Anexo 3.2

Comparación numérica de los resultados obtenidos al estimar la fuerza que ha de hacer el actuador, aplicando Lagrange y potencias virtuales.

Debido a las peculiares características del programa empleado, que no permite impresiones en formato .pdf, la única solución encontrada para integrar este anexo en este documento ha sido exportarlo como fichero .rtf e imprimirlo con un programa diferente.

PARÁMETROS GEOMÉTRICOS

$o4 := 1 \cdot m$

$o2 := .25 \cdot m$

$b := .25 \cdot m$

$g2 := .3 \cdot m$

$g3 := .2 \cdot m$

$g4 := .6 \cdot m$

$S := 3.1416 \left(.016^2 - .008^2\right) \cdot m^2$

$l := .4 \cdot m$

$S = 6.032 \cdot 10^{-4} \cdot m^2$

$li := .4 \cdot m$

$ls := .80 \cdot m$

$e := .010 \cdot m$

$m2 := 5.0 \cdot kg$

$m3 := 2.0 \cdot kg$

$m4 := 1.0 \cdot kg$

$Ig2 := \frac{1}{3} \cdot g2^2 \cdot m2$

$Ig3 := \frac{1}{12} \cdot l^2 \cdot m3$

$Ig4 := \frac{1}{3} \cdot g4^2 \cdot m2$

$t := 0, 0.01 .. 1.00$

$a(t) := (.6 + .02 \cdot \sin(t \cdot 2 \cdot \pi)) \cdot m$

$vcil(t) := .04 \cdot \pi \cdot \cos(t \cdot 2 \cdot \pi) \cdot \frac{m}{sec}$

$acil(t) := -.08 \cdot \pi^2 \cdot \sin(t \cdot 2 \cdot \pi) \cdot \frac{m}{sec^2}$

$hs := ls - \frac{e}{2} - a(0)$

$hi := a(0) - \frac{e}{2} - li$

GEOMETRIA

$d := \left|\sqrt{o4^2 + o2^2}\right|$

$Io2 := Ig2 + g2^2 \cdot m2$

$\tan(\alpha) = \frac{o2}{o4}$

$Io2 = 0.6 \cdot kg \cdot m^2$

$d = 1.031 \cdot m$

$Ig3 = 0.027 \cdot kg \cdot m^2$

$\alpha := \operatorname{atan}\left(\frac{o2}{o4}\right)$

$\beta := \operatorname{atan}\left(\frac{o4}{o2}\right)$

$Io4 := Ig4 + g4^2 \cdot m4$

$Io4 = 0.96 \cdot kg \cdot m^2$

$\phi(t) := acos\left[\frac{d^2 + b^2 - (a(t) + l)^2}{2 \cdot d \cdot b}\right]$

$vcil(0) = 0.126 \cdot m \cdot sec^{-1}$

$\theta 4(t) := \phi(t) - \beta$

$hs = 0.195 \cdot m$

$hi = 0.1$

$\psi(t) := acos\left[\frac{d^2 + (a(t) + l)^2 - b^2}{2 \cdot d \cdot (a(t) + l)}\right]$

$\theta 2(t) := \pi - \beta - \psi(t)$

ANÁLISIS CINEMÁTICO

VELOCIDADES

$\omega 4(t) := \frac{1}{b} \cdot \sin(\theta 2(t) - \theta 4(t)) \cdot vcil(t)$

$\omega 2(t) := \frac{1}{a(t) + l} \cdot \sin(\theta 2(t) - \theta 4(t)) \cdot \cos(\theta 2(t) - \theta 4(t)) \cdot vcil(t)$

$vg2(t) := \omega 2(t) \cdot g2$

$vg3(t) := \omega 2(t) \cdot (a(t) + g3)$

$vg4(t) := \omega 4(t) \cdot g4$

$vg2x(t) := -\omega 2(t) \cdot g2 \cdot \sin(\theta 2(t))$

$vg3x(t) := -\omega 2(t) \cdot (a(t) + g3) \cdot \sin(\theta 2(t)) + vcil(t) \cdot \cos(\theta 2(t))$

$vg4x(t) := -\omega 4(t) \cdot g4 \cdot \sin(\theta 4(t))$

$vg2y(t) := \omega 2(t) \cdot g2 \cdot \cos(\theta 2(t))$

$vg3y(t) := \omega 2(t) \cdot (a(t) + g3) \cdot \cos(\theta 2(t)) + vcil(t) \cdot \sin(\theta 2(t))$

$vg4y(t) := \omega 4(t) \cdot g4 \cdot \cos(\theta 4(t))$

ACELERACIONES

$\varepsilon 4(t) := \frac{1}{b} \cdot \sin(\theta 2(t) - \theta 4(t)) \cdot acil(t) + \frac{1}{b} \cdot (\omega 2(t) - \omega 4(t)) \cdot \cos(\theta 2(t) - \theta 4(t)) \cdot vcil(t)$

$$\varepsilon 2(t) := \frac{-vcil(t)^2}{(a(t) + l)^2} \cdot \frac{1}{2} \cdot \sin(2 \cdot (\theta 2(t) - \theta 4(t))) + \frac{vcil(t)}{a(t) + l} \cdot (\omega 2(t) - \omega 4(t)) \cdot \cos(\theta 2(t) - \theta 4(t)) \ ... \\ + \frac{acil(t)}{a(t) + l} \cdot \frac{1}{2} \cdot \sin(2 \cdot (\theta 2(t) - \theta 4(t)))$$

$ag2x(t) := -\omega 2(t)^2 \cdot g2 \cdot \cos(\theta 2(t)) - \varepsilon 2(t) \cdot g2 \cdot \sin(\theta 2(t))$

$ag2y(t) := -\omega 2(t)^2 \cdot g2 \cdot \sin(\theta 2(t)) + \varepsilon 2(t) \cdot g2 \cdot \cos(\theta 2(t))$

$$ag3x(t) := -\omega 2(t)^2 \cdot (a(t) + g3) \cdot \cos(\theta 2(t)) - \varepsilon 2(t) \cdot (a(t) + g3) \cdot \sin(\theta 2(t)) \ ... \\ + acil(t) \cdot \cos(\theta 2(t)) - 2 \cdot \omega 2(t) \cdot vcil(t) \cdot \sin(\theta 2(t))$$

$$ag3y(t) := -\omega 2(t)^2 \cdot (a(t) + g3) \cdot \sin(\theta 2(t)) + \varepsilon 2(t) \cdot (a(t) + g3) \cdot \cos(\theta 2(t)) \ ... \\ + acil(t) \cdot \sin(\theta 2(t)) + 2 \cdot \omega 2(t) \cdot vcil(t) \cdot \cos(\theta 2(t))$$

$ag4x(t) := -\omega 4(t)^2 \cdot g4 \cdot \cos(\theta 4(t)) - \varepsilon 4(t) \cdot g4 \cdot \sin(\theta 4(t))$

$ag4y(t) := -\omega 4(t)^2 \cdot g4 \cdot \sin(\theta 4(t)) + \varepsilon 4(t) \cdot g4 \cdot \cos(\theta 4(t))$

$\theta 2(0) = 1.571$

$\theta 4(0) = 0$

$\omega 2(0) = 0 \cdot sec^{-1}$

$\omega 4(0) = 0.503 \cdot sec^{-1}$

DINAMICA INVERSA

$Fg2x(t) := -m2 \cdot ag2x(t)$

$Fg2y(t) := -m2 \cdot ag2y(t)$

$Mg2(t) := -Ig2 \cdot \varepsilon 2(t)$

$Fg3x(t) := -m3 \cdot ag3x(t)$

$Fg3y(t) := -m3 \cdot ag3y(t)$

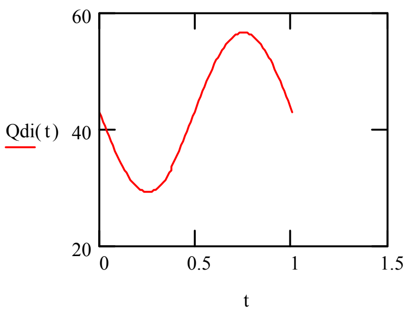
$Mg3(t) := -Ig3 \cdot \varepsilon 2(t)$

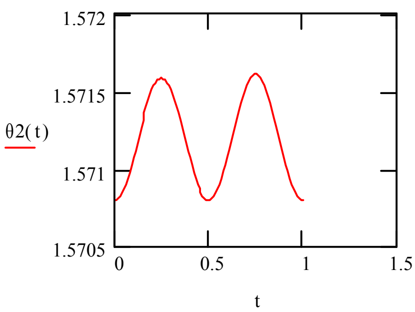
$Fg4x(t) := -m4 \cdot ag4x(t)$

$Fg4y(t) := -m4 \cdot ag4y(t)$

$Mg4(t) := -Ig4 \cdot \varepsilon 4(t)$

$$Qdi(t) := \frac{-1}{vcil(t)} \cdot \left[\begin{array}{l} Fg2x(t) \cdot vg2x(t) + (Fg2y(t) - m2 \cdot g) \cdot vg2y(t) + Mg2(t) \cdot \omega 2(t) \ldots \\ + \left[\begin{array}{l} Fg3x(t) \cdot vg3x(t) + (Fg3y(t) - m3 \cdot g) \cdot vg3y(t) + Mg3(t) \cdot \omega 2(t) \ldots \\ + Fg4x(t) \cdot vg4x(t) + (Fg4y(t) - m4 \cdot g) \cdot vg4y(t) + Mg4(t) \cdot \omega 4(t) \end{array} \right] \end{array} \right]$$





DINAMICA DIRECTA

$$
\begin{aligned}
Qdd(t) :=\ & \left(m2\cdot g2^2 + Ig2\right)\cdot\left[\frac{1}{a(t)+1}\cdot\frac{1}{2}\cdot\sin(2\cdot(\theta 2(t)-\theta 4(t)))\right]^2\cdot acil(t) - 2\cdot\frac{m2\cdot g2^2+Ig2}{a(t)+1}\cdot\omega 2(t)^2\ \ldots \\
& + \left(m2\cdot g2^2 + Ig2\right)\cdot\frac{\omega 2(t)-\omega 4(t)}{(a(t)+1)}\cdot(\cos(2\cdot(\theta 2(t)-\theta 4(t))))\cdot 2\cdot\omega 2(t)\ \ldots \\
& + \left(\frac{m2\cdot g2^2+Ig2}{a(t)+1}\right)\cdot\omega 2(t)\cdot(\omega 2(t)-(\omega 2(t)-\omega 4(t))\cdot\cos(2\cdot(\theta 2(t)-\theta 4(t))))\ \ldots \\
& + m2\cdot g\cdot g2\cdot\cos(\theta 2(t))\cdot\left[\frac{1}{a(t)+1}\cdot\frac{1}{2}\cdot\sin(2\cdot(\theta 2(t)-\theta 4(t)))\right]\ \ldots \\
& + \left[m3\cdot(a(t)+g3)^2+Ig3\right]\cdot\left[\frac{1}{a(t)+1}\cdot\frac{1}{2}\cdot\sin(2\cdot(\theta 2(t)-\theta 4(t)))\right]^2\cdot acil(t) + m3\cdot acil(t)\ \ldots \\
& + \left[m3\cdot(a(t)+g3)^2+Ig3\right]\cdot\frac{\omega 2(t)-\omega 4(t)}{(a(t)+1)}\cdot\left[-\left(\sin(\theta 2(t)-\theta 4(t))^2\right)+\cos(\theta 2(t)-\theta 4(t))^2\right]\cdot 2\cdot\omega 2(t)\ .. \\
& + (2\cdot m3\cdot(a(t)+g3))\cdot\left[\frac{1}{a(t)+1}\cdot\frac{1}{2}\cdot\sin(2\cdot(\theta 2(t)-\theta 4(t)))\right]^2\cdot vcil(t)^2 + m3\cdot g\cdot\sin(\theta 2(t))\ \ldots \\
& + m3\cdot g\cdot(a(t)+g3)\cdot\cos(\theta 2(t))\cdot\frac{1}{a(t)+1}\cdot\left[-\left(\sin(\theta 2(t)-\theta 4(t))^2\right)+\cos(\theta 2(t)-\theta 4(t))^2\right]\ \ldots \\
& + -m3\cdot\omega 2(t)^2\cdot(a(t)+g3) - 2\cdot\frac{m3\cdot(a(t)+g3)^2+Ig3}{a(t)+1}\cdot\omega 2(t)^2\ \ldots \\
& + \left[\frac{m3\cdot(a(t)+g3)^2+Ig3}{a(t)+1}\right]\cdot\omega 2(t)\cdot(\omega 2(t)-(\omega 2(t)-\omega 4(t))\cdot\cos(2\cdot(\theta 2(t)-\theta 4(t))))\ \ldots \\
& + \left(m4\cdot g4^2+Ig4\right)\cdot\left(\frac{1}{b}\cdot\sin(\theta 2(t)-\theta 4(t))\right)\cdot vcil(t)\cdot\frac{(\omega 2(t)-\omega 4(t))\cdot\cos(\theta 2(t)-\theta 4(t))}{b}\ \ldots \\
& + \left(m4\cdot g4^2+Ig4\right)\cdot\left(\frac{1}{b}\cdot\sin(\theta 2(t)-\theta 4(t))\right)^2\cdot acil(t) + m4\cdot g\cdot g4\cdot\cos(\theta 4(t))\cdot\frac{1}{b}\cdot\sin(\theta 2(t)-\theta 4(t))
\end{aligned}
$$

$Qdd(0.0) = 43.14926\,kg\cdot m\cdot sec^{-2}$

$Qdd(0.25) = 29.371299\,kg\cdot m\cdot sec^{-2}$

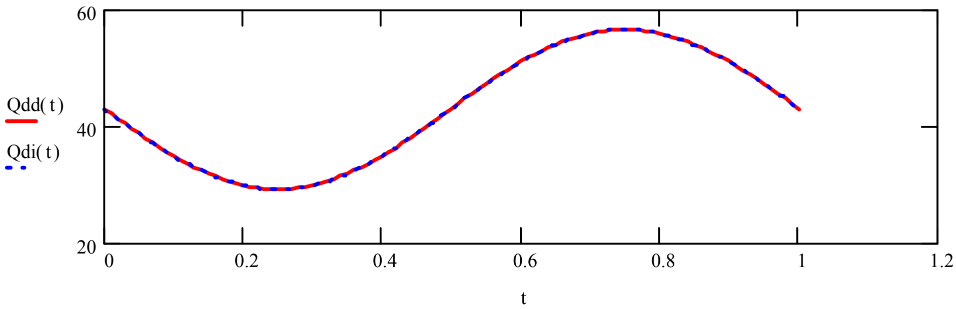
$Qdi(0) = 43.14926\,kg\cdot m\cdot sec^{-2}$

$Qdi(0.25) = 29.35809\,kg\cdot m\cdot sec^{-2}$

$Qdd(0.01) = 42.284\,kg\cdot m\cdot sec^{-2}$

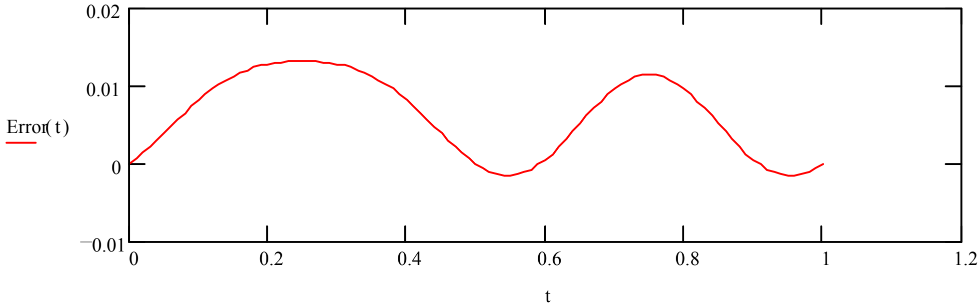
$Qdd(.75) = 56.648\,kg\cdot m\cdot sec^{-2}$

COMPARACIÓN DE LOS RESULTADOS



Las 2 gráficas se superponen.

$Error(t) := Qdd(t) - Qdi(t)$



El error máximo es 0.0132088 N y Qdi(t) siempre supera los 29 N.

$$error\_relativo := \frac{.0132088}{29}$$

$$error\_relativo = 4.555 \cdot 10^{-4}$$