DESIGN CALCULATIONS
FOR HEATING ELEMENTS
EXAMPLES

Tubular element for a flat iron

Rating, P	1000 W
Voltage, U	220 V
Final tube diameter	8 mm (0.315 in)
Final tube length	300 mm (11.8 in)

If the terminal length inside the tube is 2 × 25 mm the coil length (L_e) will be
L_e = 300 mm – (2 × 25 mm) = 250 mm (9.8 in).

Hot resistance based on equation [8] and [9]

$$R = \frac{U^2}{P} = \frac{220^2}{1000} = 48.4\ \Omega$$

Tubes surface load based on equation [5]

$$p_{tube} = \frac{P}{A_{tube}} = \frac{P}{\pi \cdot d_{tube} \cdot L_e \cdot 0.01} =$$

$$= \frac{1000}{\pi \cdot 8 \cdot 250 \cdot 0.01} = 15.91\ \frac{W}{cm^2} \quad (103\ W/in^2)$$

Wire surface load inside tube. Factor 3 is used as a rule of thumb:

$$p_{wire} = 3 \cdot p_{tube} = 3 \cdot 15.91 = 47.74 \approx$$

$$p_{wire} = 3 \cdot p_{tube} \qquad [20]$$

$$\approx 48\ \frac{W}{cm^2} \quad (309\ W/in^2)$$

Wire surface based on equation [5]

$$p_{wire} = \frac{P}{A_C} \quad \rightarrow$$

$$A_C = \frac{P}{p_{wire}} = \frac{1000}{48} = 20.83 \approx 21\ cm^2 \quad (3.3\ in^2)$$

Kanthal® D is a sensible choice and an average wire temperature of 700°C (1290°F) likely. Due to temperature factor of resistance (C_t = 1.05 for Kanthal D, table on page 3-4).

Resistance at room temperature based on equation [2]

$$R_T = C_t \cdot R_{20} \quad \rightarrow$$

$$R_{20} = \frac{R_T}{C_t} = \frac{48.4}{1.05} = 46.09 \approx 46.1\ \Omega$$

The ratio between wire surface and resistance is:

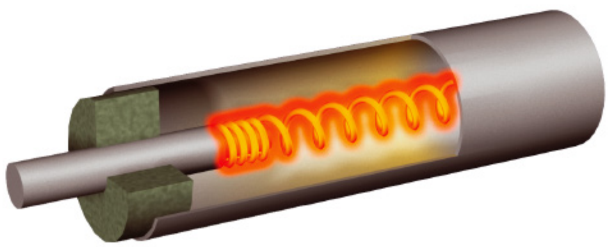
$$\frac{A_C}{R_{20}} = \frac{21}{46.1} = 0.455\ \frac{cm^2}{\Omega} \quad (0.071\ in^2/\Omega)$$

Based on the table for Kanthal D on page 3-4, this is corresponding to a wire size of about 0.3 mm (0.012 in).

We assume that a steel tube of initially 9.5 mm (0.37 in) diameter is being used and can then expect a resistance reduction of about 30% upon rolling.

The resistance of the coil should therefore be about 65.3 Ω. The wire surface prior to compression is 7% bigger, or 22.5 cm^2 (3.49 in^2), and the ratio between wire surface and resistance 0.34 cm^2/Ω (0.053 in^2/Ω).

The corresponding wire size is 0.26 mm (0.01 in). Tests with this wire size have to be made in order to check the resistance reduction as a result of compression.



Metal sheathed tubular element.

Coil suspended on a Mica-cross, element for a hair dryer

Rating, P	350 W
Voltage, U	55 V
Length of coil, l	250 mm (9.8 in)
Coil outer diameter, D	6 mm (0.236 in)

For this application a surface load, p, of 7 W/cm² (45.16 W/in²) is reasonable.

Wire surface based on equation [5]

$$p = \frac{P}{A_C} \quad \rightarrow \quad A_C = \frac{p}{P} = \frac{350}{7} = 50 \text{ cm}^2 \text{ (7.75 in}^2\text{)}$$

Assuming a wire temperature of 600°C (1110°F) and choosing Kanthal D with an C_t value of 1.04.

Hot- and cold resistance based on combining equations [8], [9] and [2]

$$R_T = \frac{U^2}{P} = \frac{55^2}{350} = 8.64 \ \Omega$$

$$R_{20} = \frac{R_T}{C_t} = 8.31 \ \Omega$$

By calculating the surface area to cold resistance ratio, a suitable wire dimension is found, combining [1'] and [6'], [7']

Wire

$$\frac{A_C}{R_{20}} = \frac{50 \text{ cm}^2}{8.31 \ \Omega} = 6.01 \ \frac{\text{cm}^2}{\Omega} \quad 0.93 \text{ in}^2/\Omega$$

According to table for Kanthal D Ø 0.70 mm (0.0276 in) has an surface area to resistance ratio of 6.27 cm²/Ω (0.97 in²/Ω).

D/d ratio has to be considered since too low as well as too high values will create problems in the coiling process. Verifying the geometry of the coil, suitable values for the D/d ratio should be between 6 and 12.
In this case:

$$\frac{D}{d} = \frac{6 \text{ mm}}{0.7 \text{ mm}} = 8.6$$

Length of wire is calculated as the ratio between resistance needed and resistance per meter (table on page 3-4, Kanthal D, d = 0.7 mm, $R_{20/m}$ = 3.51 Ω/m).

Wire length:

$$L = \frac{R_{20}}{R_{20/m}} = \frac{8.31 \ \Omega \cdot m}{3.51 \ \Omega} = 2.367 \text{ m}$$

Coil pitch, s, based on equation [17]

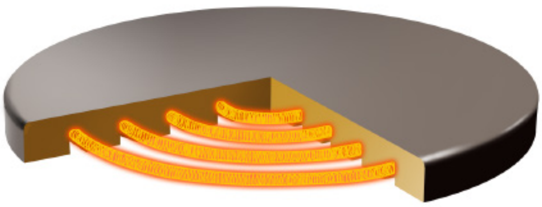
$$s = \frac{\pi \cdot (D - d) \cdot L_e}{L} = \frac{\pi \cdot (7 - 0.7) \cdot 250}{2370} = 2.09 \text{ mm}$$

Relative pitch based on equation [18]

$$r = \frac{s}{d} = \frac{2.09}{0.7} = 2.98$$

Surface load based on [5]

$$p = \frac{P}{A_{C/m} \cdot L} = \frac{350}{22 \cdot 2.37} = 6.7 \text{ W/cm}^2$$



Coils in grooved metal plates.

KANTHAL® D

WIRE DIMENSIONS AND PROPERTIES

Resistivity 1.35 Ω mm²/m (812 Ω/cmf). Density 7.25 g/cm³ (0.262 lb/in³).
To obtain resistivity at working temperature, multiply by factor C_t in following table.

°C	20	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300
C_t	1.00	1.00	1.01	1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.07	1.07	1.08	1.08

Diameter mm	Resistance at 20°C Ω/m	Resistivity at 20°C cm²/Ω*	Weight g/m	Surface area cm²/m	Cross sectional area mm²
8.0	0.0269	9358	364	251	50.3
6.5	0.0407	5019	241	204	33.2
6.0	0.0477	3948	205	188	28.3
5.5	0.0568	3041	172	173	23.8
5.0	0.0688	2285	142	157	19.6
4.75	0.0762	1959	128	149	17.7
4.5	0.0849	1666	115	141	15.9
4.25	0.0952	1403	103	134	14.2
4.06	0.104	1223	93.9	128	12.9
4.0	0.107	1170	91.1	126	12.6
3.75	0.122	964	80.1	118	11.0
3.65	0.129	889	75.9	115	10.5
3.5	0.140	784	69.8	110	9.62
3.25	0.163	627	60.1	102	8.30
3.0	0.191	493	51.2	94.2	7.07
2.95	0.198	469	49.6	92.7	6.8
2.8	0.219	401	44.6	88.0	6.16
2.65	0.245	340	40.0	83.3	5.5
2.5	0.275	286	35.6	78.5	4.91
2.0	0.430	146	22.8	62.8	3.14
1.8	0.531	107	18.4	56.5	2.54
1.7	0.595	89.8	16.5	53.4	2.27
1.6	0.671	74.9	14.6	50.3	2.01
1.5	0.764	61.7	12.8	47.1	1.77
1.4	0.877	50.2	11.2	44.0	1.54
1.3	1.02	40.2	9.62	40.8	1.33
1.2	1.19	31.6	8.20	37.7	1.13
1.1	1.42	24.3	6.89	34.6	0.950

* cm²/Ω = $I^2 \times C_t / p$ (I = Current, C_t = temperature factor, p = surface load W/cm²)

(cont.)

(cont.)

Diameter mm	Resistance at 20°C Ω/m	Resistivity at 20°C cm²/Ω*	Weight g/m	Surface area cm²/m	Cross sectional area mm²
1.0	1.72	18.3	5.69	31.4	0.785
0.95	1.90	15.7	5.14	29.8	0.709
0.90	2.12	13.3	4.61	28.3	0.636
0.85	2.38	11.2	4.11	26.7	0.567
0.80	2.69	9.36	3.64	25.1	0.503
0.75	3.06	7.71	3.20	23.6	0.442
0.70	3.51	6.27	2.79	22.0	0.385
0.65	4.07	5.02	2.41	20.4	0.332
0.60	4.77	3.95	2.05	18.8	0.283
0.55	5.68	3.04	1.72	17.3	0.238
0.50	6.88	2.28	1.42	15.7	0.196
0.45	8.49	1.67	1.15	14.1	0.159
0.42	9.74	1.35	1.00	13.2	0.139
0.40	10.7	1.17	0.911	12.6	0.126
0.35	14.0	0.784	0.698	11.0	0.0962
0.32	16.8	0.599	0.583	10.1	0.0804
0.30	19.1	0.493	0.512	9.42	0.0707
0.28	21.9	0.401	0.446	8.80	0.061
0.25	27.5	0.286	0.356	7.85	0.0491
0.22	35.5	0.195	0.276	6.91	0.0380
0.20	43.0	0.146	0.228	6.28	0.0314
0.19	47.6	0.125	0.206	5.97	0.0284
0.18	53.1	0.107	0.184	5.65	0.0254
0.17	59.5	0.0898	0.165	5.34	0.0227
0.16	67.1	0.0749	0.146	5.03	0.0201
0.15	76.4	0.0617	0.128	4.71	0.0177
0.14	87.7	0.0502	0.112	4.40	0.0154
0.13	102	0.0402	0.0962	4.08	0.0133

* $cm^2/\Omega = I^2 \times C_t / p$ (I = Current, C_t = temperature factor, p = surface load W/cm^2)