ELECTROMAGNETS

by John Langan

With special reference to the Alex Jackson uncoupler when using 12 volts DC current, and some notes on their application to signals and pointwork.

Part 1

Since the war there have been many changes in the types of electrical components used in our hobby, but one old faithful, the electromagnet, still plays a useful part in our equipment. As a mechanical engineer familiar with the problems on gearing, levers and similar things mechanical where one can see and draw the mechanism you require, I find a fascination in being able to make things work by remote electrical control, and at the press of a button. Working in 24 volts DC I generally make my own motors (MRN Nov.-Dec. 1964) and it always gives quite a thrill to connect up a new motor and see it run for the first time. (Sometimes they don't!)

Magnetism, that equally mysterious and puzzling relative of electricity has problems of its own, and a peep into a treatise on the theory of it can be quite frightening. For our purpose however, we only have to apply some of the rules to simple mechanisms, and I shall try to keep clear of the deeper waters.

In using electricity to operate equipment other than our locomotives we are of course tending to drain our power unit. It is advisable that this extra equipment be run on a separate line from the power unit so that switching the track or signals will not effect the running of an engine. Each electromagnet should be wired separately (in parallel) and not one after another (in series) so that each magnet can produce its full power.

THE ELECTROMAGNET is created when a wire is coiled into a spiral and an electrical current passed through it. The magnetic field surrounding the wire takes the form of a permanent magnet with a pole at each end, these being North or South polarity, depending upon the direction of the current in the wire, as Fig. 1. Winding the wire upon an iron core as in Fig. 2 greatly increases the magnetic effect at the poles, the core providing an easy path for the collecting and flow of the flux or magnetic field. The flux density is greatest near the wire surface but falls off rapidly away from it. One thing that magnetism does not cooperate with is an air gap, and the strength of the magnetic field deteriorates very quickly as the air gap increases.

Note that the proportions of a coil for an electromagnet require that the length is much greater than the diameter. A short coil of large diameter may have only half the field strength of a longer coil.

The 'Alex Jackson' Uncoupler

The action of this uncoupler has been fully described in the July and August 1977 issues of MR and it will be recalled that the uncoupling action is caused by having a magnetic field attract the armature of the coupling wire. This magnetic field is made by only one pole of an electromagnet between the track, the magnet itself being below the baseboard as in Fig. 3. With this arrangement it will be appreciated that quite a strong magnetic field has to be made.

Field Strength

The strength of the field or flux for a given size of coil is proportional to the amount of current in the wire, just as your engine goes faster when you feed more current to the motor armature, also each turn of the coil plays its part and so the field strength is also proportional to the number of complete turns of wire in the coil. By increasing the current or the number of turns of wire in a given size of coil increases the output of flux, and so the value 'ampere-turns' of a coil can be used as a measure of the field or magnetic strength. The existing coil which we have used to operate the 'Alex Jackson' uncoupler was designed some time ago by fellow member Mr S. Stubbs, and when tested on 24 volts it had a current value of 0.21 amperes, which with 5000 turns of wire would have an 'ampere-turns' value of $5000 \times 0.21 = 1050$.

When working on 12 volts DC the A.T. value would therefore be 525, and I found that the magnetic field produced was sufficient to operate the uncoupling. For more positive action on 12 volts I have decided to design a slightly stronger electromagnet with an A.T. value of 700.

Coil Design

You will recall from elementary electrical relationships that total resistance in ohms $= \frac{\text{Voltage}}{\text{Current in Amperes}}$, and therefore to find the resistance in one average turn of wire in our coil we divide the total resistance by the number of turns of wire.

Therefore resistance per turn

$$= \frac{\text{Volts}}{\text{amperes} \times \text{number of turns of wire}}$$

$$= \frac{\text{Volts}}{\text{A.T.}} = \frac{12}{700}$$

= 0.017 ohms per turn of wire.

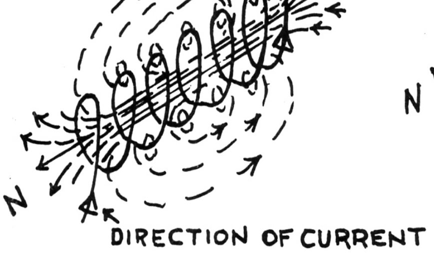


FIG. 1. MAGNETIC FIELD IN LONG COIL.

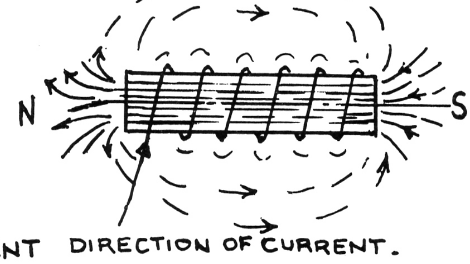


FIG. 2. ELECTROMAGNET WITH IRON CORE.

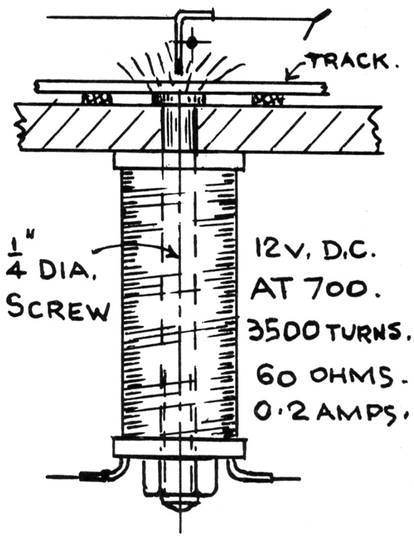


FIG. 3. ELECTROMAGNET APPLIED TO THE 'ALEX JACKSON' UNCOUPLER.

WIRE GAUGE No.	WIRE DIAM. INS.	SECTIONAL AREA. SQ. INS.	CURRENT RATING. AMPERES PER SQ. INS.			RESISTANCE AT 15°C	
			1000	2000	5000	OHMS PER 1000 YDS	YARDS PER OHM.
30	·0124	·000121	·121	·242	·605	199·2	5·021
31	·0116	·000106	·106	·212	·530	227·4	4·398
32	·0108	·0000916	·092	·183	·458	263·7	3·792
33	·0100	·0000785	·079	·157	·392	307·0	3·257
34	·0092	·0000665	·067	·133	·332	363·2	2·753
35	·0084	·0000554	·055	·111	·277	435·0	2·299
36	·0076	·0000454	·045	·091	·227	530·8	1·884
37	·0068	·0000363	·036	·073	·181	663·9	1·506
38	·0060	·0000283	·028	·057	·141	851·6	1·174
39	·0052	·0000212	·021	·042	·106	1136·8	0·8796
40	·0048	·0000181	·018	·036	·090	1331·5	0·7510
41	·0044	·0000152	·015	·030	·076	1585·5	0·6307
42	·0040	·0000126	·013	·025	·063	1912·7	0·5228

FIG. 4. WIRE DATA FOR COIL WINDING.

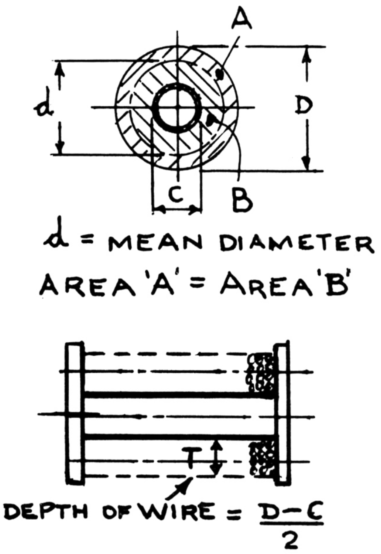
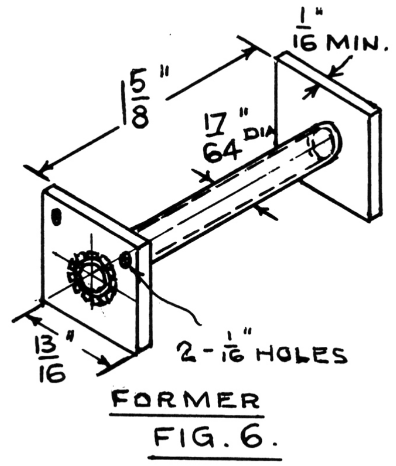


FIG. 5.

The length of wire having a resistance of 0.017 ohms varies with the size of wire. A fine wire has more resistance to current flow than a larger diameter of wire and we would not require so much of it to obtain 0.017 ohms resistance. Thus the finer the wire, the smaller the coil diameter becomes.

On the other hand a fine wire is limited in its current carrying capacity and can soon overheat and possibly burn the insulation covering. The standard rating of wires for coil design is 1000 amperes per sq. in., but this may be increased to say 2000 if the coil is not left on for a long period or 5000 or more if the coil is operated momentarily by a push button switch. The table Fig. 4, presents ampere values of the current which may be used for these ratings, and covers the gauges of wire likely to be met on small coil work. The coil to be used on the uncoupler is operated by push button as the wagon to be released is passing through the magnetic field, and therefore, as one uncoupler is generally operated at any one time on a layout, a fair amount of current may be used at a high rating of amperes per sq. in. The current of our



FORMER
FIG. 6.

existing coil using approx. 0.20 amps has been satisfactory so let us assume a figure around this value. From the chart, Fig. 4, for a rating of 5000 amps per sq. in. a wire of 36g or larger would be suitable for this current. Note that having adopted 0.2 amps for the current we automatically obtain 3500 turns of wire to obtain the ampere-turns value of 700. Also the total resistance of the coil will be $\frac{12 \text{ volts}}{0.2 \text{ amp}} = 60$ ohms.

Coil Dimensions

Using the figures from the chart the following gives the lengths of wires for a selection of wire sizes to give 0.017 ohms resistance. Length in inches = ohms required × ohms per yard for the gauge of wire × 36.

36g:- 0.017 ohms × 1.884 yds × 36 = 1.15ins

34g:- 0.017 ohms × 2.753 yds × 36 = 1.682ins

32g:- 0.017 ohms × 3.792 yds × 36 = 2.32ins.

(Calculated by sliderule)

Dividing by π we obtain the coil 'mean' diameters.

36g:- mean diameter = 0.366ins

34g:- mean diameter = 0.536ins

32g:- mean diameter = 0.74ins.

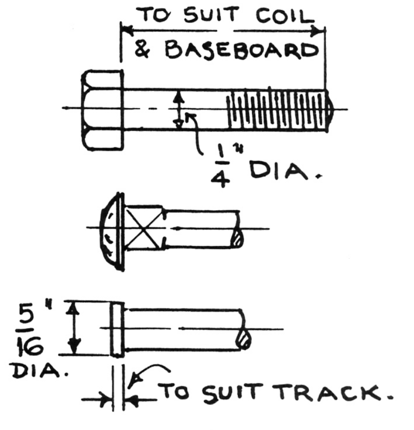


FIG. 7. ALTERATION TO STD. BOLTS FOR UN-COUPLER.

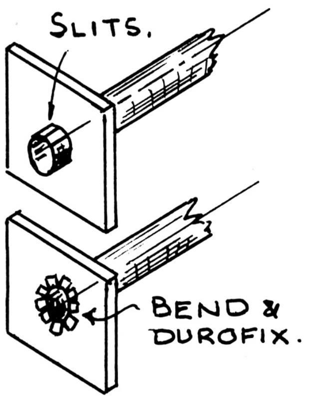


FIG. 8. SECURING ENDS.

With the finished coil diameter of ¾ins in mind, the 34g wire would seem to be most suitable. The above diameters represent the average diameters with regard to the resistance value of the wire. That is, the length of wire above this diameter will be the same as the length of wire below this figure. The mean diameter is not therefore just the middle of the coil and referring to Fig. 5 we see that the wire in area A has to equal the wire in area B. Calculation shows that for a mean diameter 'd', the outside diameter

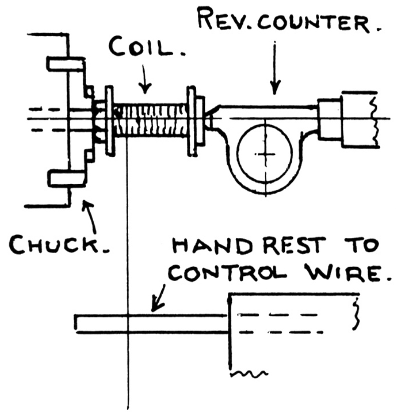


FIG. 9. COIL WINDING IN THE LATHE.

$D = \sqrt{2d^2 - C^2}$

'C' being the diameter over the core insulation. Also, if you have an existing coil and wish to obtain the mean diameter, this may be calculated from

$'d' = \frac{\sqrt{D^2 + C^2}}{2}$

For the iron core on small coils I use a ¼in. bolt and with the paper insulation the core diameter 'C' above is 17/64ins (0.266ins). So for a coil having a core diameter of 0.266ins and a mean diameter of 0.536ins the calculated outside diameter D equals 0.710ins.

Referring to Fig. 5 the depth of the wires on the coil shown as 'T' gives us an indication of the number of wires deep the coil is. The actual diameter of the enamelled wire is naturally greater than the diameter as shown against the gauge number. This is generally about 0.0006ins over the diameter of the bare wire, but this seems to vary and it is advisable to measure the actual enamelled wire. The 34g wire I used had an enamelled diameter of 0.010ins and with a depth of wire, 'T', of 0.222ins from the sizes given, we can say that we have a depth of 22 wires. I am assuming here that when winding, some wires will 'bed' in but others will overlap due to hand-winding and cancel each other out. With a total of 3500 turns of wire and 22 wires deep the length of the coil in wires will be approximately 159. With a 0.010ins diameter wire then the length in inches will be 1.59.

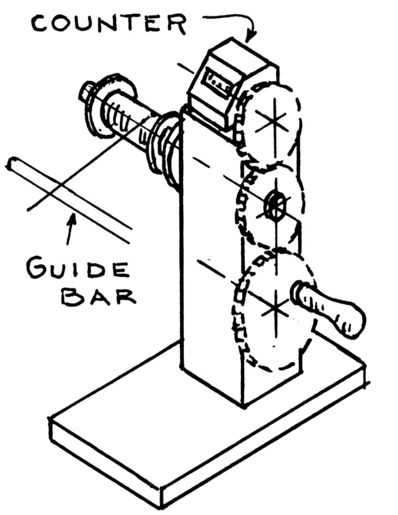


FIG. 10. WINDING BY HAND MACHINE.

It is very difficult to wind a coil uniformly by hand, as opposed to the controlled winding performed by special machinery, and therefore calculations can only be approximate. For this reason and to allow for irregular winding I therefore make the former for the coil 10 per cent longer than the calculated 1.59ins, say 1⅝ins.

We have now sufficient information to make a coil, having the following specification. 12 volts DC. 0.2 amps, 60 ohms, 3500 turns, 34g wire, A.T. 700, coil approximately ¾ins diameter × 1⅝ins long, ¼ins bolt for the core.

Heating of Coil

Before leaving the design of the coil however I would just like to mention a useful guide to apply with regard to the heating up of coils. This is caused by the resistance of the wire to the passage of the current. Power is lost in this way and the heat must be carried away by the surface of the coil. The main danger is of course from the insulation breaking down rather than the wire actually fusing or melting. At room temperature a guide to the amount of power which the surface of a coil will radiate is 0.2 watts per square inch of surface area. Power is measured in 'watts' and is equal to Current² × Resistance = I^2R. Now you will recall that when we chose a current of 0.2 amps for our coil the rating was more than the standard of 1000 amps per sq. in. and we would therefore expect it to heat up if left on, the surface area of the coil will be

$\pi \times 0.71 \times 1.62 = 3.62$ sq. ins and its capacity to radiate heat is $3.62 \times 0.2 = 0.72$ watts. Power radiated = Power lost $0.72 = I^2 \times 60$

Therefore $I = \frac{\sqrt{0.72}}{60} = 0.144$ amps.

We are using 0.2 amps and as expected the coil would warm up if left on. This proved to be the case on test, and the above check will be found useful as a guide to prevent overloading a coil.

Coil Making

From the figures we have established the 'former' for the coil will be as Fig. 6, and we shall use a ¼in. diameter bolt or coach bolt with the head altered as shown in Fig. 7. Model engineers will no doubt make their own screw for this in the lathe but for this article I have

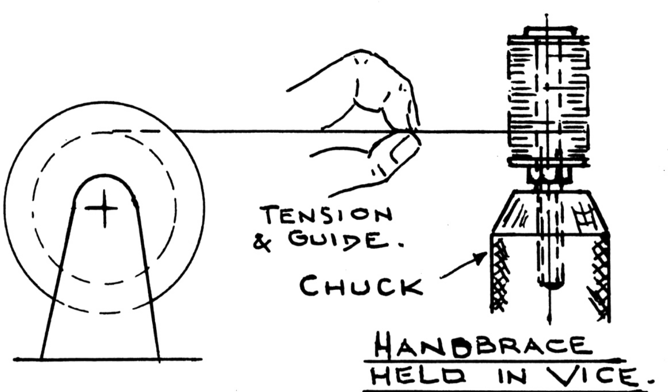


FIG. 11. HANDWINDING.

assumed only limited equipment being available. The sides of the former are of any insulating material such as Bakelite, Paxolin or even good quality card about 1/16in. thick. These are made slightly larger than the finished coil and drilled in the centre to receive the insulated core. The two 1/16in. holes shown on one of the sides are for the ends of the coil wire to come through.

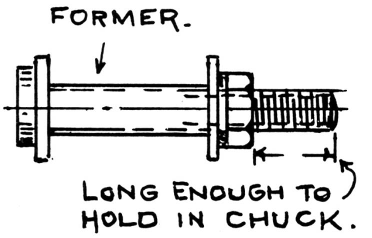


FIG. 12. HOLDER FOR FORMER WHEN WINDING.

Having prepared the bolt and removed the sharp edges from the threaded area, cut a piece of greaseproof or waxed paper (from the kitchen) about 1/8in. or so so wider than the overall length of the former and sufficient for two turns around the screw. Similarly cut a piece of paper parcel tape, sufficient for about four turns of the screw. Roll on the greaseproof paper in the manner of making a cigarette and follow with the wet sticky parcel tape. Roll tightly and allow to dry. For assembly purposes later, it is essential to be able to remove the screw from the coil as will be evident from Fig. 3. Check that the side pieces just slide onto the paper tube (still on the screw) and if required scrape the bore of the side to fit. Smear Durofix onto the end surfaces of the tube and fit the sides, checking that they are square to the tube and 1⅝in. apart, and leave to dry thoroughly. When dry cut the protruding ends with a razor blade as shown in Fig. 8, and bend back the tabs, fixing them with Durofix as shown, this will help to resist the pressure of the windings from forcing out the sideplates.

Coil Winding

The question of equipment for coil winding depends upon how much you wish to be involved in winding coils. The man with a lathe would no doubt use a set up similar to Fig. 9 where a revolution counter is necessary. I normally use a homemade winding machine with a counter attached, because for my 24V motors I require small coils each with exactly the same number of turns. One idea for this is shown in Fig. 10.

Probably for many readers the use of the simple handbrace is the most convenient way, and this is the method I have used for the purposes of this article. The general arrangement is shown in Fig. 11 with the hand brace held vertically in the vice. It is advisable to have a special screw sufficiently long for holding the former and also for being gripped in the drill chuck as shown in Fig. 12.

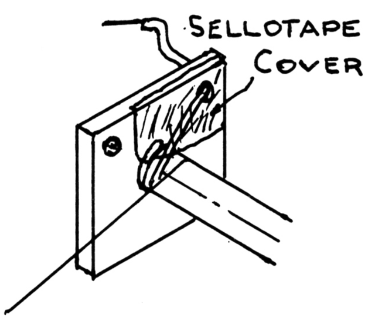


FIG. 13. PROTECT THE STARTING WIRE.

The spool of wire is held nearby suitably clamped on the bench (Fig. 11), but the spool must be entirely free to rotate without snatching and thus causing the wire to break. Keep the path of the wire in line with the coil being wound. In order to have control of the number of turns being wound onto the coil it is necessary to know the ratio of the number of turns made by the chuck when the handle of the handbrace is given one rotation. This is not always a nice easy number like 4 to 1, and mine is a very odd figure. To obtain the ratio exactly, count the number of teeth on the handle driving wheel and also on the driven pinion. The gearing ratio will then be

$$= \frac{\text{Teeth in driver gear}}{\text{Teeth in driven pinion}}$$

which on my handbrace $= \frac{56}{15}$

$= 3.733$ to 1

So to obtain 3500 turns of wire the handle must turn $\frac{3500}{3.733} = 938$ turns.

When winding I count off the hundreds of turns of the handle, ticking them off as I go, and finally add the 38 turns. Scrape the end of the start of the wire from the spool to clean off the enamel for about ¾in. and solder this to a slightly thicker plastic covered wire about 3ins. long. Flexible wire is helpful here if you have some available. Thread the thicker wire onto the former core and bring it through one of the 1/16in. diameter holes in the side plate, securing it with Sellotape or similar as shown in Fig. 13. It is important to protect the joining of these two wires, since if this joint should fail after winding, you have to unwind the coil and start again.

FIG. 14. TENSION PAD.

We are now ready to start winding, keep a steady pace, counting the turns of the handle and laying on the wire as evenly as possible, guiding it with your finger and thumb as in Fig. 11. You can imagine that winding a few thousand turns of wire onto a former in the manner described could eventually wear a nice groove in your finger, so I use a piece of soft leather to grip the wire as in Fig. 14. This not only cleans the wire, which is useful if you are using up an old coil, but produces a little squeak which in a way helps you to keep up the same tension on the wire. Without this pad your finger and thumb seem to 'forget' to hold the wire.

When you have reached the required number of turns, hold the last turn down onto the coil by a small piece of sticky tape. Leave a few inches to spare and cut the wire. Now clean off the insulation and solder to a length of thicker wire as at the beginning. Insulate the bare wire joint with tape, and wind around the coil to pass the thicker wire through the other 1/16in. hold in the sideplate. To protect the surface of the coil wind a turn of sticky tape to cover the whole of the wires and the coil is finished.

Drill a ¼in. diameter hole in the baseboard between the track and assemble the coil as shown in Fig. 3 with the surface of the screw level with the underside of the rails. On my test track the electromagnet as described operated the uncoupler at 8 volts, so that at 12 volts there is plenty of magnetic attraction available as designed.

Supplies of enamelled copper wire in small quantities may be purchased from The Scientific Wire Company, PO Box 30, London E4 9BW, who supply a list upon receipt of S.A.E.

ELECTROMAGNETS by John Langan. Next we shall be looking at electromagnets for pulling signals and designing coils for them. Also pointwork, using relay and coil calculations, etc. . . .