Modeling Power Requirements of a Burnwire Release Mechanism

Gerald Recktenwald
Portland State University

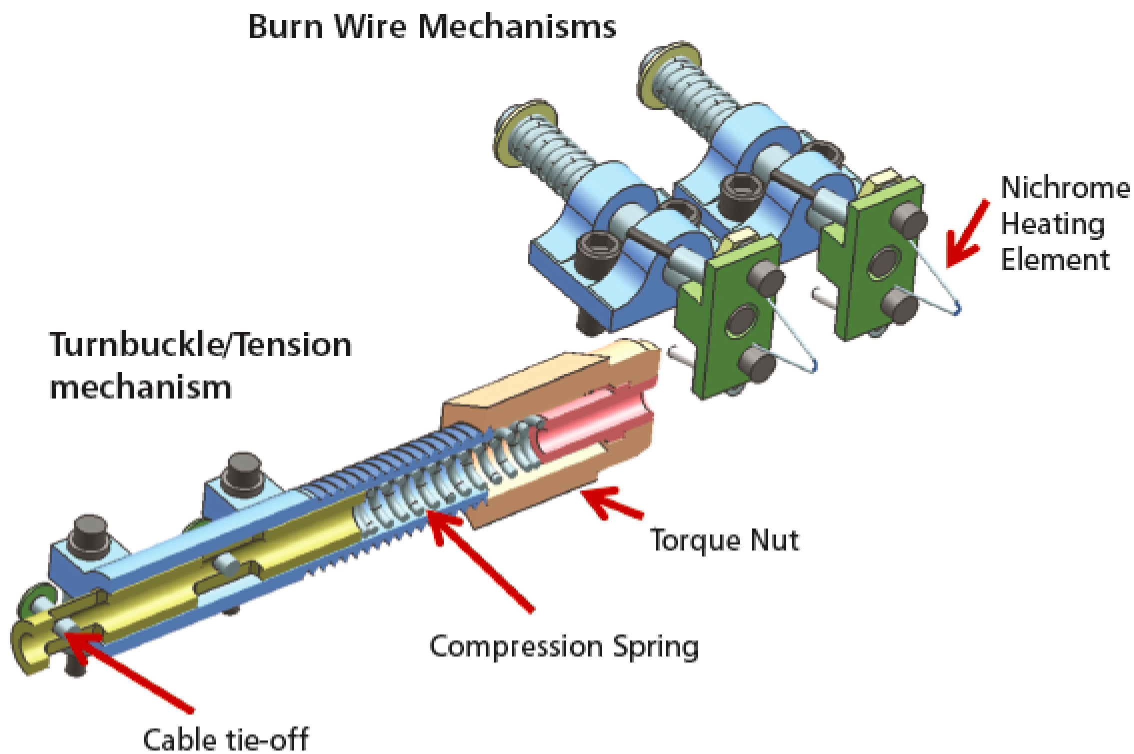
February 19, 2018

Overview

- Motivation
  - ▷ Models in conceptual Design
  - ▷ Burnwire case study
- Thermal model equations
- Sample results

Models in Conceptual Design

- Simple models are cheap and fast
- Predict, don't hack
- Guide design thinking
  - ▷ Identify performance boundaries
  - ▷ Identify sensitive parameters
  - ▷ Identify promising parameter combinations – early optimization
- Provide checks on more complex models



Credit: Launch Tie-Down and Release Mechanism for CubeSat Spacecraft NASAs Jet Propulsion Laboratory, Pasadena, California, NASA Tech Briefs, JUNE 1, 2016, MECHANICAL & FLUID SYSTEMS

https://www.techbriefs.com/component/content/article/tb/techbriefs/mechanics-and-machinery/24810

Model of Wire Heating

Energy equation for the burn wire

$$mc\frac{dT}{dt} = P - Q \qquad (1)$$

The electrical power input is

$$P = I^2 R = \frac{V^2}{R} \qquad (2)$$

where

$$R = \frac{\rho_e L}{A_c} \qquad (3)$$

m	mass of the wire
c	specific heat of the wire material
T	temperature of the wire
t	time
P	electrical power input
Q	heat loss to the ambient
I	current flowing through the wire
R	electrical resistance of the wire
V	voltage across the ends of the wire.
ρ_e	electrical resistivity of wire material
L	length of the wire for voltage drop
A_c	$= (\pi/4)d_w^2$, cross-sectional area of the wire with diameter d_w.

Model of Wire Heating

Define the heating rate

$$H = \frac{T_f - T_i}{\Delta t} \tag{4}$$

Assume $Q = 0$, then the energy equation simplifies to

$$H = \frac{P}{mc} \tag{5}$$

Model of Wire Heating

Model for voltage: Substitute $P = \dfrac{V^2}{R}$

$$H = \frac{P}{mc} = \frac{V^2}{R\rho_m c A_c L} = \frac{V^2}{\dfrac{\rho_e L}{A_c}\rho_m c A_c L} = \frac{V^2}{\rho_e \rho_m c L^2} \tag{6}$$

Solve for V

$$V = L\sqrt{Hc\rho_m\rho_e}. \tag{7}$$

Model of Wire Heating

Model for current: Substitute $P = I^2 R$

$$H = \frac{P}{mc} = \frac{I^2 R}{\rho_m A_c L} = \frac{I^2 \frac{\rho_e L}{A_c}}{\rho_m c A_c L} = \frac{I^2 \rho_e}{\rho_m c A_c^2} = \frac{16}{\pi^2} \frac{I^2 \rho_e}{\rho_m c d_w^4} \tag{8}$$

Solve for I

$$I = \frac{\pi}{4} d_w^2 \sqrt{\frac{\rho_m}{\rho_e} H c} \tag{9}$$

Model of Wire Heating

Model for power: Substitute $P = VI$ with V from Equation (7) and I from Equation (9)

$$P = VI \; = \; L\sqrt{Hc\rho_m\rho_e}\,\frac{\pi}{4}d_w^2\sqrt{\frac{\rho_m}{\rho_e}Hc} \; = \; \frac{\pi}{4}d_w^2 LHc\rho_m \tag{10}$$

Model Summary

$$V = L\sqrt{Hc\rho_m\rho_e}.$$

$$I = \frac{\pi}{4}d_w^2\sqrt{\frac{\rho_m}{\rho_e}Hc}$$

$$P = \frac{\pi}{4}d_w^2 LHc\rho_m$$

Model Heating Rate Estimates

Heating rate

melt time	10	s
Ti	-150	°C
Tmelt (low)	200	°C
Tmelt (high)	300	°C
Heating rate (low)	35	°C/s
ɫeating rate (high)	45	°C/s

Heating rate values -- table values are H (C/s)

	Time (s)		
Tmelt	10	1	0.1
180	33	330	3300
200	35	350	3500
250	40	400	4000
300	45	450	4500
350	50	500	5000

Model Results

Properties of Nichrome

ρ_m	8400 $\mathrm{kg/m^3}$
ρ_e (low)	$1 \times 10^{-6}\ \Omega \cdot \mathrm{m}$
ρ_e (high)	$1.5 \times 10^{-6}\ \Omega \cdot \mathrm{m}$
c	8400 $\mathrm{J/kg/K}$

Voltage limits -- table values are voltages

	H (°C/s) =				
L (cm)	10	50	150	300	500
2	0.12	0.27	0.48	0.67	0.87
4	0.25	0.55	0.95	1.35	1.74
6	0.37	0.82	1.43	2.02	2.61
8	0.49	1.10	1.90	2.69	3.48
10	0.61	1.37	2.38	3.37	4.35
12	0.74	1.65	2.86	4.04	5.22

Current limits -- table values are currents

		H (C/s) =				
AWG	d(m)	10	50	150	300	500
24	5.110E-04	1.26	2.82	4.88	6.91	8.92
26	4.050E-04	0.79	1.77	3.07	4.34	5.60
28	3.210E-04	0.50	1.11	1.93	2.73	3.52
30	2.540E-04	0.31	0.70	1.21	1.71	2.20
32	2.019E-04	0.20	0.44	0.76	1.08	1.39
36	1.270E-04	0.08	0.17	0.30	0.43	0.55
40	7.874E-05	0.03	0.07	0.12	0.16	0.21

Model Results

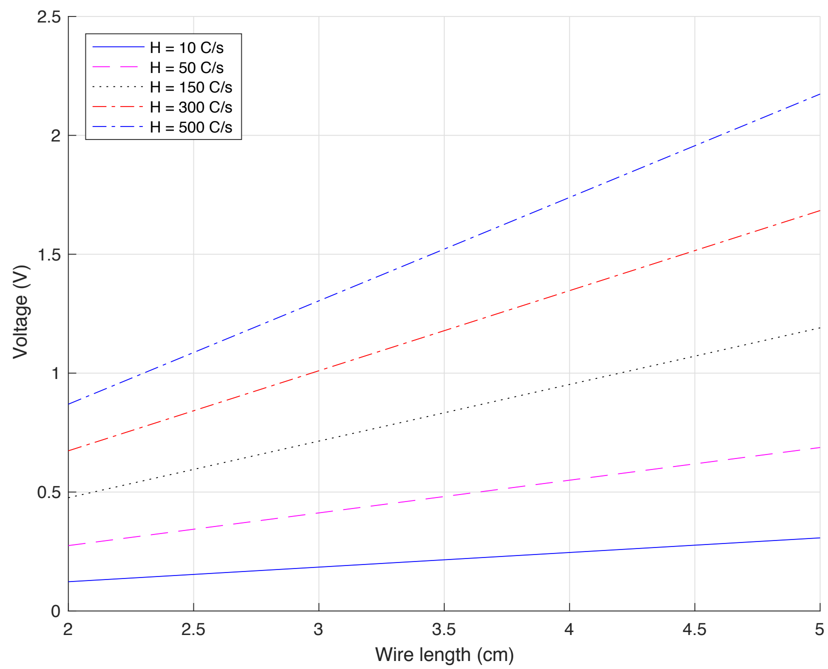


Figure 1: Voltage as a function of wire length.

Model Results

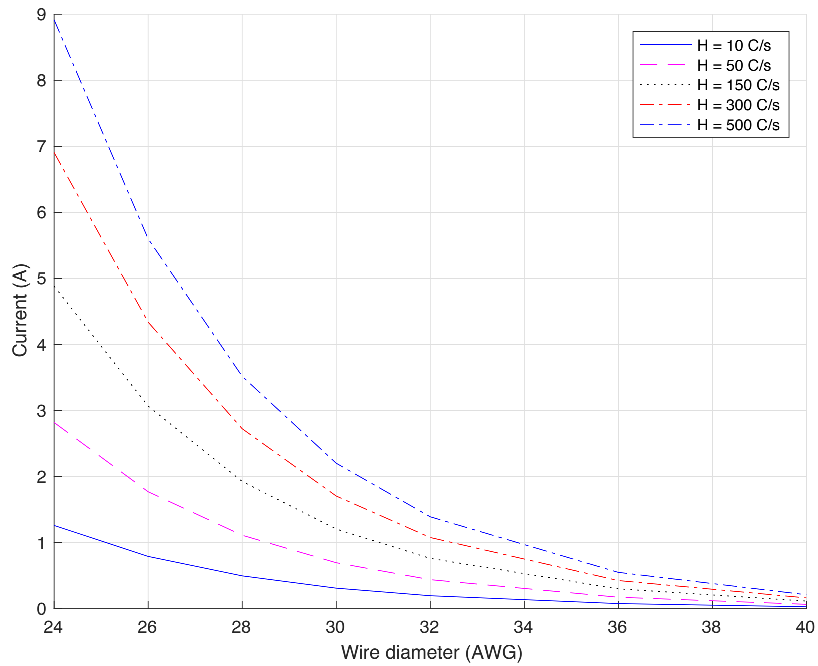


Figure 2: Current as a function of wire diameter.

Model Results

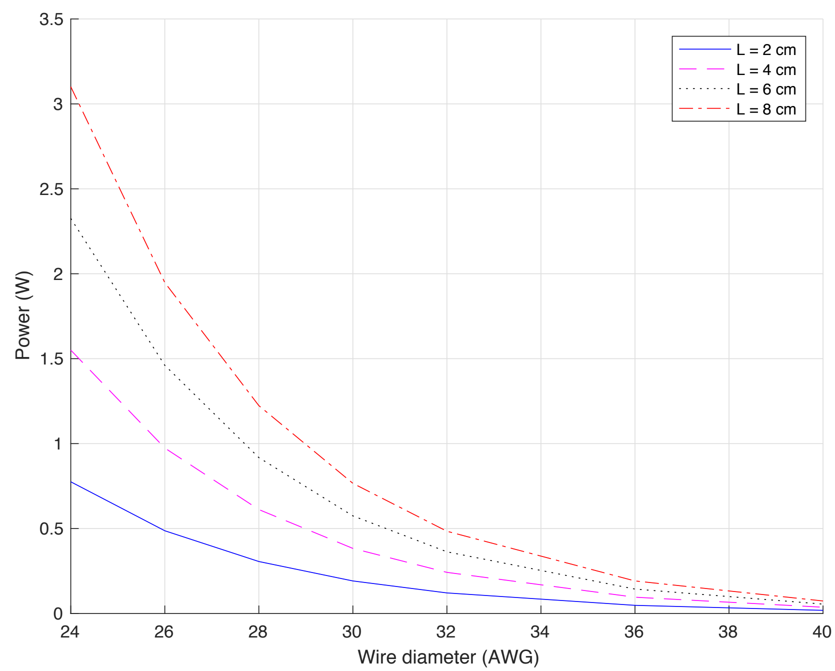


Figure 3: Power consumption as a function of wire length and diameter at $H = 50\,^{\circ}\mathrm{C/s}$.