5.5.7 Insulating varnish, wax

The pickup coil is wound from very thin copper wire onto which a film of varnish is deposited in order to protect from short-circuit and aggressive substances in the air. The substances most often used as insulating varnish are "Plain Enamel", "Formvar", "Polysol" and "Polyurethane-Nylon". The resulting insulated wire is often called magnet-wire – it is of course non-magnetic (or, more exactly, paramagnetic) and has the same magnetic resistance as air has.

The noun **enamel** also stands for glaze, lacquers in general or special lacquers (e.g. synthetic resin varnish). The verb *to enamel* also means *to varnish*. "Enamelled copper wire" therefore is **varnished copper wire**, and as such every magnet wire used in pickups merits the designation *enamelled copper wire*. The situation is, however, not that simple since enamel is often used in a more specialized sense:

The name **plain enamel** designates one of the first industrially produced insulating varnishes. It is an oil varnish manufactured with oil which oxidizes while drying and generates an irreversible film. In order to increase hardness and gloss, resins are added. The also used designations *oleoresinous email* and *oleoresinous insulation* are derived from this oil/resin mixture. The *plain enamelled wire* used in old (i.e. "vintage") pickups has a brown or voilet color.

Formvar (sometimes incorrectly spelled "Formivar") was a trademark of the *Monsanto Chemical Company* (St. Louis, Missouri, USA). It was renamed from Formvar to Vinylec after the sale of a business unit to *Structure Probe, Inc*. Formvar varnishes contain polyvinyl-acetal = polyvinylformal. In a two-step process first polyvinylalcohol is manufatured from polyvinylacetate; the polyvinylalcohol is then acetalyzed. To produce magnet-wire, the phenolic resin polyvinylformal (also called *modified polyvinyl acetal resins*) is added. Formvar magnet wire is of a glossy-gold color and cannot be soldered.

Polysol varnish is a polyurethan lacquer which can be soldered and is mixed as a two-component varnish. It usually is of a glossy bright-red. Or it could be brown-violet if a "vintage" vibe is asked for ☺.

Polyurethan-nylon is a polyurethan insulation with a nylon coating.

It should not be assumed that the designations for varnish as given above seek to be a 100%-correct material designation. While e.g. the chemical formula *NaCl* unambiguously designates common salt, a term such as *oil varnish* merely indicates a group of substances which are similar but individually chemically and physically different lacquers.

No big demands are placed on the **insulation properties** of the copper-varnish-wire used in pickups since the voltages to be handled are very small. Even considering a peak voltage of 5 V (which is quite a high value) and a varnish thickness of 2x2,5 µm = 5 µm we obtain a "worst-case"-field-strength of about 1 kV/mm – which is rather undemanding for an insulator. Formvar, for example, is specified to handle up to 80 kV/mm – but such high field strengths cannot be reached in a pickup.

The **magnetic** properties of the insulators mentioned above are highly similar; they all show a permeability of very close to 1 and can be seen as non-magnetic as a good approximation. Regarding the **dielectric numbers**, however, differences can be measured. The ε_r of such insulators is typically between 2 and 5 – exact numbers are not published by the manufacturers. Variations in the dielectric number correspondingly change the capacitance of the coil. Considering a change in capacitance from 50 pF to 100 pF (which is very much on the high side) would lead – in conjunction with a 450-pF-cable – to a 10% capacitance change corresponding to a 5%-change in the resonance frequency. The same resonance shift would occur with changing the cable length by 11% i.e. increasing it from 3,75 m to 4,15 m. It cannot be excluded that such small changes are noticeable in a true A/B-comparison. The internet is full of speculations regarding the contribution of the varnish insulation to the sound of a pickup, or regarding the sound differences due to different lacquers. Since however rarely any guitarist will consider (in order to obtain a different sound!!) whether he/she should today use the 3,75-m-cable rather than the 4.15-m-cable, it seems rather excessive to attribute a big significance to the type of varnish. Anybody in doubt is cordially invited to listen to the difference caused by a 50-pF-capacitor connected in parallel to the guitar output ... and if indeed it does sound much better with the capacitor: grab the soldering iron and install it!!

Apart from the potential dielectric differences, there are occasional reports that a specific varnish was applied more thickly than another, this leading to a different coil geometry. Of course the coil inductance and coil capacitance depend on the geometry – however the **thickness of the varnish** is not generally typical for a type of varnish. It must not be assumed that all manufacturers produce a 42AWG-wire with the exact same thickness of the varnish – even if the insulating material would be the same. The dimensions of copper and varnish are subject to manufacturing tolerances; it also should be considered that many manufacturers offer a special wire (e.g. 42AWG, Formvar) deliberately with different varnish thicknesses. For high-voltage installations a thicker (multiple) insulation layer is desirable while for pickups a single varnish process is sufficient. Even though some manufacturers use wire with multiple varnishing for pickups.

So: what changes if, instead of wire with a single coat of varnish, one with a double coat is used? That depends on which parameter is kept constant. With an equal number of turns the coils grows larger. Conversely, filling up a given bobbin with wire of a thicker insulation will lead to a smaller number of turns. As an approximation we can assume that a double-insulated wire will require 20% more cross-sectional surface than the single-insulated wire.

- For a constant coil cross-section (i.e. wind until the bobbin is full) we obtain a 17% smaller number of turns – connected to a reduced inductance, diminished sensitivity and smaller DC-resistance.
- Keeping the number of turns constant (i.e. wind unto the counter shuts down the process) enlarges the surface of the winding. However, this does not necessarily lead to an increased sensitivity because the turns are located also in the range of smaller flux density. Sensitivity and inductance cannot be calculated in any simple manner; for the DC-resistance we get an increase of about 2%. This increase is so relatively small despite the 20% surface area change because the coil is oblong, not circular.

The pickup parameters depend only little on the thickness of the varnish if the number of turns is kept constant; larger effects will be connected to keeping constant the cross-section of the winding.

Besides the varnish, there is another dielectric between the turns of the coil in many pickups: they are **immersed** (*potted, dipped*) **in wax** in order to give more stability to the coil. In the middle of the 1960s a mishap occurred in the guitar production at Fender [Duchossoir]: the newly introduced polysol-insulation dissolved in the wax bath and the pickups suffered from short circuits. From that point in time production continued without wax-potting (apparently the differences were not that serious), and not until the 1980s did Fender (now post-CBS) return to the old recipes. Wax can solidify the coil windings and reduce pickup self-oscillations (microphonics) on the one hand but also increase the coil capacitance on the other hand. However, compared to the all-dominating cable capacitance only marginal changes in capacitance are to be expected. For **microphonics** see chapter 5.14.

The **losses** within the insulation between the windings of the coil do not play any role at all: the loss resistance in parallel to the coil capacitance is larger than 10 MΩ and thus negligible. However, depending on the material it may be necessary to consider **hydroscopicity**: the insulators may be able to absorb water which can – due to its high dielectricity – cause a noticeable capacitance increase (see table)

Material	ε_r at 1kHz	tanδ in ‰
Casting resin	4 – 8	20 – 80
Cellulose acetate	3,5 – 6	12 – 25
Cellulose ethyl	2,5 – 3,5	5 – 25
Vulcanized fiber	4	80
Polyurethane	3,0 – 5,5	5 – 50
Paraffin	1,9 – 2,3	< 5
Shellac	3 – 4	10
Bakelite	4,8 – 5,3	10
Pertinax	4,8 – 5,4	25
Water	approx. 80	

Table: dielectric properties of insulating materials. The numbers should be taken as guide values, the material compositions vary depending on the manufacturer.

As a **bottom line** it should be noted that potting a pickup in wax on one hand, and the material and the thickness of the varnish on the other hand, can lead to small, measurable differences in capacitance. The significance of these differences is, however, subordinate in practice. Microphonics can be efficiently fought by potting.

5.5.8 Bobbin, coil former

In old Fender pickups the 6 cylindrical magnets were pushed through 2 planar coil formers made of vulcanized fiber (hydrate cellulose): these coil formers kept both the magnets in position, and the would wire on the magnets. An urgent warning needs to be heeded: the axial position of the magnets in these pickups must not be manipulated by "light hammer-blows". Doing this will in many cases rupture the fine winding wire which necessitates replacing the pickup (or rewinding it). It is inconceivable why some authors recommend this kind of "adjustment" – possibly they are sponsored by the pickup manufacturing industry ..... Much better mechanical protection is afforded by pickups with complete plastic die-cast bobbins.

Regarding any influence of the bobbins or coil formers on the sound, what was said for insulators holds again: the materials used may have varying ε and thus potentially could have an effect on the coil capacitance and the resonance emphasis. Compared to the cable capacitance and the dampening afforded by the potentiometers, such differences are however to be taken as *highly* secondary.

