$Q = mpq = 3 \times 10 \times \frac{8}{5} = 48$ total slots

$q = \frac{Q}{3 \times 10} = \frac{48}{30} = \frac{8}{5} = 1 + 3/5$

A1-3. The Layout of a Fractional-Slot Winding. The layout of a fractional-slot winding on the basis of the slot star will be demonstrated by an example.

Assume $p = 10$, $q = 1\frac{3}{5} = \frac{8}{5} = 1 + \frac{3}{5}$, $\beta = 5$, $N = 8$, $m = 3$, $a = 1$, $b = 3$; $\alpha_s = 37.5°$, $\alpha_m = 7.5°$, 5 poles make a unit (recurrent group). There will be, in 5 poles, $3 \times N = 24$ slots, $N = 8$ for each phase. Each phase will have, per unit, $b = 3$ coil groups with 2 single coils and $\beta - b = 5 - 3 = 2$ coil groups with 1 single coil. It follows from Eq. (A1-4) that

$\beta = 5$ poles in R.u.
$N = 8$ slots per ϕ in R.u.
$3 \times N = 24$ slots in R.u.

$$d = \frac{3 \times 8 \times P + 1}{5}, \quad P = 1, \quad d = 5.$$

smallest P to make d a whole number

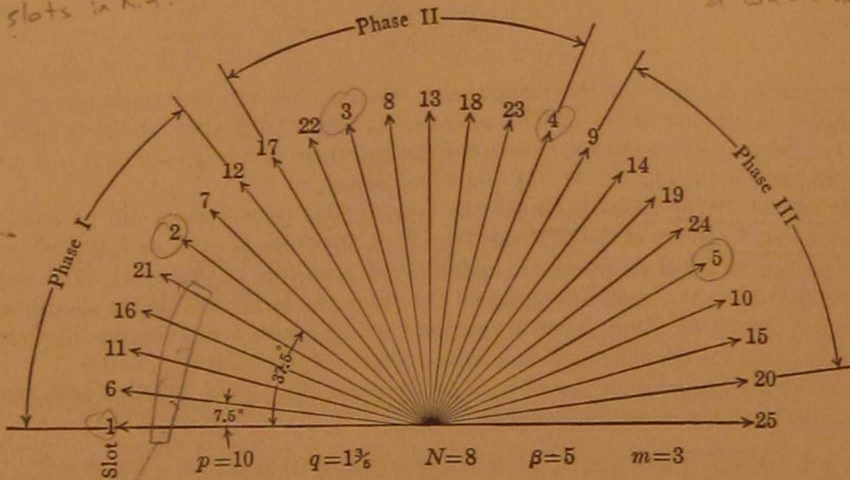

FIG. A1-4a. Slot star for the winding of the example. shows one R.u.

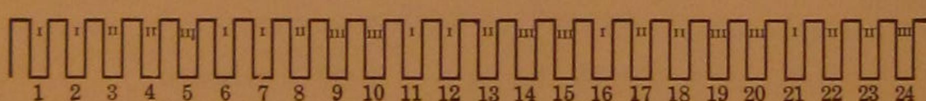

FIG. A1-4b. Slot distribution among the 3 phases to the winding of Fig. A1-4a.

The $N = 8$ slots which belong to the phase I therefore are

1	$1 + d$	$1 + 2d$	$1 + 3d$	$1 + 4d$	$1 + 5d - 3N$	$1 + 6d - 3N$	$1 + 7d - 3N$,	(A1-M)
1	6	11	16	21	2	7	12	

or, arranged corresponding to the sequence of the slots in the machine,

$$1\ 2 \quad 6\ 7 \quad 11\ 12 \quad 16 \quad 21 \qquad \text{(A1-L)}$$

2 2 2 1 1

The 8 slots which belong to phase II are

$1 + 8d - 3N$,	$1 + 9d - 3N$,	$1 + 10d - 6N$,	$1 + 11d - 6N$,	$1 + 12d - 6N$,
17	22	3	8	13
		$1 + 13d - 6N$,	$1 + 14d - 6N$,	$1 + 15d - 9N$,
		18	23	4

or, arranged corresponding to the sequence of the slots in the machine,

3 4 8 13 17 18 22 23

The 8 slots which belong to phase III are

5 9 10 14 15 19 20 24

Fig. A1–4a shows the slot star of this winding, Fig. A1–4b the distribution of the slots among the 3 phases.

In phase I the sequence of the coil groups, in each unit, is: 3 coil groups with 2 single coils and 2 coil groups with 1 single coil. *This sequence of the coil groups must be the same for all 3 phases in each unit*, i.e., when β (here $\beta = 5$) poles are divided into $m = 3$ equal parts, the sequence of the coil groups must be the same, starting from the beginning of each part. This is shown in the following chart:

Part 1					Part 2					Part 3					Sequence of coil groups in
2			2			2			1			1			Phase I
		1			2			2			2			1	Phase II
	2			1			1			2			2		Phase III
2	2	1	2	1	2	2	1	2	1	2	2	1	2	1	Sequence of coil groups for 5 poles (recurrent group of the winding)

$\beta=5$

If $m \times \beta$ (in the example $3 \times 5 = 15$) divisions are used, each part will consist of β (= 5) divisions, and from the beginning of each part the sequence of the coil groups must be the same. The beginnings of the 3 parts therefore lie in slots 1, $1 + N$, and $1 + 2N$ (in the example in the slots 1, 9, and 17). The sequence of the slots per recurrent group *for all 3 phases* then can be obtained easily, as shown in the chart. Fig. A1–5 shows the complete winding.

In the integral-slot winding, the beginnings of the *phases* are displaced by 120 and 240 electrical degrees. Also in the fractional-slot windings the distances between the beginnings of the phases can be made 120 and 240°. This will be the case, for example, when the beginnings are placed in slots 1, $1 + N$, and $1 + 2N$, when β is an even number, and in slots 1, $1 + 2N$, and $1 + (1 + m)N$, when β is an odd number. This arrangement of the beginnings of the phases will place them far apart from each other mechanically while it usually is desirable to have them near to each other. In order to place the beginnings of the phases near to each other, the beginnings can be placed *approximately* 120 and 240 electrical degrees apart and the winding still will be balanced, i.e., the 3-phase voltages still will have the same magnitude and will be displaced exactly by 120 and 240 electrical degrees. This is due to the fact that in the fractional-slot winding the emfs of the consecutive coil groups are not in-phase, and the sequence of the geometric addition of the single emfs is of no influence on the resultant phase emf. So in the example considered, the beginnings of the phases can be placed in slot 1 which belongs to phase I, in slot 5 which belongs to phase III, and in slot 8 which belongs to phase II. The angles between the beginnings are then 150 and 262.5 electrical degrees. In a winding with $q = 1\frac{1}{4}$ the beginnings of the phases can be placed in the slots 1, 4, and 6 which are 144 and 240 electrical degrees apart.

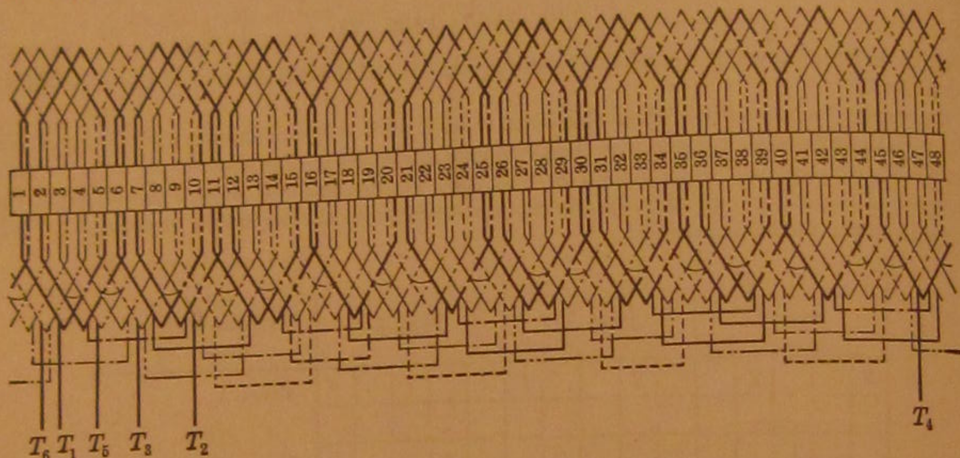

FIG. A1–5. Complete winding to Figs. A1–4a and A1–4b.

In the winding with $q = 1\frac{5}{13}$ the beginnings of the phases can be placed in the slots 1, 7, and 13 which are 140 and 260 electrical degrees apart.

If

$$\frac{\beta}{m} = \text{integer,} \tag{A1-5}$$

there will be no value of P which makes d in Eq. (A1–4) an integer. In this case the fractional-slot winding is *unbalanced,* i.e., neither the phase voltages nor the phase angles are equal to each other.

Summary. In order to lay out a fractional-slot winding, determine first from Eq. (A1–4) the magnitude of d and set up for phase I only the series A1–M and the slot sequence A1–L. Use $m \times \beta$ divisions (best on squared paper) and place the coil *groups* of phase I m divisions apart as shown in the foregoing chart. For the other phases use the same coil group sequence as for phase I but start them β divisions apart. This yields the coil grouping for a recurrent part of the winding with $m \times N$ slots. All recurrent parts of the winding are alike.

A1–4. Distribution and Pitch Factor. It can be seen from the slot star, Fig. A1–3, that the fractional-slot winding behaves like a winding with N slots per pole per phase shifted with respect to each other by the magnetic field angle α_m. Fig. A1–3 relates to the main (synchronous) wave. Therefore, the distribution factor of the main wave of the fractional-slot winding (see Art. 5–2)

N

same except $\angle \alpha_m$

$$k_d = \frac{\sin N\,\alpha_m/2}{N \sin \alpha_m/2} \tag{A1-6}$$

The value of α_m is given by Eq. (A1–3). Inserting this equation into Eq. (A1–6) there