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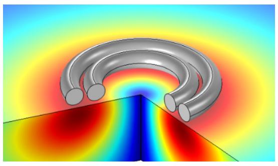

Electoheat - laboratory

Title of exercise:

Design of medium-temperature spiral resistance heating elements for a 3-phase resistance furnace

Date:	Date of assessment:	Rate:

Introduction

Task:

Design medium-temperature resistance heating elements in the form of a spiral (Fig.1) for a 3-phase resistance furnace of a given power P (value of power given individually to each student). The furnace is supplied from a 3-phase 230/400 V line. The heating elements should be made of a ***Kanthal A-1*** *round wire. Assume the temperature of the heating element equal to 1200℃.*

It should be assumed that three equal spiral elements will be used, each supplied with 400 V. Assuming additionally the supply line voltages symmetry and load symmetry, the task is limited to making calculations only for a single heating element generating power P/3.

Parameters of Kanthal A-1 round wires are given in Fig.2 and Fig.3.

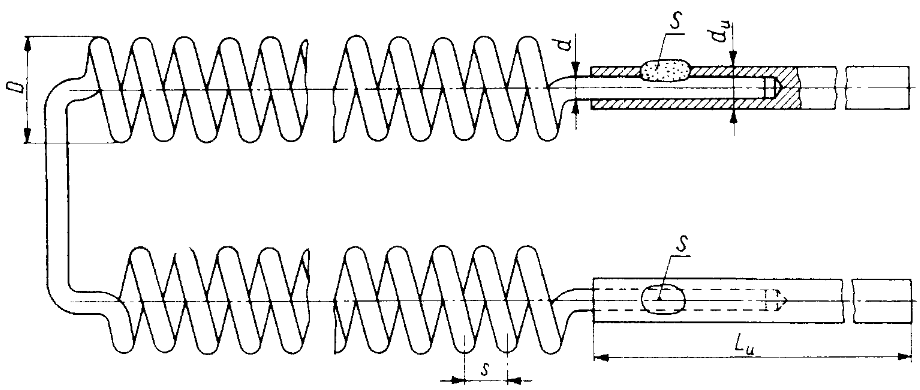

Fig.1. Spiral heating element

I. Determination of the heating element parameters

1. Resistance *R* of a (single) heating element

On the one hand

$$R = \frac{U^2}{P_1}, \qquad (1)$$

where

$$P_1 = \frac{P}{3}$$

is the power of one heating element. On the other hand

$$R = \frac{\rho\, l}{S} = \frac{\rho\, l}{\frac{\pi\, d^2}{4}} = \frac{4 \rho\, l}{\pi\, d^2} \tag{2}$$

where

- ρ – resistivity of the Kanthal A-1 wire at its maximum temperature,
- l – length of the wire,
- d – diameter of the wire,
- S – cross-section of the wire.

Comparing (1) and (2) length l and diameter d of the wire can be computed. But note that there are many solutions and a question arises: which pair of d and l computed is the right one?

Advice: Heating element *surface load* p_o has to be taken into account.

2. Heating element surface load

Surface load p_o, of a heating element, W/m^2, is determined by

$$p_o = \frac{P_1}{A_o} = \frac{P_1}{\pi\, d\, l} \tag{3}$$

where

$$A_o = \pi\, d\, l \tag{4}$$

is the side surface of the wire.

The correct value of the heating element surface load depends on the type of the wire used, on the structure of the heating element and its ceramic supports, on the structure of the furnace and its working conditions (temperature, atmosphere, the rate of the furnace on-offs, etc.).

Admissible ranges of the surface load can be found in proper data sheets and the choice of its value is done experimentally basing on working conditions of the heating element. At a higher load surface:

- less material is needed to build the heating element,
- durability of the heating element is reduced.

Note: The surface load p_o of the heating element and its resistivity should be read from Figs. 3 and 2 respectively, taking into account its working temperature.

3. Determination of the wire diameter

Comparing (1) with (2) and taking into account l determined from (3) gives

$$d = \sqrt[3]{\frac{4\, \rho\, P_1^2}{\pi^2\, p_o\, U^2}} \tag{5}$$

From the data sheet in Fig.2 we choose a diameter d_z possibly close to the value d calculated from (5).

4. Determination of the wire length

After comparing (1) with (2) and replacing d with d_z the wire length l can be calculated

$$l = \frac{\pi\, d_z^2\, U^2}{4 \rho\, P_1} \qquad (6)$$

The obtained value of l should be rounded to whole centimeters and marked as l_z.

Note: The computed value of length l_z should not be increased to take the heating element terminals into account etc.

5. Determination of the spiral heating element diameter *D*

The relation between the spiral heating element external diameter D and the wire diameter d_z should be chosen in the range (round D to whole millimeters):

$D = (5 \div 7)\, d_z$ - for $d_z > 1$ mm (7a)

$D = (4 \div 10)\, d_z$ - for $d_z < 1$ mm. (7b)

A too small heating element diameter D makes it difficult to wind the spiral (a too small radius of curvature); a too big heating element diameter D decreases the heating element endurance.

6. Determination of the spiral heating element pitch *s*

The spiral pitch s is chosen in the range (round s to whole millimeters):

$$s = (2 \div 3)\, d_z \qquad (8)$$

7. Determination of the number of the turns of the spiral heating element

The number n of the turns of the spiral heating element is determined from

$$n = \frac{l_z}{\pi (D - d_z)} \qquad (9)$$

where $\pi (D - d_z)$ is the average length of one turn of the spiral heating element.

8. Determination of the spiral heating element length

The spiral heating element length l_s is determined as

$$l_s = ns \qquad (10)$$

Note: In case of using Excel for calculations, its function *PI*() can be used.

II. Verification calculations

Basing on the input data and the calculated wire diameter d_z and wire length l_z determine the following parameters of the heating element: (*reminder* - our calculations concern only one phase):

a) heating element resistance,
b) current through the heating element,
c) current density,
d) power dissipated in the heating element,
e) surface load of the heating element.

Note: In the verification calculations above use d_z and l_z (obtained after rounding) – not d and l, calculated directly from (5) and (6).

III. Report contents

1. Place a summary of the following quantities obtained during execution of p. I quoting also the formula used:
   a) resistance furnace assumed power P, kW,
   b) power P_1 of a single phase, kW,
   c) calculated heating element resistance, equal to the wire resistance, Ω,
   d) surface load of the heating element assumed,
   e) wire diameter d calculated from (5), mm,
   f) wire diameter d_z chosen from the catalogue (Fig.2), mm,
   g) wire length l calculated from (6), m,
   h) wire length l_z rounded to whole centimeters, m,
   i) spiral heating element external diameter D, mm,
   j) spiral heating element pitch s, mm,
   k) number of the turns of the spiral heating element,
   l) spiral heating element length l_s, m.
2. Place the results of the verification calculations from p. II. Make sure that the surface load calculated here is within the permissible area (Fig.3).
3. Place a summary of the following quantities assumed or calculated in p.1 of the report and verified in p.2 of the report adding also relative errors:
   a) heating element resistance,
   b) heating element power,
   c) heating element surface load.

   Make sure that the relative errors are small.

IV. Bibliography

[1] Hering M.: Podstawy elektrotermii cz.I, WNT, Warszawa 1992 (in Polish).

[2] KANTHAL datasheet:

http://www.kanthal.com/Global/Downloads/Materials%20in%20wire%20and%20strip%20form/Resistance%20heating%20wire%20and%20strip/S-KA026-B-ENG-2012-01.pdf

KANTHAL

DRUT OKRĄGŁY

mm

Ciągniony

Skrót telegraficzny: EIDRA

Temperatura elementów: 1350° C

Oporność właściwa przy 20° C: 1.45 $\Omega \cdot mm^2/m$

Ciężar właściwy: 7.1

Oporność dla temperatury roboczej otrzymuje się mnożąc przez niżej podane współczynniki C_t:

Temp. °C	20	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1350
C_t	1.000	1.000	1.001	1.002	1.005	1.010	1.017	1.023	1.028	1.032	1.036	1.038	1.040	1.042	1.043

Ø mm	Ω/m 20° C	cm^2/m	m/kG	G/m	Ω/kG	cm^2/Ω 20° C
6.50	0.04370	204.2	4.244	235.6	0.1855	4680
6.00	0.05128	188.5	4.981	200.8	0.2554	3676
5.50	0.06103	172.8	5.928	168.7	0.3618	2832
5.0	0.07385	157.1	7.173	139.4	0.5297	2127
4.75	0.08184	149.2	7.948	125.8	0.6505	1823
4.5	0.09117	141.4	8.856	112.9	0.8074	1551
4.25	0.1022	133.5	9.928	100.7	1.015	1306
4.00	0.1154	125.7	11.21	89.22	1.294	1089
3.75	0.1313	117.8	12.75	78.40	1.674	897.2
3.50	0.1507	110.0	14.64	68.31	2.206	729.7
3.25	0.1748	102.1	16.98	58.89	2.968	584.2
3.00	0.2051	94.25	19.93	50.19	4.088	459.5
2.8	0.2355	87.96	22.87	43.72	5.386	373.5
2.60	0.2731	81.68	26.53	37.70	7.245	299.2
2.5	0.2954	78.54	28.39	34.85	8.386	266.0
2.40	0.3205	75.40	31.13	32.12	9.977	235.2
2.30	0.3490	72.26	33.90	29.50	11.83	207.1
2.20	0.3814	69.12	37.05	26.99	14.13	181.2
2.10	0.4186	65.97	40.66	24.59	17.02	157.6
2.00	0.4616	62.83	44.83	22.31	20.69	136.1
1.9	0.5114	59.69	49.68	20.13	25.41	117.3
1.8	0.5698	56.55	55.35	18.07	31.54	99.25
1.7	0.6388	53.41	62.05	16.12	39.64	83.60
1.60	0.7212	50.27	70.05	14.28	50.52	69.70
1.50	0.8205	47.12	79.70	12.54	65.33	57.43
1.40	0.9419	43.98	91.49	10.93	86.17	46.69
1.30	1.092	40.84	106.1	9.424	115.9	37.33
1.25	1.182	39.27	114.8	8.716	135.7	33.23
1.20	1.282	37.70	124.5	8.030	159.6	29.41
1.15	1.396	36.13	135.6	7.375	189.3	25.88
1.10	1.526	34.56	148.2	6.747	226.2	22.85
1.05	1.675	32.99	162.7	6.151	272.5	19.71
1.00	1.846	31.42	179.3	5.576	331.0	17.02

Fig.2. Parameters of Kanthal A-1 round wires.

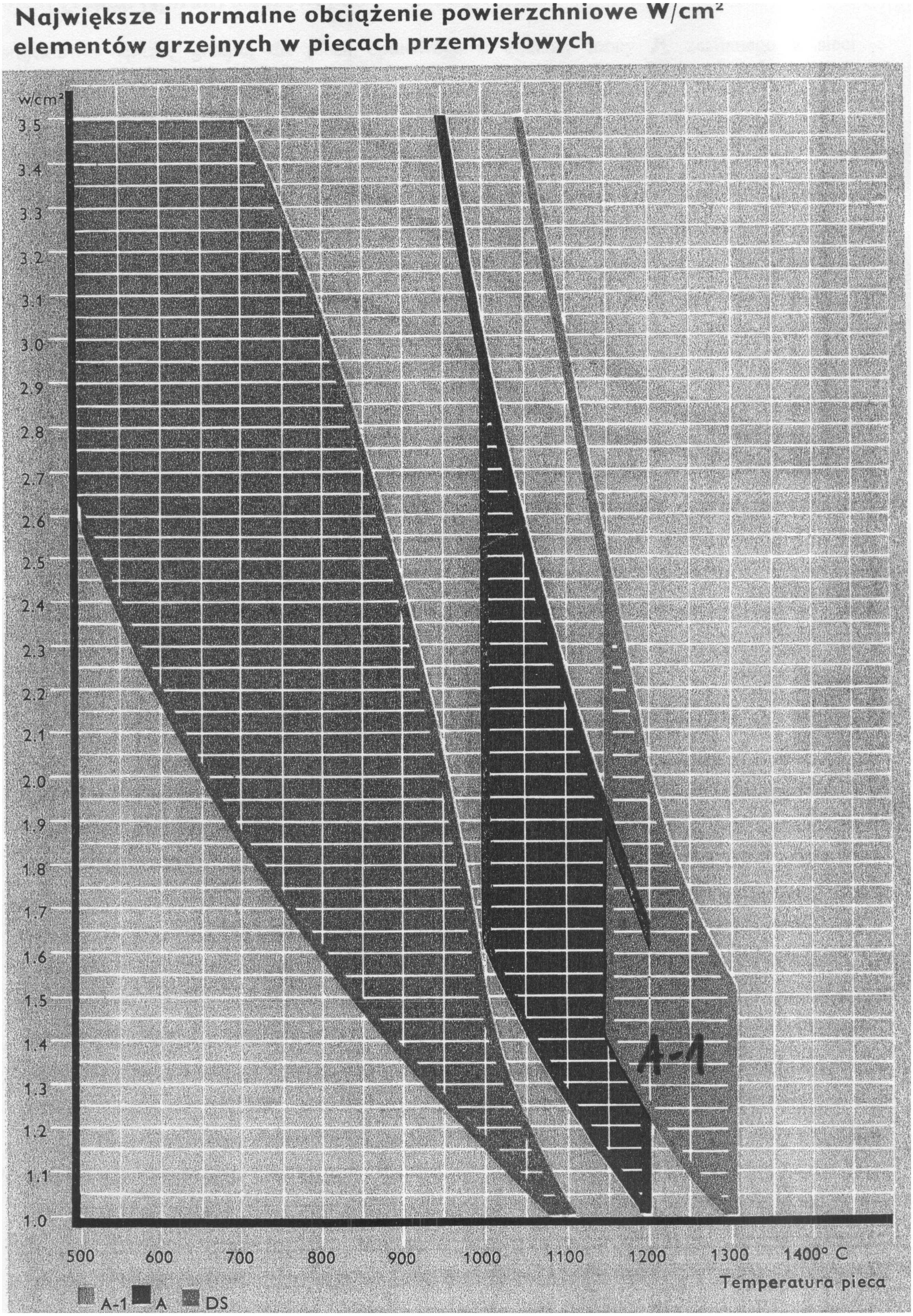

Fig.3. Surface load of round wires used in industry furnaces. Consider Kanthal A-1.