The Voice Coil (Part 1)

A look at the bobbin, the voice coil wire, and the collar

In this month’s installment, we’re going to discuss the voice coil. The voice coil comprises three major components: the bobbin (also called the former), the voice coil wire, and the collar. The bobbin provides a rigid structure on which the voice coil wire can be wound and the collar can serve several purposes. It secures the coil lead-out wires, reinforces the bobbin, and provides a convenient material for diaphragm attachment (see Photo 1).

In some cases—headphone speakers, for example—a monolithic (self supporting no bobbin or collar) voice coil may be used. But this article will focus on the more commonly used bobbin, coil, and collar designs.

Loudspeaker voice coils are seldom considered critical elements that contribute to sound quality, and few technical papers have addressed this issue. But when designing a voice coil, the selection and application of materials can have profound effects upon sound quantity, quality, and power handling. The mechanical energy from the winding stack moves by transconduction through the bobbin and collar before reaching the diaphragm. Any non-linearities in this path are superimposed upon the response of the speaker. Intrinsic characteristics of materials such as internal damping and Young’s modulus create specific sonic signatures and contribute to the residual distortion spectrum of the transducer (see Photo 2).

During sound reproduction, the cone resists movement by the actions of inertia, the air mass load on the cone surface, and tightness of the back chamber, including mechanical losses of the suspension elements. If these restrictive forces acting on the cone exceed the mechanical strength of the former, or of the adhesive bonds, then the speaker will fail. Recent subwoofer designs, employing very stiff suspensions, have created unprecedented stress on the former.

To prevent bobbin crushing, design engineers specify appropriate bobbin and speaker. If the bobbin’s wall strength is inadequate, the materials may flex, creating non-linearities, or they may crease or collapse. Virtually all coil components will soften significantly when heated, creating errors, and if the temperature exceeds their limits, they degrade to the next level of distress, which may be out-gassing, blistering, embrittlement, deformation, or burning.

**PRODUCTION TECHNIQUES**

Most bobbin and collar materials are coated with a thin layer of adhesive on one side, and then dried at low temperature without curing the adhesive. These materials are cut to the required dimensions from master rolls or large sheets of material. Although some manufacturers cut materials in-house, the majority of them receive it cut into “blanks” by a converter. These voice coil blanks are wrapped around tubular steel or aluminum winding-mandrels, at which point their name changes from blank to bobbin. The former is wetted with solvent by brush, by spray, or by in-line wetting of the insulated, adhesive-coated wire. After the wire is wound onto the bobbin, the solvent then activates the adhesives, creating a secure bond between all the components (see Photos 3 and 4).

**BOBBIN STRENGTH**

In selecting a particular material, a coil winder makes important trade-offs on the winding process. Knowledge of these variables can ensure better, more cost-effective coils, avoid conflicts, and improve production yields. Torsional resonances, internal losses, and electrical conductivity of the bobbin materials are some of the factors effecting the distortion, sensitivity, and sound quality of the finished loudspeaker. If the bobbin’s wall thickness is inadequately, the materials may flex, creating non-linearities, or they may crease or collapse. Virtually all coil components will soften significantly when heated, creating errors, and if the temperature exceeds their limits, they degrade to the next level of distress, which may be out-gassing, blistering, embrittlement, deformation, or burning.
Engineering Consulting for the Audio Community

MENLO SCIENTIFIC

- Liaison Between Materials, Suppliers, & Audio Manufacturers
- Technical Support for Headset, Mic, Speaker & Manufacturers
- Product Development
- Test & Measurement Instrumentation
- Sourcing Guidance

sponsors of “The Loudspeaker University” seminars

USA • tel 510.758.9014 • Michael Klasco • info@menloscientific.com • www.menloscientific.com
collar materials in a thickness calculated to provide adequate wall strength that will endure some abuse. When drivers are operated at high-power levels, the temperature of the voice coil can be greater than 200°C. Clearly the mechanical stiffness of the former and collar materials must be considered at both room temperature and at elevated temperatures. At elevated temperatures, all materials soften to a degree. This is especially noticeable with Kapton (polyimide) which softens significantly at extreme elevated temperatures in the mid-200°C range, resulting in deformation or collapse of the former immediately above the winding. Lower-grade polyimides become soft at even lower temperatures.

Mechanical property considerations for formers include: dimensional stability under varying conditions of temperature and humidity, material mass, (specific gravity/weight), stiffness (torsional and flexural modulus), strength (tensile and compressive strength, plastic deformation limit and ultimate yield limit), fabrication and handling criteria, material fatigue, brittleness, and intrinsic damping characteristics.

### THERMAL CONSIDERATIONS

The real temperature limit of a driver may be determined by the failure or softening of any of the following: bobbin material, bobbin adhesive, wire insulation, wire adhesive, adhesive to cone, spider, or dome, or the materials of cone, spider, or dome.

Wire insulation, bobbin or collar materials, or adhesives with upper temperature limits of less than 180°C are not suitable for high-power drivers, but they are appropriate when the input power to the driver is a known and controlled factor, such as a self-amplified subwoofer. Where high-input power is anticipated and not controlled, materials rated for greater than 200°C are required. Because of their graceful over-temperature behavior, some types of 180°C wire are still used. Although voice coil materials and adhesives may tolerate exposures to temperatures well beyond their nominal rating, such exposures tend to have a cumulative effect.

Former thermal conductivity has both positive and negative aspects. On the positive side, it sinks heat from the coil, spreading it over a wider area, cooling the winding, which is always good. The most effective heat path in thermally conductive materials is through the thin film rather than along it, allowing it to transfer heat to the steel pole piece more efficiently, reducing the coil temperature without endangering the cone-coil-spider bond or plastic cone materials. Thermal conductivity also spreads the heat from hot regions over a larger area. Various black materials such as black anodized aluminum, black Kapton (MTB and variants), and black composites exploit the "black body effect," shedding heat more efficiently than pale colored materials. The effectiveness of this emissive cooling is relatively small at approximately 5% (see Photo 5).

### THE ADHESIVE BONDS

The adhesive coating on the wire and the adhesive coating on the bobbin must be solvent compatible. Compatibility between former material and coating adhesive is more commonly an issue. The low surface energy of polyimide films such as Apical and Kapton, together with their smooth, pore-free surfaces makes them a challenge for any adhesive. Although a driver manufacturer may specify a specific former material, the adhesive coating rarely receives the attention it deserves. Yet, it has dramatic effects on power handling and reliability. At the other end of the scale, Kraft, press, and bond papers have highly porous surfaces, with intrinsically high adhesion. But, their propensity to embrittle and adhesive wicking offset this benefit (see Photo 6).

There is also a thermoplastic flow failure, a classic catastrophic failure mode, producing rapid destruction of the coil structure, as windings slide around, or become loose like "slinky" toys. This failure mode is often seen in wire-to-wire bonds within the winding. One contributing factor is butyl rubber-modified phenolic adhesives, which are strong at room temperature, but their strength drops in a predictable, almost linear manner with increasing temperature. Their thermoplastic flow points run from 160°C for elementary types, approximately 190°C for better wire and competitive types, approximately 220°C for highly cross-linked types.

### MAGNET WIRE INSULATIONS

The insulation and adhesive coatings must be removed (stripped) to allow electrical termination of the voice coil to
the tinsel lead-wires. Stripping of these coatings can be performed with chemical agents, a hot solder pot, boiling caustic salts, or a mechanical abrasive. Another option may be ultrasonically welding the wire through the coating, or connecting to the tinsel wire with an insulation piercing crimp.

Dipping the wire ends into a pot of molten solder, which also simultaneously tins them, can strip polyurethane and polyester-based insulations. Higher temperature wire requires stronger treatments, such as dipping in boiling fused salts, which are available from the Eraser Co., New York (315-454-3237). Corrosive chemicals can also be used to strip high-performance wire insulations.

There are arguments, occasionally battles, between designers, who need to use 220°C wire to get close to the power specifications that the marketing department writes, and the manufacturing folks, who want to use 155°C wire because “it strips so nicely.” Sadly, wire that strips nicely also fails nicely (see Photo 7).

**DRY WINDING WITH BOND COATED INSULATED WIRE**

The majority of voice coil winders find “dry” winding to be the simplest and most economical technique for producing consistently good voice coils. Dry winding employs insulated wire pre-coated with a thermoplastic adhesive, which is reactivated with solvent during winding. It is then baked in an oven, or heated by applying current to the coil, which produces the good general purpose voice coils. Thermoplastic bond-coats allow fast, and fairly clean, winding and processing. But since they re-soften at high temperatures, they cannot tolerate high power.

**WET WINDING WITH INSULATED WIRE**

As an alternative to the “dry” technique, some coil manufacturers have had success using a technique involving simple insulated wire, which is passed through a bath of wet adhesive during winding. An almost perfect film thickness is achieved by drawing the wet wire through a precision “bullet” extrusion die, although pulling it through a simple felt pad saturated with adhesive is almost as effective. Wet winding allows the choice of adhesives that have been specifically engineered for loudspeaker voice coils, instead of trans-
former and electric motor industry bond coats. Wet wound coils are acknowledged to be superior to “dry” types, and wet winding is practiced extensively in Europe. But since it requires some operator skill, it is not as popular as it should be. Wet winding provides an excellent wire-to-wire bond, and the highest structural strength when used with adhesive-coated formers.

WIRE DIMENSION
In the United States, wire follows the American Wire Gauge (AWG) scales, which provides convenient increments between sizes, while outside the United States, the metric (IEC) scale dominates. The dimensions of some AWG sizes closely parallel those of IEC wire, and over the range that interests us in the loudspeaker industry, there are near perfect equivalents.

WIRE CONDUCTOR MATERIALS
Copper is the dominant material for voice coils wire due to its high conductivity and widespread availability. The vast majority of copper wire is used in electric motors and transformers, so it is produced in many gauges. Although copper is heavy, it is inexpensive (although it has gone through huge fluctuations during the last decade). Dead-soft annealed copper is the reference standard for conductivity, against which all other metals are measured, so it naturally rates 100% on the International Annealed Copper Standard (IACS) scale. High purity, oxygen-free, and long-crystal copper can rate up to 102% IACS. Copper wire is available insulated with hundreds of different resins, and some are available with a bondable over-coat. Some insulation coats are strong and flexible enough to allow the wire to be flattened (milled) into ribbon profiles. Several manufacturers produce voice coil wire in high-aspect ratios, by starting with a bare conductor, which is highly malleable. They mill it to the desired profile, then apply the insulation and bond coats, but this approach requires a substantial investment in equipment.

Aluminum and copper-clad aluminum are options in voice coils where mass is an issue. Like copper, aluminum wire can be milled into rectangular profiles, although it requires subsequent heat treatment to relieve the work hardening induced by the milling process. For extreme power applications, where wire insulation enamels may be a limiting factor, aluminum conductors can be anodized with a 0.05-mm layer of anodized insulation on all its surfaces (see Photo 8).

Copper-clad aluminum (CCA) wire is a combination of an aluminum conductor, clad with a thin outer layer of copper for easier termination. CCA wire is produced with 10% (USA) and 15% (Japan) copper by volume, equating to 25 to 37% by weight, making it appreciably heavier than pure aluminum. CCA wire can be milled into flat profiles, or “ribbon” wire, and is then termed CCAR. All of the normal insulation enamels and adhesives are compatible with aluminum conductors, but few varieties are offered as standard products.

VOICE COILS CONTINUED
Next month, we continue our exploration of voice coils, including secrets of the impact of the materials on sound quality.

---

Test Equipment Depot
800.517.8431

www.TestEquipmentDepot.com

Oscilloscopes
Power Supplies
Spectrum Analyzers
Digital Multimeters
Network Analyzers
Function Generators
Impedance Analyzers
Frequency Counters
Audio Analyzers
Soldering Equipment
Assembly Hand Tools
Tool Kits
And Many More...

The Invisible Switch
The Switch Is Connected With The Shortest Possible Leads. The Wired, Battery Driven Selector Is Placed Anywhere.

KAB RSX-1
Remote Switch Control
Two Turnables
Select Two Sources
Change Stereo
To Mono

KAB
Preserving The Sounds Of A Lifetime
www.kabusa.com