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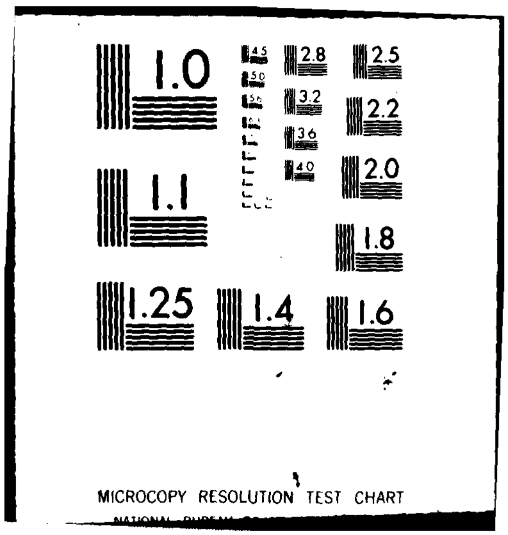
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FOREIGN TECHNOLOGY DIVISION

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ON THE PROBLEM OF THE CALCULATION OF THE INDUCTANCE OF MULTIPLATE FLAT AND CYLINDRICAL CONDENSERS WITH A NONINDUCTIVE WINDING

by

V. V. Konotop

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EDITED TRANSLATION

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By: V. V. Konotop

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

ON THE PROBLEM OF THE CALCULATION OF THE INDUCTANCE OF MULTIPLATE FLAT AND CYLINDRICAL CONDENSERS WITH A NONINDUCTIVE WINDING

Candidate of Technical Sciences V.V. Konotop
Kar'kov Order of Lenin Polytechnic Institute im. V.I. Lenin

Certain types of low-voltage and high-voltage pulse condensers are gathered from cylindrical or multiplate sections included so that the system of conductors inside the condenser can be examined as a rectilinear conductor of complex cross section.

Used in determining the inductance of the multiplate condenser section (Fig. 1) are the formulas given in [1, 2], and for the inductance of the cylindrical condenser section (Fig. 2) - formulas given in [2, 3].

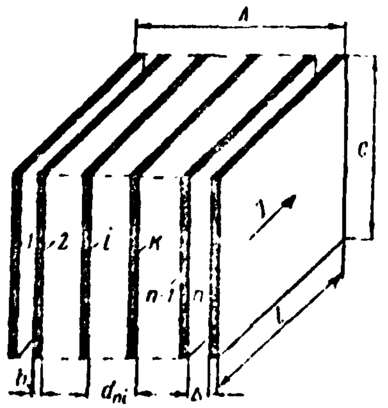

Fig. 1. Multiplate flat section.

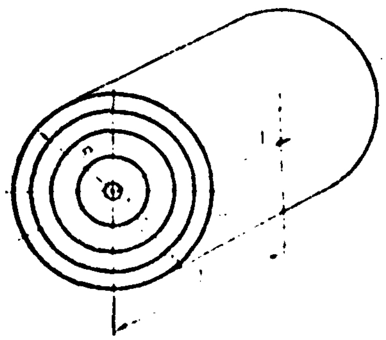

Fig. 2. Wound cylindrical section.

It is possible to show that the formula for determining the inductance of the multiplate condenser section is valid only with equality A and C, whereas the ratio of the sides in the section can reach up to one to ten.

The formula [2] for determining the inductance of the cylindrical section is valid only for the case of the passage of current over the surface of the section [4], which fundamentally cannot be in the condenser section of the examined type. The formula given in [3] is accurate only for the case $l \gg 2R$. When $l \approx 2R$ a considerable error in determining the inductance is obtained, and when $l < 2R$ there is even a negative value of the inductance.

It should also be noted that in the derivation of these formulas no analysis was conducted of the effect of the number of facings and coils on the inductance of the section, whereas the number of the facings and coils in the condenser can be varied from two to several thousand.

The system of facings of the section of the condenser can be represented as a rectilinear conductor of complex cross section, for which in the inductance L can be found according to formula [4], which after conversions will have the following form:

$$L = \frac{\mu_0 l}{2\pi}\left[\ln 2l - \frac{\sum_{k=1}^{n} s_n^2 \ln g_k + \sum_{k=1}^{n}\sum_{i=1}^{n} s_n s_i \ln g_{ki}\,(k = i)}{\left(\sum_{k=1}^{n} s_k\right)^2} - 1 + \frac{\sum_{k=1}^{n} s_k^2 a_k + \sum_{k=1}^{n}\sum_{i=1}^{n} s_n s_i a_{ki}\,(k \neq i)}{l\left(\sum_{k=1}^{n} s_k\right)^2} - \frac{\sum_{k=1}^{n} s_n^2 q_k^2 + \sum_{k=1}^{n}\sum_{i=1}^{n} s_k s_i q_{ki}^2\,(k \neq i)}{4l^2\left(\sum_{k=1}^{n} s_k\right)^2}\right], \quad (1) \quad (1)$$

where l is the length of the section;

- s - area of the facing;
- n - number of facings;
- g_k - mean geometric distance of the area of the facing from itself (m.g.d.);
- g_{ki} - m.g.d. between areas of the facings;
- a_k - mean arithmetic distance of the area of the facings from itself (m.a.d.);

a_{ki} - m.a.d. between areas of facings;

q_k - mean quadratic distance of the area of facings from itself (m.q.d.);

q_{ki} - m.q.d. between areas of the facings.

Flat multiplate condenser. For the flat multiplate condenser the following relations are evident:

a) areas of facings are equal to

$$s = s_k = s_i = bc, \tag{2}$$

b) distance between facings d_{ki} with subscripts k and i equals

$$d_{ki} = (b + \Delta)(k - i), \tag{3}$$

where b is the thickness of the facing;

Δ - thickness of the dielectric.

Furthermore, for the condenser, as a rule, b≪c.

Considering (2) and (3), we can find the m.g.d., m.a.d. and m.q.d. of facings of the condensers from themselves and between areas of separate facings according to the appropriate formulas [4] for conductors of the rectangular section

$$\ln g_k = \ln g_{об} = \ln 0,223C; \tag{4}$$

$$a_k = a_{об} = \frac{C}{3}; \tag{5}$$

$$q^2 = q^2_{об} = \frac{C^2}{6}; \tag{6}$$

$$\ln g_{ki} = \ln 0,223(d_{ki} + C) + \frac{3d^2_{ki} - 4d_{ki}C}{2(d_{ki} + C)^2}; \tag{7}$$

$$a_{ki} = \frac{d_{ki}}{C}\ln\frac{C + \sqrt{d^2_{ki} + C^2}}{d_{ki}} - \frac{d^2_{ki}}{C^2}\sqrt{d^2_{ki} + C^2} - $$

$$+ \frac{(d^2_{ki} + C^2)^{\frac{3}{2}}}{3C^2} + \frac{2}{3}\cdot\frac{d^3_{ki}}{C^2}; \tag{8}$$

$$q^2_{ki} = d^2_{ki} + \frac{C^2}{6}. \tag{9}$$

By substituting (2)-(9) into (1), we obtain

$$L_1 = \frac{\mu_0 l}{2\pi}\left\{\ln 2l - 1 - \left[\frac{\ln g_{об}}{n} + \frac{1}{n^2}\sum_{k=1}^{n}\sum_{i=1}^{n}\ln g_{ki}\right]_{k \ne i} + \right.$$

$$\left. + \frac{1}{l}\left[\frac{a_{об}}{n} + \frac{1}{n^2}\sum_{k=1}^{n}\sum_{i=1}^{n}a_{ki}\right]_{k \ne i} - \frac{1}{4l^2}\left[\frac{q^2_{об}}{n} + \frac{1}{n^2}\sum_{k=1}^{n}\sum_{i=1}^{n}q^2_{ki}\right]_{k \ne i}\right\}. \tag{10}$$

Let us find the expression of the sums entering into (10)

$$\sum_{k=1}^{n}\sum_{i=1}^{n}\ln g_{ki} = 2[(n-1)\ln g_{k-i=1} + (n-2)\ln g_{k-i=2} \cdots + \\ \cdots + 1\ln g_{k-i=n-1}] = 2\sum_{x=1}^{n-1}(n-x)\ln g_x. \quad (11)$$

The remaining sums by analogy with (11) will be equal to

$$\sum_{k=1}^{n}\sum_{i=1}^{n} a_{ki} = 2\sum_{x=1}^{n-1}(n-x)\,a_x; \quad (12)$$

$$\sum_{k=1}^{n}\sum_{i=1}^{n} q_{ki} = 2\sum_{x=1}^{n-1}(n-x)\,q_x^2. \quad (13)$$

It is possible to calculate the expressions (11)-(13) according to the Katalan formula [5]

$$\int_a^{b+1} f(x)\,dx < \sum_a^b f(x) < \int_{a-1}^{b} f(x)\,dx. \quad (14)$$

By substituting (11) into (14) and considering (4) and (7), we have

$$n^2\ln g_э - 2n\ln g_{об} + \ln g_{об} < 2\sum_{x=1}^{n-1}(n-x)\ln g_x < n^2\ln g_э. \quad (15)$$

Substituting (12) into (14) and considering (4) and (8), we get

$$n^2 a_э - 2n a_{об} + a_{об} < 2\sum_{x=1}^{n-1}(n-x)\,a_x < n^2 a_э. \quad (16)$$

Substituting (13) into (14) and considering (6) and (9), we get

$$n^2 q_э^2 - 2n q_{об}^2 + q_{об}^2 < 2\sum_{x=1}^{n-1}(n-x)\,q_x^2 < n^2 q_э^2. \quad (17)$$

Substituting (15) and (16) into (10) and making the conversions, we get

$$L_э + L_{n1}\left(1 - \frac{1}{n}\right) < L_1 < L_э + L_{n1}, \quad (18)$$

where

$$L_э = \frac{\mu_0 l}{2\pi}\left(\ln 2l - 1 - \ln g_э + \frac{a_э}{l} - \frac{q_э^2}{4l^2}\right); \quad (19)$$

$$L_{n1} = \frac{\mu_0 l}{2\pi n}\left(\ln g_{об} - \frac{a_{об}}{l} + \frac{q_{об}^2}{4l^2}\right), \quad (20)$$

where $g_э$, $a_э$ and $q_э$ are, correspondingly, the m.g.d., m.a.d. and m.q.d. of areas of the metallic conductor with a cross section equal to the cross section of the section of the condenser. These values can be found by the appropriate formulas [4] for the conductor of the rectangular section

$$\ln g_э = \ln 0{,}223\,(C + A); \tag{21}$$

$$a_э = \frac{1}{6}\cdot\frac{A^2}{C}\ln\frac{C + \sqrt{A^2+C^2}}{A} + \frac{1}{6}\cdot\frac{C^2}{A}\ln\frac{A + \sqrt{A^2+C^2}}{C} + \frac{\sqrt{A^2+C^2}}{3} - \frac{1}{15}\cdot\frac{(A^2+C^2)^{\frac{3}{2}}}{A^2C^2} + \frac{1}{15}\cdot\frac{A^3}{C^2} + \frac{1}{15}\cdot\frac{C^3}{A^2}; \tag{22}$$

$$q_э^2 = \frac{A^2+C^2}{6}. \tag{23}$$

The nomograms for determining $L_э$ and L_{nl} are given on Figs. 3 and 4, respectively.

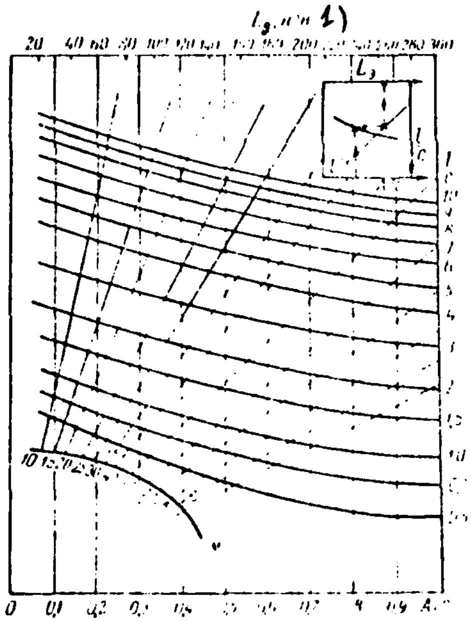

Fig. 3. Nomograms for determining $L_э$. Key: 1) $L_э$, nH.

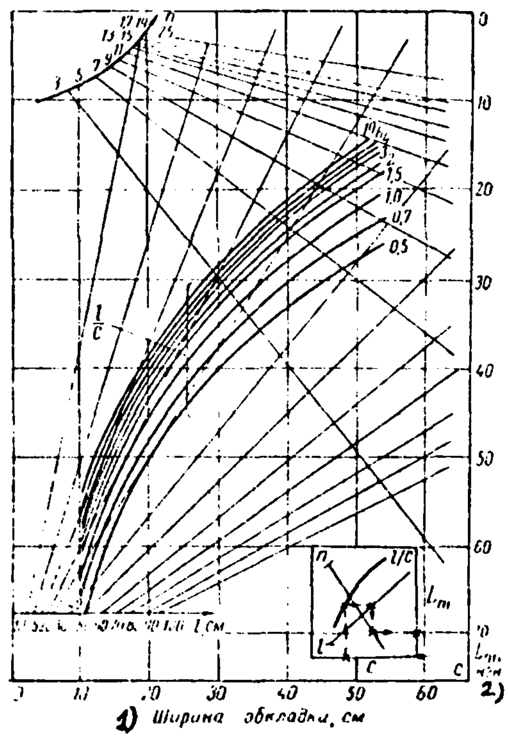

Fig. 4. Nomograms for determining L_{nl}. Key: 1) Width of facing, cm; 2) nH.

Cylindrical wound condenser. Having used the expression (1), it is possible to obtain the formula for determining the inductance of the section of the cylindrical condenser

$$L_2 = \frac{\mu_0 l}{2\pi}\left[\ln 2l - 1 - \left(\ln 0{,}778 R + \frac{1}{3}\cdot\frac{\ln 0{,}778 R}{n}\right) + \right.$$
$$\left. + \frac{1}{l}\left(0{,}91 R + 1{,}45\frac{R}{n}\right) - \frac{1}{4l^2}\left(R^2 + 1{,}6\frac{R^2}{n}\right)\right]. \qquad (24)$$

When $n \gg 1$, formula (24) is considerably simplified

$$L_2 = \frac{\mu_0 l}{2\pi}\left(\ln\frac{2l}{R} - 0{,}75 + \frac{0{,}91 R}{l} - \frac{R^2}{4l^2}\right). \qquad (25)$$

Example 1. The determination of the inductance of a multiplate section of a high-voltage pulse condenser with these parameters: A = 5 cm, n = 50, l = 27.5 cm, C = 50 cm. According to the formula of [1, 2] $L_1 \approx 40\cdot10^{-9}$ H, and according to the refined formula, $L_1 \approx 70\cdot10^{-9}$ H.

The relative error in the determination of inductance according to [1] consists of 43%.

Example 2. Determination of the inductance of a cylindrical section with a noninductive winding with parameters R = 25 cm, l = 25 cm. According to formulas of [1-3] $L_2 < 0$. According to formula (25), L = 30 nH.

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