METAL DETECTOR USING DIFFERENCE RESONATOR

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Here is described a simple metal detector using a difference resonator and a couple of transistors. It can detect conductors(metals) in its vicinity as far as >4cm. The instrument is a prototype, one can build a larger model on similar principles by increasing the dimensions of detector components and using more power. Hidden metallic structures like metal foils enclosed in plastic cover(like those in consumer items, for instance toothpaste tubes etc) etc can be easily detected using this instrument. However very thin metallic foils may go undetected due to large

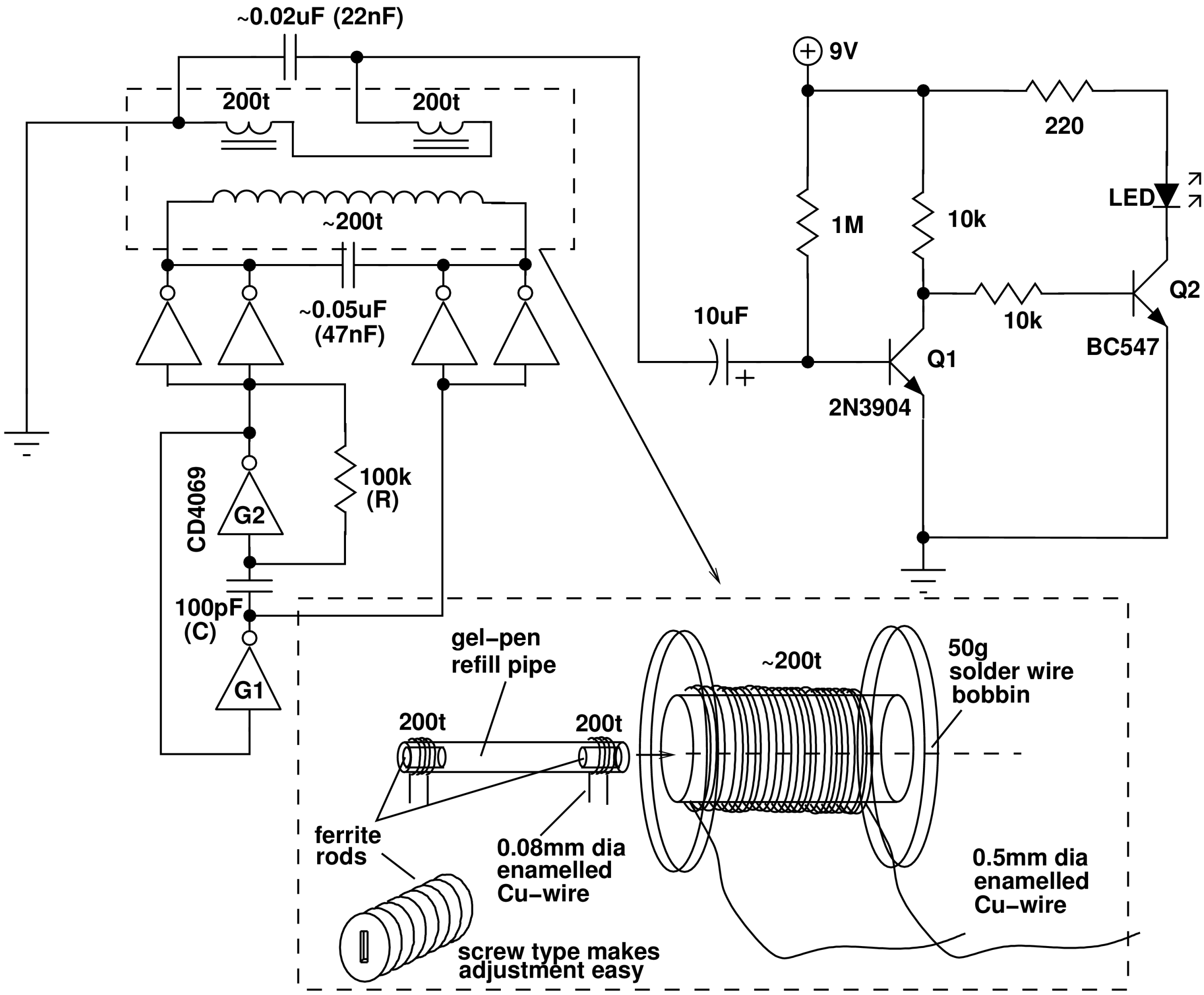

Fig 1: Circuit diagram of Metal Detector. The coils are just indicative bearing no resemblence to practical appearance. The pipe inside the bobbin has to be secured firmly using non-magnetic, non-conducting materials and should be sufficiently rugged. The ferrite rods must be sufficiently secure in their position this can done using synthetic enamel. A slight unintentional displacement can upset the balance of the resonator drastically. G1,G2 form the oscillator while the other 4-gates act as buffers to drive the outer coil.

resistance offered by them to eddy currents. A small ring of copper wire at a distance of 2cm is sufficient to trigger the detector. Small objects like refill tips made of magnetic materials are also sufficient to trigger the detector. Another use of the detector is in testing transformer windings which has been shown pictorially in fig 3.

How it Works : The principle of operation of the instrument is based on detecting the magnetic field produced by eddy currents(refer a standard text book on electrical engineering) generated in conductors when they are placed in varying magnetic fields. Since a varying magnetic field produces an electric field according to Faraday's law, this electric field in the presence of a conductor will set up currents in it as conductors have copious amounts of free charge in them. The induced electric fields will be circular and when produced inside a conductor will naturally give rise to currents, as per Ohm's law. These currents are called eddy currents. These currents in turn will give rise to a magnetic field(an electric current gives rise to a magnetic field) which opposes the parent field(i.e the one that is producing the eddy currents) thus reducing the strength of the field in its vicinity. The current instrument uses this effect to detect the presence of a conductor. Two small coils(200 turns of 0.08mm copper(Cu) wire on gel pen refill pipe) are placed inside a much bigger outer coil which induces resonant currents in the two coils(the two coils in series form a difference resonator along with the capacitor connected to them) by the varying magnetic field it produces. The bigger coil itself is made to resonate by driving it with a square wave(G1,G2 oscillator) approximately equal to the resonance frequency of the LC circuit formed by the outer coil and the capacitor connected to it. This sets up sinusoidal currents in the outer coil, producing sinusoidal magnetic field coupling the inner two coils. If the two coils are symmetrically placed relative to the outer coil they will be induced equally and if one were to take a difference between them then one would get a zero signal. As shown in the schematic diagram the two coils are connected such that the difference of the induced emfs(electro motive force) is fed to the transistor detector circuit. Now when a conductor is brought near one of the inner coils the eddy currents in the conductor will reduce the magnetic flux through the coil reducing the induced emf in the particular coil. This in turn means a large difference signal from the two coils, as an asymmetry in the flux has been set up due to the presence of a conducting object near one of the coils. Next this difference signal is fed to the transistor Q1, via dc filter capacitor of 10uF, which has been configured as a small signal amplifier. The amplifier is biased using a large base resistor of 1MΩ . The a.c difference signal directly appears across the base-emitter junction of the transistor producing large changes in the emitter current(The emitter current is connected exponentially with the base-emitter voltage, which comes from approximation to Eber-Molls model of the transistor). This correspondingly produces large voltage changes in the collector circuit which has a large resistance. A tiny signal produced due to magnetic field of eddy currents in a small piece of conductor like a screw or nut is sufficient to trigger Q2 through Q1. Normally the two coils are adjusted such that the difference signal from them is a minimum. In this particular model it was possible to adjust this to a voltage as small as V_{pk}-V_{pk} of 5mV of sine wave. Q2 more or less plays the role of an electronic switch. Magnetic objects tend to gather the flux and increase it, increasing the emf induced in the near coil, while non-magnetic conductors due to their eddy currents tend to reduce the magnetic field thus reducing the induced emf in the near coil. These two have opposite effects on the difference signal. But since the difference signal has been set to a very small value nontheless the required increase in the difference voltage is always possible for both the types of materials, which is enormous when compared to the residual difference of 5mV peak-to-peak sine wave. So when a metallic object is brought near the detector coil it causes an enormous change in the difference voltage and causes the transistor Q2 to turn on and off through Q1. Which amplifies the difference voltage fed to it from the inner coils.

One can vary the capacitors(connected with the resonators) on trial and error basis and fix the value for maximum sensitivity or else one can refer a text book on electrical engineering to calculate the inductance of the coils and manually select a resonant frequency(here a frequency of ~55kHz has been selected) and drive the oscillator(G1,G2) at that frequency. Make sure that the two resonators(one with the inner two coils in series and the one with the outer coil) have approximately the same frequency of resonance. Some useful formulae are given below,

The frequency of resonance of a LC circuit(as found in many text books on electrical engineering) is given by

$$f = \frac{1}{2\pi\sqrt{LC}}$$

The frequency of the RC oscillator using gates is roughly given by

$$f = \frac{1}{2.2\,RC}$$

one can vary the R,C values using variable resistors and capacitors to fine tune the frequency.

Another way to build a portable model would be to use a 20g glue stick tube to build the detector. The outer coil can be wound(or already wound coil can be installed) on the cap with the central pipe supported and glued on either side by to two non-conducting, non-magnetic solid circular frames along the axis with holes in them. All the connections to the coils can be drawn from the hind portion of the tube and connected to a box with a convenient handle housing the electronics, indicators and 9V power battery. Figure 3 shows how the metal detector can be used to test transformer windings without making any electrical contact with the coil.

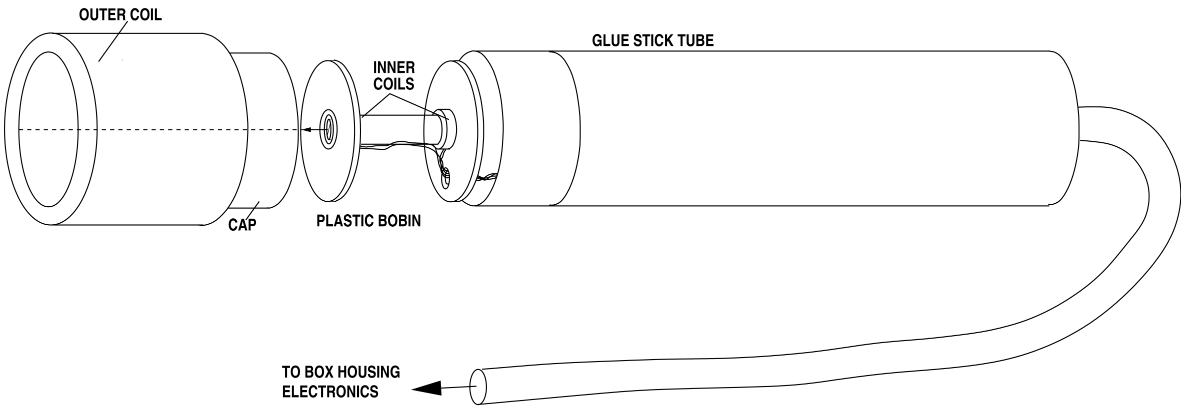

Fig 2: A possible arrangement of the detector coil.

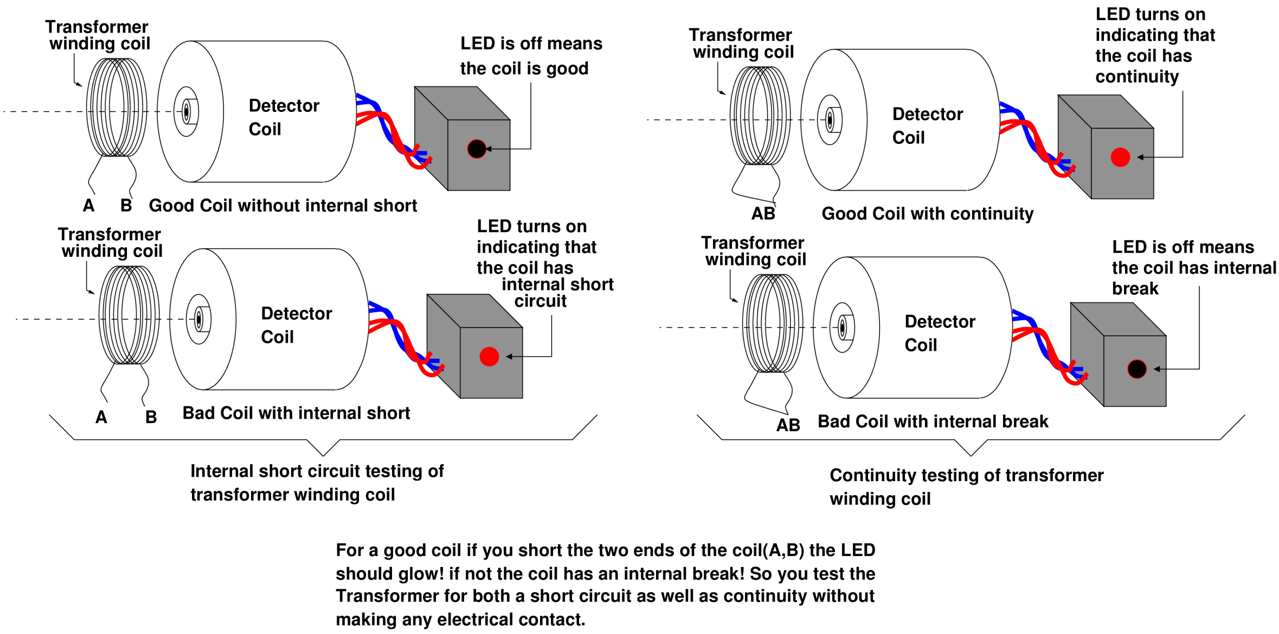

Fig 3 : Pictorial indication on how to test transformer winding coils.

APPENDIX

ANALYSIS OF FORCED RESONATOR

The analysis of the forced resonator is as follows. We consider the model shown in the figure-4 below

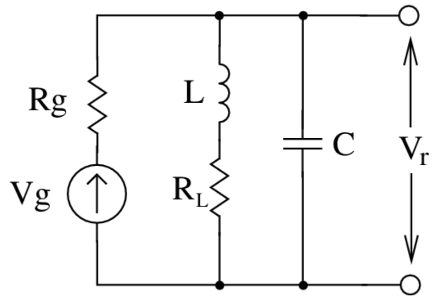

Fig 3: Model for the forced resonator. Vg and Rg are for the gate, while most of the external resistance is concentrated in the inductance L , shown as R_L.

V_g is a rectangular pulse with a small time period supplied by the gate and R_g is its internal resistance at the output. The frequency of V_g is the same as that of the resonant frequency of LC circuit. The output across the LCR circuit is sinusoidal at resonance. The driving voltage V_g and the voltage across the LCR network are shown in the figure below. Let V_r be the voltage across the LCR network then the current through the internal resistance of the gate can be written as,

$$I_g = \frac{V_g - V_r \sin(\omega_r t)}{R_g} \tag{1}$$

where ω_r(period T) is the resonant frequency of the LC circuit. We first consider a single pulse drive, however the present resonator is a double pulse drive with approximately $T_P=\pi$. Let T_P (in terms of phase angle this will be called φ) be the period of the pulse that drives the LC circuit. The power transfered to the LCR network is then(pulse T_P is assumed to be positioned symmetrically across the positive peak of the sinusoid),

$$P_{LCR}^{T} = \int_{\frac{\pi}{2}-\frac{\varphi}{2}}^{\frac{\pi}{2}+\frac{\varphi}{2}} \left(\frac{V_g - V_r \sin(\omega_r t)}{R_g} \right) V_r \sin(\omega_r t)\, dt \tag{2}$$

When the output of the gate is low the capacitor discharges through Rg and the sinusoidal currents through the inductive resistance R_L also produce loss in power. These can be summed up in dissipiative power written as,

$$P_{LCRR_g}^{diss} = \int_0^{\pi/2-\phi/2}\left(\frac{V_r\sin(\omega_r t)}{R_g}\right)^2 R_g\,dt + \int_{\pi/2+\phi/2}^{2\pi}\left(\frac{V_r\sin(\omega_r t)}{R_g}\right)^2 R_g\,dt + \int_0^{2\pi}(C\omega_r V_r\cos(\omega_r t))^2 R_L\,dt \quad (3)$$

It should be noted that T represents 2π in terms of phase angle. We solve the above equation by using $\omega_r t = \theta$. Solving $P_{LCR}^{T} - P_{LCRR_g}^{diss} = 0$ for V_r, one sees that

$$V_r = \frac{2V_g L\ \sin(\pi f T_P)}{\pi(C R_L R_g + L)} \quad (4)$$

which is the amplitude of the forced resonance driven by a pulse period T_P of the same frequency $\omega_r = 2\pi f$. This formula has been checked by simulation and agrees pretty well. It should be noted that in eqn-2 and eqn-3 the limit π has been expressed in terms of f, i.e 1/2f . In the case of double pulsed resonator, the resonator is driven by a positive pulse of width T_P in the positive phase and with a negative pulse of the same width in the negative phase. This is actually the case with the metal detector resonator. The voltage acheived by this resonator is just the double of (4).