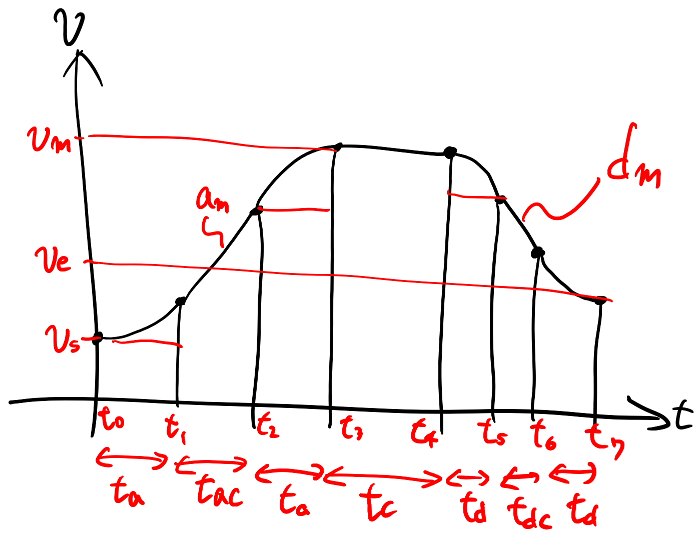


$$v_0 = v_s$$
$$v_{01} = v_s + \frac{1}{2t_a} a_m (t-t_0)^2$$
$$v_1 = v_s + \frac{1}{2} a_m t_a$$
$$v_{12} = v_s + \frac{1}{2} a_m t_a + a_m (t-t_1)$$
$$v_2 = v_s + \frac{1}{2} a_m t_a + a_m t_{ac}$$
$$v_{23} = v_2 - \frac{1}{2t_a} a_m (t-t_3)^2 + \frac{1}{2} a_m t_a$$
$$v_3 = v_s + a_m t_a + a_m t_{ac} = v_m$$
$$v_4 = v_m$$

〈$t_c=0$として, v_mを算出する〉

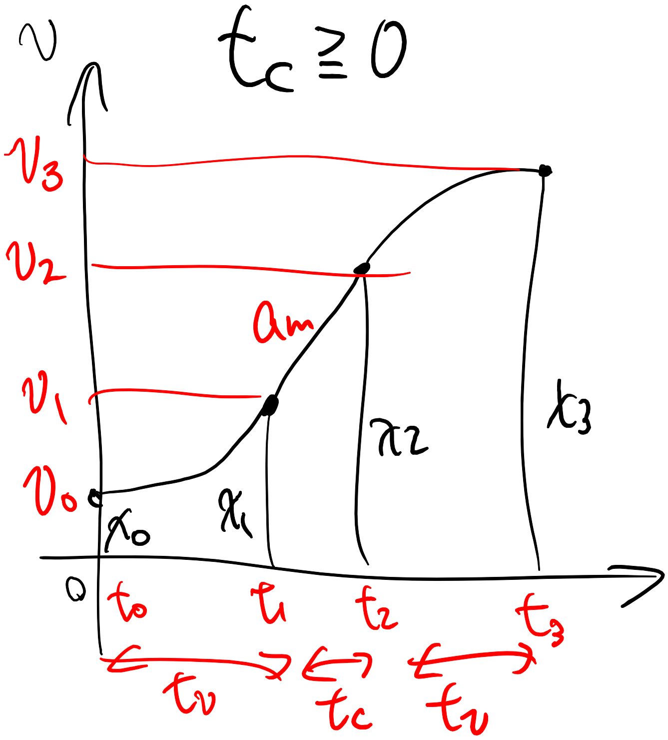
$$x = \frac{1}{2}(v_s + v_m)\left(t_v + \frac{v_m - v_s}{a_m}\right) + \frac{1}{2}(v_m + v_e)\left(t_v + \frac{v_m - v_e}{a_m}\right)$$

$$\begin{aligned}
2a_m x &= (v_m + v_s)(v_m - v_s + a_m t_v) + (v_m + v_e)(v_m - v_e + a_m t_v) \\
&= v_m^2 + (\cancel{v_s} - \cancel{v_s} + a_m t_v) v_m + v_s(-v_s + a_m t_v) \\
&\quad\; v_m^2 + (\cancel{v_e} - \cancel{v_e} + a_m t_v) v_m + v_e(-v_e + a_m t_v) \\
&= 2v_m^2 + 2a_m t_v v_m - (v_s^2 + v_e^2) + (v_s + v_e) a_m t_v
\end{aligned}$$

$$\Leftrightarrow \; 2v_m^2 + 2a_m t_v v_m + (v_s + v_e) a_m t_v - 2a_m x - (v_s^2 + v_e^2) = 0$$

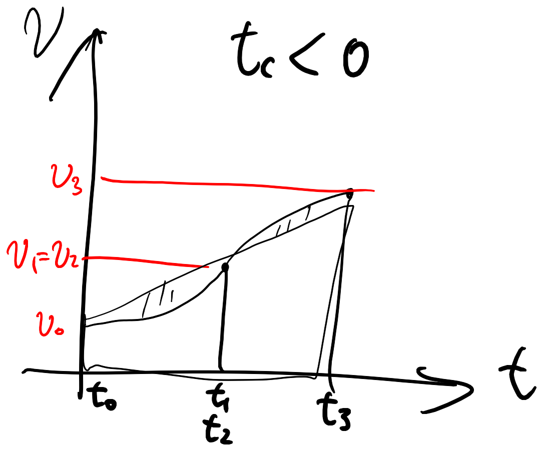
$$v_m = \frac{-a_m t_v \pm \sqrt{a_m^2 t_v^2 - 2(v_s + v_e) a_m t_v + 4a_m x + 2(v_s^2 + v_e^2)}}{2}$$

$t_c \geqq 0$



$$v_0 = v_s$$
$$v_{01} = v_0 + \frac{1}{2t_v} a_m (t-t_0)^2$$
$$v_1 = v_0 + \frac{1}{2} a_m t_v$$
$$v_{12} = v_1 + a_m (t-t_1)$$
$$v_2 = v_1 + a_m t_c = v_0 + \frac{1}{2} a_m t_v + a_m t_c$$
$$v_{23} = v_2 - \frac{1}{2t_v} a_m (t-t_3)^2 + \frac{1}{2} a_m t_v$$
$$= v_0 + a_m t_v + a_m t_c - \frac{1}{2t_v} a_m (t-t_3)^2$$
$$v_3 = v_0 + a_m t_v + a_m t_c$$
$$\Longleftrightarrow \quad t_c = \frac{v_3 - v_0}{a_m} - t_v \quad //$$

$t_c < 0$



$t_c < 0$ のとき, $t_1 = t_2$

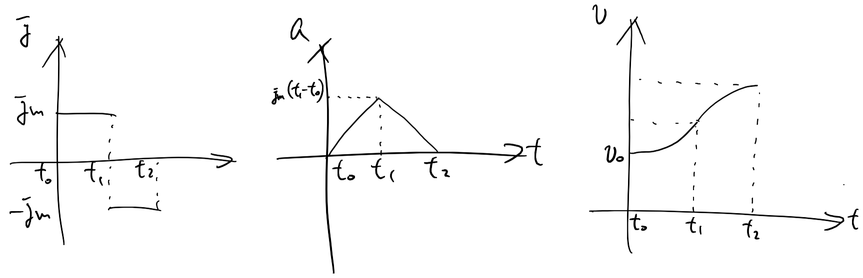
$$v_1 = v_2 = v_0 + \frac{1}{2t_v} a_m (t_1 - t_0)^2 = \frac{1}{2}(v_0 + v_3)$$
$$\Longleftrightarrow \quad t_1 = t_2 = t_0 + \sqrt{\frac{t_v}{a_m}(v_3 - v_0)} \quad //$$

$$x_3 - x_0 = \frac{1}{2}(v_0 + v_3)(t_v + t_c + t_v)$$
$$= \frac{1}{2}(v_0 + v_3)\left(t_v + \frac{v_3 - v_0}{a_m}\right)$$
$$d = \sqrt{\frac{t_v}{a_m}(v_3 - v_0)} \; (v_0 + v_3)$$
$$\frac{a_m d^2}{t_v} = (v_3 - v_0)(v_3 + v_0)^2 = (v_3^2 - v_0^2)(v_3 + v_0)$$
$$v_3^3 + v_0 v_3^2 - v_0^2 v_3 - v_0^3 - \frac{a_m d^2}{t_v} = 0$$

$$
\begin{cases}
v_0 = v_s \\
v_{01} = v_0 + \frac{1}{2t_v} a_m (t - t_0)^2 \\
v_1 = v_0 + \frac{1}{2} a_m t_v \\
v_{12} = v_1 + a_m (t - t_1) \\
v_2 = v_1 + a_m t_c = v_0 + \frac{1}{2} a_m t_v + a_m t_c \\
v_{23} = v_2 - \frac{1}{2t_v} a_m (t - t_3)^2 + \frac{1}{2} a_m t_v \\
\quad = v_0 + a_m t_v + a_m t_c - \frac{1}{2t_v} a_m (t - t_3)^2 \\
v_3 = v_0 + a_m t_v + a_m t_c
\end{cases}
$$

$$
\begin{cases}
x_0 = x_0 \\
x_{01} = x_0 + \int_{t_0}^{t} v_{01}(t)\,dt = x_0 + \left[v_0 t + \frac{1}{6t_v} a_m (t - t_0)^3 \right]_{t_0}^{t} = x_0 + v_0 (t - t_0) + \frac{1}{6t_v} a_m (t - t_0)^3 \\
x_1 = x_0 + v_0 (t_1 - t_0) + \frac{1}{6t_v} a_m (t_1 - t_0)^3 \\
x_{12} = x_1 + \int_{t_1}^{t} \left\{ v_1 + a_m (t - t_1) \right\} dt = x_1 + \left[v_1 t + \frac{a_m}{2} (t - t_1)^2 \right]_{t_1}^{t} \\
\quad = x_1 + v_1 (t - t_1) + \frac{1}{2} a_m (t - t_1)^2 \\
x_2 = x_1 + v_1 (t_2 - t_1) + \frac{1}{2} a_m (t_2 - t_1)^2 \\
x_{23} = x_2 + \int_{t_2}^{t} \left\{ v_0 + a_m (t_v + t_c) - \frac{1}{2t_v} a_m (t - t_3)^2 \right\} dt \\
\quad = x_2 + \left\{ v_0 + a_m (t_v + t_c) \right\} (t - t_2) - \frac{1}{6t_v} a_m (t_2 - t_3)^3 \\
\qquad + \frac{1}{6t_v} a_m (t - t_3)^3 \\
x_3 = x_2 + \left\{ v_0 + a_m (t_v + t_c) \right\} (t_3 - t_2) - \frac{1}{6t_v} a_m (t_2 - t_3)^3
\end{cases}
$$

〈曲線→曲線〉



$t_0 \le t \le t_1$, $t_1 \le t \le t_2$

$$
\begin{cases}
j(t) = j_m \\
a(t) = \cancel{a(t_0)} + \int_{t_0}^{t} j\,dt \\
\quad = j_m(t-t_0) \\
v(t) = v(t_0) + \int_{t_0}^{t_1} a\,dt \\
\quad = v_0 + \left[\frac{1}{2} j_m (t-t_0)^2\right]_{t_0}^{t} \\
\quad = v_0 + \frac{1}{2} j_m (t-t_0)^2 \\
x(t) = x(t_0) + \int_{t_0}^{t} v\,dt \\
\quad = x_0 + v_0(t-t_0) + \frac{1}{6} j_m (t-t_0)^3
\end{cases}
$$

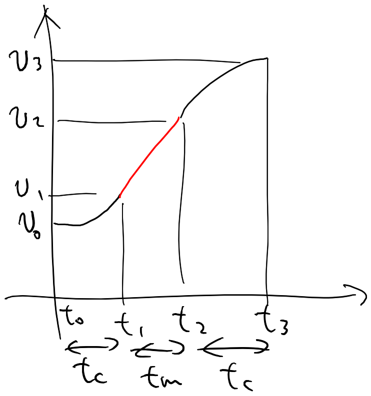
(In $a(t)$, the crossed-out $a(t_0)$ is annotated 0.)

$$
\begin{cases}
j(t) = -j_m \\
a(t) = a(t_1) + \int_{t_1}^{t} j\,dt \\
\quad = j_m(t_1-t_0) - j_m(t-t_1) \\
v(t) = v(t_1) + \int_{t_1}^{t} a\,dt \\
\quad = v_0 + \frac{1}{2} j_m (t_1-t_0)^2 + \left[j_m(t_1-t_0)t - \frac{1}{2} j_m (t-t_1)^2 \right]_{t_1}^{t} \\
\quad = v_0 + \frac{1}{2} j_m (t_1-t_0)^2 + j_m(t_1-t_0)(t-t_1) - \frac{1}{2} j_m (t-t_1)^2 \\
x(t) = x(t_1) + \int_{t_1}^{t} v(t)\,dt \\
\quad = x_0 + v_0(t_1-t_0) + \frac{1}{6} j_m (t_1-t_0)^3 \\
\qquad + \left[\left\{ v_0 + \frac{1}{2} j_m (t_1-t_0)^2 \right\} t + \frac{1}{2} j_m (t_1-t_0)(t-t_1)^2 - \frac{1}{6} j_m (t-t_1)^3 \right]_{t_1}^{t} \\
\quad = x_0 + v_0(t_1-t_0) + \frac{1}{6} j_m (t_1-t_0)^3 \\
\qquad + \left\{ v_0 + \frac{1}{2} j_m (t_1-t_0)^2 \right\}(t-t_1) + \frac{1}{2} j_m (t_1-t_0)(t-t_1)^2 - \frac{1}{6} j_m (t-t_1)^3
\end{cases}
$$

$t_m = 0$ のとき、

$$d = x(2t_c) = x_0 + v_0 t_c + \cancel{\frac{1}{6} j_m t_c^3} + \left(v_0 + \frac{1}{2} j_m t_c^2\right) t_c + \frac{1}{2} j_m t_c^3 - \cancel{\frac{1}{6} j_m t_c^3}$$

$$= x_0 + 2v_0 t_c + j_m t_c^3$$

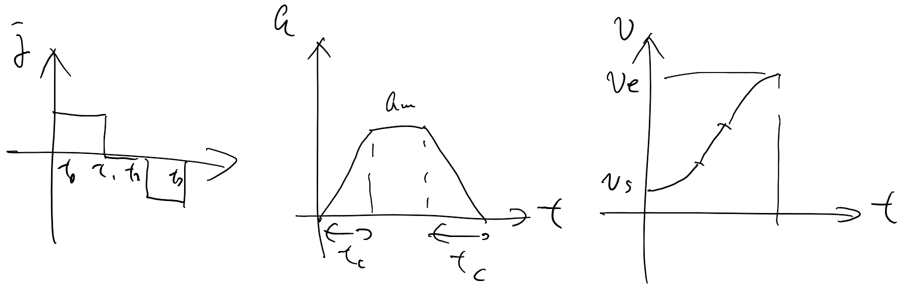


$$v_0 = v_s$$
$$v_{01} = v_0 + \frac{1}{2t_c} a_m (t-t_0)^2$$
$$v_1 = v_0 + \frac{1}{2} a_m t_c$$
$$v_{12} = v_1 + a_m (t-t_1) = v_0 + \frac{1}{2} a_m t_c + a_m (t-t_1)$$
$$v_2 = v_0 + \frac{1}{2} a_m t_c + a_m t_m$$
$$v_{23} = v_2 + \frac{1}{2} a_m t_c - \frac{1}{2t_c} a_m (t-t_3)^2$$
$$v_3 = v_2 + \frac{1}{2} a_m t_c = v_0 + a_m (t_c + t_m)$$

$t_m = \frac{1}{a_m}(v_e - v_s) - t_c > 0$ のとき.

$$t_3 - t_0 = t_c + t_m + t_c$$
$$= t_c + \frac{1}{a_m}(v_e - v_s)$$
$$x_3 - x_0 = \frac{1}{2}(v_s + v_e)(t_3 - t_0)$$
$$= \frac{1}{2}(v_s + v_e)\left\{t_c + \frac{1}{a_m}(v_e - v_s)\right\}$$

〈曲線→直線→曲線〉



〈$t_m > 0$ のとき、v_s と d から v_e を算出〉

$$d = \frac{1}{2}(v_s + v_e)\left(t_c + \frac{v_e - v_s}{a_m}\right)$$
$$2 a_m d = (v_e + v_s)(v_e - v_s + a_m t_c)$$
$$v_e^2 - v_s^2 + a_m t_c v_e + a_m t_c v_s - 2 a_m d = 0$$
$$v_e^2 + a_m t_c v_e + a_m t_c v_s - v_s^2 - 2 a_m d = 0$$
$$v_e = \frac{-a_m t_c \pm \sqrt{a_m^2 t_c^2 - 4(a_m t_c v_s - v_s^2 - 2 a_m d)}}{2}$$

〈$t_m < 0$ のとき, v_s と d から v_e を算出〉

$$v_e^3 + v_s v_3^2 - v_s^2 v_e - v_s^3 - \frac{a_m}{t_c} d^2 = 0$$

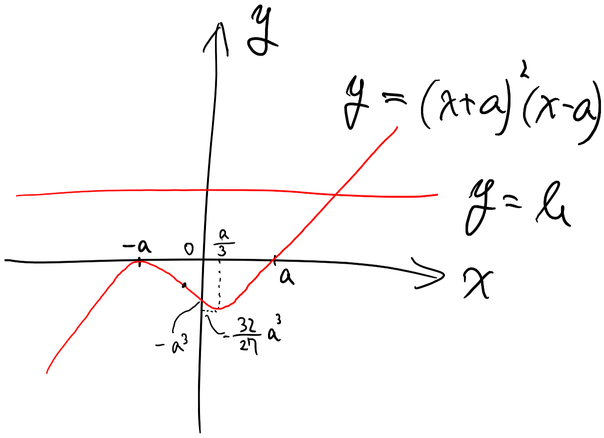
ここで,

$$x = v_e,\quad a = v_s,\quad h = \frac{a_m}{t_c} d^2 = j_m d^2$$

3次方程式

$$x^3 + a x^2 - a^2 x - a^3 - h = 0$$

$$\Leftrightarrow (x+a)^2(x-a) = h$$



$x = x_1, x_2, x_3$

$$x_1 = \frac{1}{3}\left\{\sqrt[3]{\frac{16a^3+27h+\sqrt{27h(32a^3+27h)}}{2}} + 4a^2\sqrt[3]{\frac{2}{16a^3+27h-\sqrt{27h(32a^3+27h)}}} - a\right\}$$

$$= \frac{1}{3}\left\{\sqrt[3]{\frac{16a^3+27h+\sqrt{27h(32a^3+27h)}}{2}} + \sqrt[3]{\frac{16a^3+27h-\sqrt{27h(32a^3+27h)}}{2}} - a\right\}$$

$$\left[\, 4a^2 \cdot \sqrt[3]{\frac{2}{\sqrt{27h(32a^3+27h)}+16a^3+27h}} = \cdots = -\sqrt[3]{\frac{\sqrt{27h(32a^3+27h)}-(16a^3+27h)}{2}} \,\right]$$

$$\sqrt[3]{\frac{128a^6}{\sqrt{27b(32a^3+27b)}+16a^3+27b}}$$

$$=\sqrt[3]{\frac{128a^6\left(\sqrt{27b(32a^3+27b)}-(16a^3+27b)\right)}{\left(\sqrt{27b(32a^3+27b)}+16a^3+27b\right)\left(\sqrt{27b(32a^3+27b)}-(16a^3+27b)\right)}}$$

$$\cancel{27b(32a^3+27b)}-(16a^3)^2-2\cdot\cancel{16a^3\cdot 27b}-\cancel{(27b)^2}$$

$$=\sqrt[3]{\frac{\sqrt{27b(32a^3+27b)}-(16a^3+27b)}{-2}}=-\sqrt[3]{\frac{\sqrt{27b(32a^3+27b)}-(16a^3+27b)}{2}}$$

$$\sqrt[3]{\frac{\sqrt{27b(32a^3+27b)}+16a^3+27b}{2}}-\sqrt[3]{\frac{\sqrt{27b(32a^3+27b)}-(16a^3+27b)}{2}}$$

$$=\sqrt[3]{\frac{\sqrt{27b(32a^3+27b)}+16a^3+27b}{2}}+\sqrt[3]{\frac{-\sqrt{27b(32a^3+27b)}+16a^3+27b}{2}}$$

$$\left(\sqrt[3]{\frac{\sqrt{27b(32a^3+27b)}+16a^3+27b}{2}}+\sqrt[3]{\frac{-\sqrt{27b(32a^3+27b)}+16a^3+27b}{2}}\right)^3$$

$$=\frac{\sqrt{27b(32a^3+27b)}+16a^3+27b}{2}+\frac{-\sqrt{27b(32a^3+27b)}+16a^3+27b}{2}$$

$$+3\sqrt[3]{\left(\frac{\sqrt{27b(32a^3+27b)}+16a^3+27b}{2}\right)^2\frac{-\sqrt{27b(32a^3+27b)}+16a^3+27b}{2}}$$

$$+3\sqrt[3]{\frac{\sqrt{27b(32a^3+27b)}+16a^3+27b}{2}\left(\frac{-\sqrt{27b(32a^3+27b)}+16a^3+27b}{2}\right)^2}$$

$$=16a^3+27b+3\sqrt[3]{\frac{\sqrt{27b(32a^3+27b)}+16a^3+27b}{2}\cdot\frac{(16a^3)^2}{4}}+3\sqrt[3]{\frac{-\sqrt{27b(32a^3+27b)}+16a^3+27b}{2}\cdot\frac{(16a^3)^2}{4}}$$

$$=16a^3+27b+3a^2\cdot 4\left\{\sqrt[3]{\frac{\sqrt{27b(32a^3+27b)}+16a^3+27b}{2}}+\sqrt[3]{\frac{-\sqrt{27b(32a^3+27b)}+16a^3+27b}{2}}\right\}$$

$$(x+iy)^3=(x^3-3xy^2)+i(3x^2y-y^3)$$