UNIVERSAL COIL WINDING

Editor's Note: We present this article, which originally appeared some years ago in *Radiotronics*, with the idea that it will be of great assistance to all those who are interested in coil winding. There is no reason why the small workshop should not be equipped to wind its own coils, since a knowledge of the basic principles as set out here is all that is needed to enable anyone to build a simple hand winder for himself.

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SUMMARY: A typical coil winding machine and the winding patterns derived from it are described. The various factors which influence the choice of the coil winding gear ratio are explained and analysed. The results are presented in a form suitable for slide rule computation. The detection of faults in winding machines is discussed and the paper includes a bibliography of the existing literature on universal coil winding.

Introduction

The object of this paper is to present coil winding from a physical rather than a mathematical point of view—to build up a mental picture of the coil winding process and from this picture to deduce the requirements which a coil winding gear ratio must meet. In addition, in the calculation of gear ratios consideration is given to a factor which although not normally taken into account has been found helpful in the mass production of coils. The attached bibliography gives details of universal coil winding literature already in existence.

Symbols

The symbols used in the following treatment with their meanings are set out below for convenience:

d = coil former diameter (inches).
c = cam throw (inches).
n = nominal number of crossovers in one former revolution.
q = nominal number of crossovers in one winding cycle.
v = number of former revolutions in one winding cycle.
$R = \text{gear ratio} = \dfrac{\text{former gear}}{\text{cam gear}}$
w^1 = wire diameter (inches). See text.
w = modified wire diameter (inches). See text.
$P = qc/s$.
$s = w + x$.
x = smallest amount necessary to make $(qc + s)/vs$ an integer (inches).
T = number of turns in coil.
N = number of spokes on side of coil.
H = winding space.
$\propto$ = angle between wire and edge of coil.

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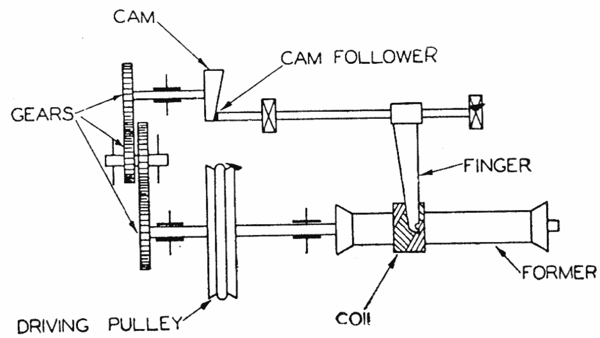

Figure 1. Essential features of a typical coil winding machine.

Description of Machine

The most generally used type of machine is belt driven at a fixed speed, although it is possible for the operator to slip the foot operated clutch to minimize strains on the wire when starting. The drive operates on a shaft directly connected to the former and from this shaft a gear drive to the cam shaft is provided. There is provision for a chain of four gears although the middle pair can be replaced by a single idler if desired. In general the number of teeth on the gears used lies between 20 and 60.

The shape of the cam is such that the displacement of the cam follower is linear with respect to rotation of the cam. The cam follower is spring loaded against the face of the cam and drives a carriage along guides running parallel with the length of thet coil former. On this carriage is mounted the finger which directs the wire on to the former. Figure 1 shows the essential features of such a machine. The wire is fed to the finger over a chain of spring loaded pulleys which, by controlling the pressure on a brake band mounted on the same shaft as the reel of wire, maintain an approximately even tension on the wire, prevent it from snapping when it has to set the reel in rotation and take up the slack wire when the machine is stopped suddenly.

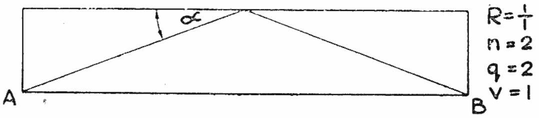

Figure 2. The winding pattern produced with a 1 to 1 gear ratio; $n = 2$, $q = 2$, $v = 1$.

Derivation of Pattern

While many defects will prevent a coil from winding correctly, the first requirement for a properly wound coil is a suitable gear ratio between former and cam. In considering the effects of different gear ratios it is convenient to use a developed pattern of the coil winding. This is obtained by allowing the coil to proceed for one winding cycle, i.e., for the maximum number of complete turns which can be placed on the former before one turn lies against a previously wound turn. The former is then considered to be split lengthwise and flattened and the pattern results from the excursions of the wire across the former.

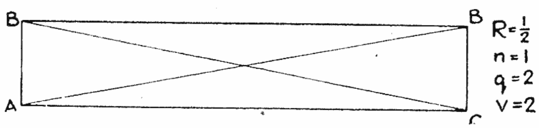

Figure 3. The winding pattern produced with a 1 to 2 gear ratio; $n = 1$, $q = 2$, $v = 2$.

Under these conditions Fig. 2 shows the pattern obtained with a 1 to 1 gear ratio, giving one cam revolution for each former revolution. Since each cam revolution gives two crossovers, $n = 2$ when the gear ratio is unity. In the list of symbols, n is defined as the nominal number of crossovers per turn and q as the nominal number of crossovers per winding cycle because no account is taken when determining them, of the slight variation in the number of crossovers brought about by the necessity for wire spacing. As a result, n is always an integer or a simple fraction. and q is

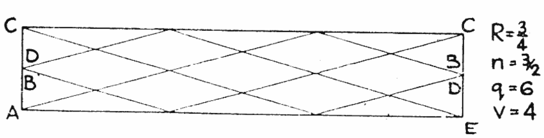

Figure 4. The winding pattern produced with a 3 to 4 gear ratio; $n = 3/2$, $q = 6$, $v = 4$.

always an even number. A discussion of wire spacing is given later. Figure 3 shows the pattern when $R = \frac{1}{2}$ and Fig. 4 the pattern for $R = \frac{3}{4}$. The method of drawing the pattern in the case of Fig. 4, for example, is as follows. Starting at A the wire makes n crossovers by the time the former has travelled πd, finishing the first turn at B. The second turn starts at B^1 and after n more crossovers finishes at C. The third turn starts at C^1 and the pattern continues in this manner until it finishes in the bottom right hand corner at E. Each of the above patterns shows one winding cycle of q crossovers and v turns. In the case of Fig. 4 it will be seen that $v = 4$ and $q = 6$.

The necessity for making use of patterns other than that obtained from a 1/1 ratio will be appreciated when it is realized that if the angle $\propto$ at which the wire crosses the former is too great, the wire will slide on the former at the point at which the cam alters its direction of movement. On the other hand the coil gains its mechanical rigidity only from the fact that wires in a layer are held in position by wires in the next layer crossing them at an angle thus holding them down firmly. Because of this $\propto$ must not be too small. The angle of $\propto$ is obviously dependent on d and c, and to wind coils with different cams and on formers of different diameters, it is necessary to vary the value of n, with consequent variations in the pattern. Although the maximum angle at which the wire will lie on the former without slipping varies with different wire coverings and different types of former materials, it is found that so long as

$$n \leq \frac{2d}{3c} \qquad \text{.......... (1)}$$

coils with all commonly used wire coverings can be wound on any of the former materials normally encountered without trouble from slipping being experienced. When $n = 2d/3c$, $\propto$ is approximately 12 degrees. However, as the winding proceeds, the effective diameter of the coil increases and consequently $\propto$ decreases so that when a coil is required to build up appreciably it is desirable to start the winding with $\propto$ near its maximum permissible value.

It is found that the simpler the pattern the more mechanically stable will be the resulting coil and mechanical stability is essential if coils are to duplicate electrical properties accurately. Consequently, when deciding the value of n, it is desirable to choose an integer or a simple fraction, to complete the winding cycle after as few former revolutions as possible. Since n must not exceed the maximum obtained from (1) the next smallest convenient value below the maximum must be used. For example, suppose a coil is to be wound on a $\frac{9}{16}$ inch diameter former with a $\frac{1}{4}$ inch cam, $2d/3c = 3/2$ and n can be given this value, in which case the pattern of Fig. 4 will result. A simpler pattern and a better coil will result if n is made equal to unity, giving the pattern of Fig. 3.

Other factors to be borne in mind when determining n are firstly that the maximum speed at which a coil winding machine can be operated is usually the greatest speed at which the cam follower will accurately follow the shape of the cam when its direction of movement is reversed. Consequently the value of n determines the speed at which the machine can be operated and the larger the value chosen for n the slower the machine must run. With normal adjustments a machine will wind a coil using a $\frac{1}{8}$ inch cam and two crossovers per turn at 1400 r.p.m. without the cam follower "hopping", but higher speeds, a larger cam, or more crossovers per turn may give trouble. The lower limit for n

seems to be more dependent on cam throw, wire diameter and details of machine adjustment than the upper, but it can usually be assumed that a coil will build up until $n = d/6c$ and it may sometimes be convenient to design so that this limit is approached at the top of the coil.

The second restriction on the choice of n is that if n gives a pattern with crossing wires (Figs 3 and 4, but not Fig. 2), i.e. if n has any value other than an even integer, then one or more ridges will appear in each layer of the coil at the point of the cam travel marked by the crossing wires. These ridges are not themselves undesirable, but if the wire used in the winding is insulated only with enamel it is difficult to prevent the finger, as it travels to and fro across the face of the coil, from removing the enamel from the wire forming the ridge.

Despite the apparent complexity of the above considerations, it is found in practice that the majority of coils are wound with two crossovers per turn, this being the correct choice for a $\frac{1}{16}$ inch cam on a former of $\frac{3}{16}$ inch to $\frac{3}{8}$ inch diameter, or for a $\frac{1}{8}$ inch cam on a former of $\frac{3}{8}$ inch to $\frac{3}{4}$ inch diameter.

Choice of Cam

Where the cam is to be chosen before n can be decided, the following points should be remembered.

Q of Coil

Maximum Q is usually obtained for a coil in which the diameter of the winding is approximately equal to its length whether or not the coil is wound in sections. This assumes that there is reasonable clearance (about equal to the radius of the coil) between the outside of the coil and any shield that it may have. If the clearance is smaller, a flatter coil will give a better Q.

Ratio of Cam to Wire Diameter

The cam should always be wide enough for at least six and preferably more wires to lie across the face of the coil. If this requirement is not met, difficulty will be experienced in making the coil build up.

Distributed Capacitance

The smaller the cam the lower will be the distributed capacitance of the winding for a given inductance and wire size.

Split Windings

A coil wound in sections with thin individual windngs usually has a smaller distributed capacitance than a solid winding, and thus a better Q since the losses in stray capacitances in coils are high.

Height of Coil

The larger the cam the smaller will be the height of the coil for a given inductance and wire size.

Wire Spacing

Consideration so far has been given only to the angle at which the wire is placed on the former. After

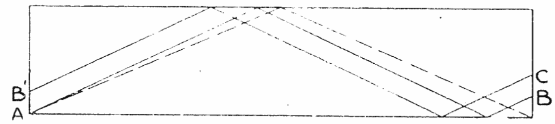

Figure 5. A retrogressive coil winding.

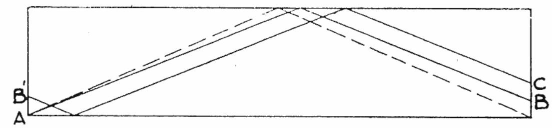

Figure 6. A progressive coil winding.

the first cycle the patterns described would begin a second cycle on top of the first. This would not give a stable winding and the second purpose of the gear drive is to displace each pattern, or winding cycle, by some convenient amount from the preceding one. Normally the wire in the second cycle is made to lie alongside and as close as possible to the wire in the first cycle, although this slight displacement is not usually taken into account in the drawing of the pattern. This gives two possibilities, as shown in Figs 5 and 6. The dotted line shows the pattern produced by a 1/1 gear ratio, and the winding, shown in full lines, proceeds from A to B during the first revolution of the former, and from B^1 to C during the second revolution. Figure 5 shows the effect produced when the cam returns, just before the end of the winding cycle, to the side of the coil from which it started; in Fig. 6, it returns to the side of the coil just after the end of the winding cycle. Coils wound as shown in Fig. 5 are retrogressive coils, and those shown in Fig. 6 are progressive coils. In each case the former is rotating towards the left hand side of figure and the wire is placed on it under tension by a finger located on the right hand side. In Fig. 5 the tension from the right pulls each turn against the preceding turn, while in Fig. 6 the tension pulls the turn away from the preceding ones. The result is that a more solid winding is obtained with retrogressive gears and in practice it is found that with coils that are at all difficult to wind, as for example when very fine wire is beng used or if a machine is not in perfect condition, retrogressive coils build up more readily than progressive ones. For this reason the treatment that follows is for retrogressive coils.

The spacing needed between adjacent wires can only be found by experiment and it is not possible to specify any one spacing factor which will give the best results with enamelled wire, litz wire, and fabric covered wire. In fact, to obtain the best results, i.e. to wind large coils under difficult conditions, even with fabric covered wire, it is necessary to use different spacing factors depending on the flexibility of the wire and the sponginess of the coverings. However, it is possible to give a rule from which gears can be calculated, resulting in a coil that will build up (other requirements being met satisfactorily) and with a likelihood that they will be the best gears for a given set of con-

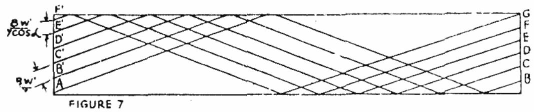

Figure 7. The relation between wire spacing and cam movement.

ditions. A problem in deciding the spacing to allow for each wire is the determination of the thickness of the wire itself. Even when wire tables are available, many wires do not conform sufficiently accurately with the figures stated for them to be used, and with fabric covered wires the method of measurement has a considerable effect on the result. The method used in work on which this paper is based is to tighten the micrometer until the wire can only just be pulled between the measuring surfaces by a tension similar to that exerted by the tension device on the coil winding machine. An occasional high spot can be ignored and under these conditions the micrometer setting is taken as the wire diameter.

Normally a coil is wound as tightly as possible so that it will be small physically, and a spacing between

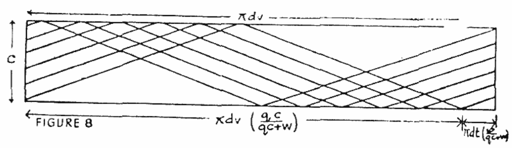

Figure 8. The first few turns of a coil for which $n = 2$, $q = 2$, $v = 1$.

centres of adjacent wires of approximately $8w^1/7$ is found experimentally to meet this requirement for fabric covered wires. When the wire is enamelled only, the same spacing can be used if the diameter of bare wire is used for w^1. The required spacing factor is governed by the type of finger used and for the spacing mentioned, a finger such as that described in section 13.2 which places the wire in position on a coil is assumed. For cases in which the wire is fed through a groove on top of the finger larger spacing factors are needed, and accurate control of wire position in the coil is not possible. It will often be found that solid wires with fabric covering will give an improved winding with smaller spacing factors, while litz wire windings may improve with more spacing. However, the spacing quoted seems to be the best compromise for the conditions stated and can usually be depended upon to give a winding sufficiently stable for production purposes.

It will be seen from Fig. 7 that to give a spacing of $8w^1/7$ between the centres of adjacent wires, it would be necessary for the cam to give a spacing of $8w^1/7 \cos \alpha$ at the same point of former rotation in the winding cycle.

However, since $\alpha \leqq 12$ degrees, so that $\cos \alpha$ lies between unity and 0.978, it is convenient in practice to ignore $\cos \alpha$ and to measure $8w^1/7$ in terms of cam displacement across the face of the coil.

Spokes

Since each cam revolution produces two crossovers of the wire on the former it is necessary when comparing cam travel with former travel to use two crossovers, $2c$ as the unit of cam travel and one former revolution πd, as the unit of former travel. A gear ratio can be expressed as the ratio R of former gear to cam gear, but since a large former gear driving a small cam gear gives a small former movement and a large cam movement,

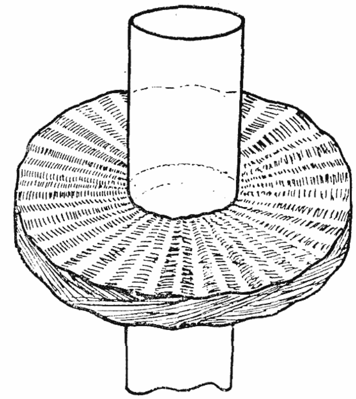

Figure 9. Illustration of side pattern obtained with suitable gear ratio.

$$R = \frac{\text{cam travel}}{2c} \div \frac{\text{former travel}}{\pi d}$$

$$= \frac{\text{cam travel}}{\text{former travel}} \; \frac{(\pi d)}{(2c)}$$

To produce the patterns of Figs 2, 3, or 4, in which the cam travel is qc and the former travel πdv,

$$\mathrm{R} = \frac{qc\ (\pi d)}{\pi dv\ (2c)}$$

To give the necessary spacing between the wires at the end of one winding cycle and the beginning of the next in a retrogressive coil, the total cam travel must be $qc + 8w^1/7$ for a former travel of πd. For convenience the quantity $8w^1/7$ is termed the modified wire diameter w, and the required gear ratio for a retrogressive coil is

$$R = \frac{qc + w}{\pi dv} \; \frac{(\pi d)}{(2c)}$$

$$\therefore R = \frac{qc + w}{2cv} \qquad \text{.......... (2)}$$

Since the total cam movement is $qc + w$ while the former completes a winding cycle, the coil former moves through $qc/(qc + w)$ of a winding cycle, while the cam completes q crossovers. Thus, towards the end of each winding cycle (after q crossovers) the finger returns to the side of the coil from which it started and reaches the side displaced

$$\left\{1 - \frac{qc}{qc + w}\right\}$$

i.e. $w/(qc + w)$ of a winding cycle from its starting point. Since a winding cycle is πdv, the finger returns to the edge of the coil displaced $\pi dv.w/(qc + w)$ from its position at the beginning of the cycle.

The amount $\pi dv.w/(qc + w)$ is a winding space, H, and in terms of the actual winding it represents the distance around the edge of the coil between adjacent wires at the peak of the cam travel. Figure 8 shows the first few turns of a coil in the case where $n = 2$, $q = 2$, and $v = 1$.

When the coil has been wound the winding spaces can be seen on the edge of the coil, and if successive layers have winding spaces directly above each other spokes appear on the side of the coil extending radially outwards from the former as shown in Fig. 9. Where there is a slight displacement of the winding cycles in each layer, these spokes become spirals and with large displacements the spokes tend to disappear completely. It is considered desirable to produce straight spokes in production coils because this allows a very easy check on the condition of coil winding machines. A badly adjusted machine, or one with faulty bearings or a worn finger shows up these faults with an indistinct set of spokes, or none at all, before it will give trouble through coils not building up or being rejected electrically. In addition coils wound with straight spokes appear to build up more readily than those with none.

To produce coils with straight spokes it is necessary for the number of winding spaces per turn to be an integer. However, one turn of the former is πd and one winding space is $\pi dv.w/(qc + w)$, so that $\pi d \div \pi dv.w/(qc + w)$ i.e. $(qc + w)/vw$ must be an integer. None of these quantities is a variable, so some modification is required. The modification consists of increasing the spacing between adjacent wires by a small amount x, and the required gear ratio (equation 2) can be written as:

$$R = \frac{qc + s}{2cv} \qquad \text{.......... (3)}$$

where $s = w + x$; x is the smallest amount necessary to make $(qc + s)/vs$ an integer N, where N is the number of spokes on the side of the coil. Similarly, the formula for a winding space is modified to

$$H = \pi dv \frac{s}{(qc + s)} \qquad \text{.......... (4)}$$

NOTE: The term at the bottom right hand corner of diagram should read

$$\pi dv \left\{\frac{w}{qc + w}\right\}$$

Calculation of Gear Ratio

All the information necessary to determine the gear ratio for a given set of requirements is now available, but the form is unsuitable for manipulation on a slide rule, since it involves adding s, which will be of the order of 0.01 inch and which must be maintained accurately, to qc which may be 0.5 inch or larger. However,

$$R = \frac{qc + s}{2cv};$$

but by definition $q = nv$. Therefore

$$R = \frac{n\,(qc + s)}{2qc}$$

$$= \frac{n}{2}\left\{1 + \frac{s}{qc}\right\}$$

$$= \frac{n}{2}\left\{1 + \frac{1}{P}\right\} \text{since } P = qc/s$$

$$\therefore R = \frac{n}{2}\left\{\frac{P + 1}{P}\right\} \qquad \text{.......... (5)}$$

$$\textit{Moreover } N = \frac{qc + s}{vs} = \frac{1}{v}\left\{\frac{qc}{s} + 1\right\}$$

$$\therefore N = \frac{P + 1}{v} \qquad \text{.......... (6)}$$

On the basis of the above treatment, a concise instruction for the calculation of gears has been prepared. This instruction is presented in Appendix I.

Estimation of Coil Size

It is often desirable to estimate the size of a coil before actually winding it, and to do this it is necessary to know the number of layers in the coil and the thickness of each layer.

A layer is most conveniently defined as the smallest number of turns that will just cover the area on which the layer is wound. This definition results in a layer with a thickness of two wires, and the number of turns in the layer can be readily determined, since

Turns per layer = (turns per winding cycle) × (winding cycles per winding space) × (winding spaces per layer).

By definition there are v turns per winding cycle. Since there are q crossovers per winding cycle and two crossovers are needed to form one winding space, there are $q/2$ winding spaces per winding cycle, and $2/q$ winding cycles per winding space. In addition from equation 6, the number of winding spaces per winding cycle is

$$\frac{P+1}{v}$$

Thus the number of turns per layer is

$$x \times \frac{2}{q} \times \frac{P+1}{v} = \frac{2(P+1)}{q}$$

Now if T is the number of turns in the coil, the height of the coil is $Tq/2(P+1)$ multiplied by the height of one layer which is approximately $2w^1$. Thus the height of a coil of T turns is $Tqw^1/(P+1)$.

Example

A coil is to be wound with 500 turns of 42 S.W.G. enamelled wire;

$$R = \frac{n}{2}\left\{\frac{P+1}{P}\right\} = \frac{44}{43}$$

The diameter of 42 S.W.G. enamelled wire is 0.0044 inch, so the height of the coil will be

$$\frac{500 \times 2 \times 0.0044''}{44} = 0.1 \text{ inch}$$

Practical Modifications

In practice it is found that heights calculated as above may vary as much as $\pm$ 10 per cent. However, a very close approximation of the final size can be obtained, if the following points are remembered.

(1) Coils of large gauge solid wire and coils with ridges, tend to become larger than calculated.

(2) Coils of fine enamelled wire without ridges are nearly exact.

(3) Coils with fabric covering, particularly if the wire is stranded, tend to be smaller than calculated.

Gear Ratio by Inspection

If a retrogressive coil has been properly wound so that it is possible to count the winding spaces on the side, the gear ratio with which the coil was wound can be determined by inspection. The number of spokes N is $(P+1)/v$ and the gear ratio is known to be

$$\frac{n}{2}\left\{\frac{P+1}{P}\right\}$$

From an inspection of the top layer of the coil, the number of crossovers per turn, n, may be found and from n the number of turns per winding cycle, v, can be deduced, or obtained from Table 1 in the Appendix.

Now $Nv = P+1$ so that

$$\frac{P+1}{P} = \frac{Nv}{Nv-1}$$

Therefore the required gear ratio is

$$R = \frac{n}{2}\left\{\frac{Nv}{Nv-1}\right\} \qquad \text{.........} \quad (7)$$

Example

A coil has seventeen spokes on the side and is wound with two crossovers per turn. Thus $n = 2$, $v = 1$ and

$$R = \frac{n}{2}\left\{\frac{Nv}{Nv-1}\right\} = \frac{17}{16}$$

Use of Slide Rule in Unusual Cases

It sometimes happens through a required gear being unavailable that it is not possible to set up the coil winding machine with the simple ratio

$$\frac{n}{2}\left\{\frac{P+1}{P}\right\}$$

In such cases a coil cannot usually be wound with straight spokes, but for experimental purposes it may be desirable to ignore this feature to obtain a coil which will approximate a production coil wound with the correct gears. This can be done in the following manner. Reduce R to a single fraction and set this up on the slide rule with the denominator on the C scale and the numerator on the D scale. Choosing two gears known to be available, multiply by the number of teeth in the first and divide by the number of teeth in the second. Scan the C and D scales for integers exactly opposite each other for which gears are available. If there are none, shift a second number under the cursor and continue in this manner until a matching pair of integers is obtained on the C and D scales. Set up the four integers as gears in the coil winding machine in the order:

$$R = \frac{\text{D scale number}}{\text{C scale number}} \times \frac{\text{dividing number}}{\text{multplying number}}$$

The D scale number will be the gear mounted on the same shaft as the former.

Example

A coil is to be wound with $c = 0.125$ inch and $R = 17/16$, but suitable gears with this ratio are not available. Set up 17/16 on the slide rule, multiply by 43 and divide by 44 and it will be found that 26 on C scale coincides with 27 on the D scale. Thus the desired ratio is

$$\frac{27}{26} \times \frac{44}{43}$$

Once the gears have been obtained a simple way of remembering the order in which to use them is that starting with the D scale gear the numbers are written down in the reverse order of their occurrence.

Progressive Coils

No attention has been paid in the foregoing to progressive coils because of their undesirable winding characteristic as explained previously. However, for the sake of completeness all formulae which are altered for the use of progressive coils are given below:

	Retrogressive Coil	*Progressive Coil*
Required gear ratio R:	$\frac{n}{2}\,\frac{(P+1)}{P}$	$\frac{n}{2}\,\frac{(P-1)}{P}$
Winding space H:	$\pi dv\,\frac{s}{(qc+s)}$	$\pi dv\,\frac{s}{(qc-s)}$
Number of winding spaces N:	$\frac{P+1}{a}$	$\frac{P-1}{v}$
Number of turns per layer:	$\frac{2(P+1)}{q}$	$\frac{2(P-1)}{q}$
Height of coil:	$\frac{Tqw^1}{P+1}$	$\frac{Tqw^1}{P-1}$
Gear ratio R by inspection:	$\frac{n}{2}\,\frac{Nv}{(Nv-1)}$	$\frac{n}{2}\,\frac{Nv}{(Nv+1)}$

In the case of the formulae for determining gear ratios by inspection, it should be noted that unless a coil is known beforehand to be wound retrogressively it is necessary to determine this point as well as N and n or the wrong gear ratio may result. The type of coil is obvious from an examination of the top layer.

Fault Finding

As mentioned previously, it is not possible to wind coils with incorrect gears, but correct gears are only one of the many requirements for a coil to build up correctly. The following points may need investigation if poor results are obtained.

Maintenance

Coil winding machines must be kept in good condition so that excessive play does not develop in bearings. Naturally, the finer the wire being wound, the better must be the machines. If a coil is being wound with 0.004 inch wire, a lateral play of 0.001 inch at the finger is more than 20 per cent. of the required spacing between adjacent wire centres.

Fingers

Probably the most important single part of the machine is the finger. Both the original design and the maintenance are important; the design shown in Fig. 10, made in steel with the tip hardened, is satisfactory.

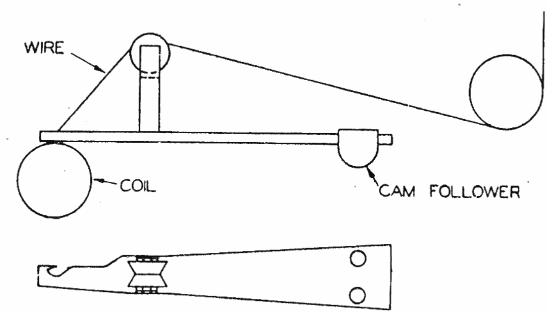

Figure 10. Winding finger.

With this finger the tension of the wire pulls the finger on to the coil and the wire leaves the finger after having been placed in the correct position. The carriage holding the finger must be secured by means of the collars on the cam follower shaft so that no side play occurs, but loosely enough to allow the finger to fall on to the coil due to its own weight. Otherwise if the finger is knocked upwards during the winding, it may allow a few turns to take up an incorrect position and so spoil the winding.

The shape of the slot in the finger is important, particularly with fine wires. The best shape is a straight V groove with as sharp an apex as possible and with the bottom of the slot rounded only sufficiently to prevent enamel or any other covering from being removed from the wire as it passes through. It is advisable to use a finger made especially for each size of wire to be wound and when the fingers are hardened before use quite satisfactory life can be obtained. As the finger wears, a groove forms underneath it and this groove may not be symmetrical. A coil with good spokes on one side and poorly defined spokes on the other is usually the result of a worn finger.

A convenient method of adjusting the finger to its correct position with respect to the former is to thread the wire through the finger, loosen the finger and pull on the wire. This will pull the finger forwards until the wire passes freely through the groove. If the finger is then pushed backwards just sufficiently to hold the wire between the bottom of the finger and the former, the finger will be correctly located.

Hopping of Cam Follower

Where a coil does not build up satisfactorily and the spacing between wires is greater on one edge of the coil than elsewhere, it will be found that the cam follower is leaving the face of the cam at the peak of the cycle. A stronger spring may cure the trouble at the expense of additional wear in the machine, but a better remedy is to reduce the cam speed.

Worn Cam Follower

If one side of a coil continually falls down and the finger is in good condition, it sometimes happens that the cam follower has worn until it will not follow the face of the cam right to the bottom of the cam movement. Sharpening of the follower to a well defined V will remove this trouble.

Excessive Tension

Excessive tension, apart from the snapping of wires, often shows up in coils which fall over on either side after winding some few layers with no apparent defects. A more obscure trouble due to too much tension is low Q in litz wire coils. This can be caused by the increased resistance of stretched wire. Excessive tension may also show up by coils being rejected through having too much distributed capacitance in cases where this is important.

Insufficent Tension

If not enough tension is used the rest of wire will continue to unwind when the machine is stopped suddenly and the coil will tend to be "spongy" when wound.

Appendix I

Symbols

d = coil former diameter (inches).
c = cam throw (inches).
n = nominal number of crossovers in one former revolution.
q = nominal number of crossovers in one winding cycle, i.e. before wire lies alongside proceding wire. (See Table I.)
v = number of former revolutions in one winding cycle. (See Table I.)
R = gear ratio $= \dfrac{\text{former gear}}{\text{cam gear}}$
w = modified wire diameter (inches). See note.
$P = \dfrac{qc}{w + x}$ = an integer.
x = the smallest amount necessary to make $(P + 1)/v$ an integer (inches).

NOTE: For fabric covered wire, w = (diameter of covered wire) $\times$ 8/7.

If the wire is enamelled only, the same formula is used, but the wire diameter is multiplied by 8/7.

Procedure

(a) From $n \leqq 2d/3c$ determine the largest convenient value of n. Do not use values of n less than 2 for bare enamelled wire. Obtain values of q and v from the table below for the value of n chosen.

TABLE I

n	6	4	2	1	2/3	1/2	1/3	1/4
q	6	4	2	2	2	2	2	2
v	1	1	1	2	3	4	6	8

(b) Determine w from information given in the note above.

(c) Calculate P from $P = qc/(w + x)$.

(d) Obtain R from $R = \dfrac{n}{2}\left\{\dfrac{P+1}{P}\right\}$

Example 1

Given $d = \frac{1}{2}$ inch and $c = 1/10$ inch, determine the gears to wind a coil with 42 S.W.G. enamelled wire.

(a) $2d/3c = 1.0/0.3$. Take $n = 2$, giving $q = 2$ and $v = 1$ from the table.

(b) The diameter of bare 42 S.W.G. wire is 0.004 inch, so $w = 0.00457$ inch.

(c) $P = qc/(w + x)$ and $(P + 1)/v$ must be an integer; thus P must be an integer since $v = 1$, Now $qc/w = 200/4.57 = 43.7$. But $P = qc/(w + x)$ is an integer, so that $P = 43$.

(d) $R = \dfrac{n}{2}\left\{\dfrac{P+1}{P}\right\} = \dfrac{1}{3} \times \dfrac{27}{26}$.

Example 2

Given $d = \frac{1}{4}$ inch and $c = \frac{1}{4}$ inch, determine the gears to wind a coil with 0.016 inch litz wire.

(a) $\dfrac{2d}{3c} = \dfrac{2}{3}$. Take $n = \dfrac{2}{3}$ giving $q = 2$ and $v = 3$.

(b) $w = 0.016$ inch $\times 8/7 = 0.0183$ inch.

(c) $\dfrac{qc}{w} = \dfrac{500}{18.3} = 27.3$. But $(P + 1)/v$ is an integer, so that $P = 26$.

(d) $R = \dfrac{n}{2}\left\{\dfrac{P+1}{P}\right\} = \dfrac{1}{3} \times \dfrac{27}{26}$.

To obtain suitable gears write

$$R = \frac{2}{3} \times \frac{1}{2} \times \frac{27}{26}$$
$$= \frac{28}{42} \times \frac{27}{52}$$

When it is known that n will be 2, as is the case with the majority of coils, the method reduces to dividing the modified wire diameter into twice the cam throw (ignoring any fractions in the answer). This gives P and the required ratio is $(P + 1)/P$.

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