	3.9	62.2	27.76
6	103.2	39.8	39.8	2.4	126.1	35.6
8	182.9	44.8	44.8	1.57	203.2	41.0
10	272.5	47.9	47.9	0.99	289.4	44.8

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Step 8 of 8

On the basis of above calculated data, the plot of this complete solution can be drawn as:



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