Transformer Bobbin and Core Selection Involves Interdisciplinary Design and Cost Issues

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At the heart of a transformer is the bobbin or coil former that serves as its winding and termination platform. The bobbin or coil former supports the winding, aligns the cores, channels the winding and provides a termination and connection method. Each bobbin is designed for use with a specific core shape, whether that core is ferrite, stacked laminations, or tape wound. There are many ways to design a transformer, so it is important to make the best bobbin and core combination selection. Product cost, availability, material limitations, safety agency requirements and, ease of production are all-important considerations. *Figure 1* shows an example of the types of bobbins that are available.

Figure 1. *Bobbins for transformer cores cover a broad range of sizes and plastic materials.*

The designer must also consider bobbin and core orientation and geometry. Vertical mount bobbins take up less board space, but more height than a horizontal mount type. Wire termination is also more difficult than the horizontal mount bobbin and very few multi-section types are offered. Horizontal mount bobbins have a lower profile, but take up more board space. Horizontal types offer easier wire termination and many multi-section types are available.

Several significant issues confront the magnetics designer when selecting a bobbin and core combination for a transformer application, including the material characteristics, shape, cost, and regulatory compliance.

Another consideration is how to package and ship the finished assembly for shipment to the point of p. c. board insertion. While magnetic devices are not susceptible to static discharge, other components at the p. c. board insertion point may be. It is recommended that assemblies be packaged in anti-static trays or tubes, which also protect it during shipping and handling.

Cost Considerations

Designers may start by asking which bobbin and core combination meet the form, fit and function of the design, but cost considerations won't be far behind. The lowest cost core and bobbin combination with the widest availability are based on the square stack lamination sizes like E187, E24/25, E375, E21, E42/15. However, these square or rectangular center leg shapes may need to be shielded around the core with copper foil to reduce EMI, which will increase cost.

The engineer may also consider the newer round center leg cores and bobbin combinations. ETDs, PQs, EFDs and EPs are popular examples of this core style, which are usually made of ferrite. These newer cores and bobbin combinations are higher cost, however they are easier to wind and provide good shielding from EMI.

Bobbin termination is an important consideration, because it must connect the transformer or inductor to a circuit. Bobbins without terminals cost less than bobbins with them. However, bobbins with terminals improve production and facilitate p. c. board insertion. Terminal size and shape will vary, depending on the size and nature of the winding wire that will be used. Also, surface mount or through-hole terminal styles must be evaluated. Practically all bobbins are available with through-hole terminals, but only selected smaller core and bobbin combinations are available in surface mount. This is primarily do to the weight of the assembly and the limitations of pick and place equipment.

Class	Temperature Rating
A	105°C (221°F)
B	130°C (266°F)
F	155°C (311°F)
H	180°C (356°F)
N	200°C (392°F)
R	220°C (428°F)
S	240°C (464°F)

Table 1. *Plastic-molded bobbin temperature classifications.*

Multi-section bobbins have molded walls or barriers that divide the winding area into two or more parts. This allows for winging isolation in high voltage applications. But, multi-section bobbins are usually more expensive.

Because of the high tooling cost, a custom-tooled core and/or bobbin is usually out of the question for most applications. The core and bobbin tooling charge could be from $5,000 to $20,000 each. Another limitation is that there would only be one source for the custom core and/or bobbin. With these costs in mind, most engineers focus on standard bobbins and cores when reviewing an application.

Bobbin material also impacts cost.

Type	**Thermoplastic**								**Thermoset**				
Group	Polyamide (Nylon 66)				Polyester	PPS	LCP		Epoxy	Diallyl Phthalate (DAP)			Phenolic
Trade Name	RTP 205FR	Vydyne 909	Zytel FR50	Technyl A20-V25	Rynite FR-530	Ryton R-4	Zenite 7130	RTP 3407-4	E4920	D72	Rx 3-1-525F	DAP 5562	PM 9630
Manufacturer	RTP Co.	Monsanto	Dupont	Nytech	Dupont	Phillips	Dupont	RTP Co.	Cosmic	Cosmic	Rogers	Syres Almoco	Sumitomo
UL File No.	E84658 (N)	E70062 (M)	E41938 (M)	E44716 (M)	E69578	E54700 58(M)	E1239	E84568	E64213	E64213 (S)	E123472 (M)	E41429 (M)	E41429 (M)
UL Flammability**	94-VO	94-VO	94-VO	94-VO	94-VO	94-VO	94-VO	94-VO	94-VO	94-VO	94-VO	94-VO	94-VO
Temperature Classification*	B	B	B	B	B	N	R	--	N	F	F	F	F
Max Temp (°F)***	480	482	475	482	489	500	552	610	>700	>700	>700	>700	>700
Water Absorption %	0.6	0.7	0.7	0.6	0.05	0.05	--	--	0.15	0.25	0.25	--	0.15
Coefficient Thermal Expansion m/m/°C 10^{-8}	3.4	1.7	2.5	2.3	1.4	2.0	1.4	--	3	1.8	1.7	4.5	1.5
Dielectric Constant @ 1MHz (dry)	3.8	3.5	3.4	3.7	3.6	3.8	3.5	3.6	3.2	4.0	3.6	4.4	4.5
Volume Resistivity Ω-cm (10^{15})	1.0	3.8	0.1	1.0	1.0	4.5	1.0	--	5.5	0.01	0.01	1.0	--

*The material manufacturer has determined this to be the maximum continuous operation temperature as defined by UL system temperature classifications: B=266°F, F=311°F, N=392°F, R=428°F.

** All plastic materials listed in this table are formulated to have an Underwriter's Laboratory flammability rating of UL 94-VO. This rating characterizes the ability of the plastic to self-extinguish under specific conditions when exposed to and then removed from an open flame.

*** This is the estimated temperature where the integrity of the plastic body will be challenged by the heat transformed through the terminal to the plastic body.

NOTE: This table is for reference only and is intended to highlight the differences between materials. Current material performance information should be obtained from the manufacturer prior to design finalization.

Table 2. *Plastic material specifications.*

There are a wide variety of materials to chose from and each material has advantages and disadvantages that are application dependent. In general, the higher the temperature a material can tolerate, the more expensive a bobbin molded from it will be.

Material Considerations

To select the material that meet safety agency requirements, the designer must understand the operational environment of the finished device. There are several agency-determined temperature classes that cover working environments ranging from an office, to a truck engine compartment. *Table 1* lists the material classes and the associated temperature for plastic-molded bobbins.

In addition, the plastic must tolerate soldering temperatures for a brief period during the manufacturing and p. c. board soldering process. How much heat a plastic molded bobbin needs to tolerate is usually the most important material consideration.

Plastics used in bobbin molding fall into two main groups, thermoplastic and thermoset. Thermoplastic materials are the most widely used in bobbin molding and are readily available. Thermoplastic bobbins are inexpensive and capable of meeting many agency heat and flammability requirements when mixed with mineral, quartz, or glass fillers. *Table 2* lists the different types of plastic materials and their characteristics.

Thermoset materials are more expensive, but offer the greatest strength and temperature performance. DAP (Dially Phthalate) and epoxy plastics are suitable for toroid mounts and potting cups, but their brittleness makes them unsuited for bobbin applications. Phenolic plastic is well suited for bobbin applications, and they are especially stable in high temperature applications for which they are becoming more popular.

Besides temperature class regulations, a plastic's ability to resist burning, or its flammability rating, is also critical factor. Underwriter's Laboratory (UL) has specific flammability requirements depending on the working environment of the finished product. Referred to as UL94, this regulation classifies plastic materials on their ability to self extinguish when put in contact with, and then removed, from an open flame. In most applications, the highest level of UL94VO is preferred. *Table 3* describes the UL 94 flammability requirements for plastic materials.

Type	Comments
V0	Will support combustion for up to 10 seconds and self extinguishes when tested under specific conditions.
V1	Will support combustion for up to 30 seconds and self extinguishes when tested under specific conditions.
V2	Will support combustion for up to 30 seconds and self extinguishes when tested under specific conditions. Dripping of melted material is allowed.
V5	Will support combustion for up to 60 seconds after 5 test burnings of 5 seconds each and self extinguishes when tested under specific conditions.
HB	Will support combustion and may not self extinguish when tested under specific conditions.

NOTE: For information on ordering a copy of "UL Tests for Flammability of Plastic Materials" from Underwriters Laboratories call (888) 853-3503, or via the Internet at www.ulstandardsinfonet.ul.com.

Table 3. *UL 94 flammability of plastic materials classification description.*

Plastic molded bobbins must also meet the requirements of UL746, which requires the plastic used in molding the bobbin to be traceable by batch number through the molding operation back to the plastic manufacturer. This is to insure that only the plastic material recognized by UL is actually used to make the bobbin. The design engineer and the purchasing department must be confident that the source for the bobbins has the procedures and documentation in place that ensures material traceability.

Availability

Bobbin and core availability is also a critical issue. With product design cycles getting shorter, it is important that the products are available to meet production deadlines. Checking with core manufacturers and distributors, as well as bobbin manufacturers, will provide a good indication of available stock and lead times for bobbin and core combinations.

Some core manufactures do offer a limited selection of bobbins to match their cores. However, in most cases these bobbins are purchased from bobbin manufacturers and offered only as a convenience and are not always cost effective. The manufacturer or their authorized distributor will have a wider product range, more material and terminal options. They can also offer material suggestions, material traceability, all at a lower cost.

Although several bobbin molders will make bobbins for a standard ferrite or lamination size, they may all have slight differences. The most common differences include: wire slots and flange shape, locator marks or notches, standoffs, material, terminal shape and terminal style. When evaluating bobbins, it is recommended that the designer request a sample from the bobbin molder or their authorized distributors.

Production Considerations

Production consideration is another key factor in bobbin and core selection. The winding method, the wire size to be used, bobbin capacity, and assembly techniques must be carefully reviewed to make sure they are compatible with production capabilities.

Bobbin and core combinations with round center legs are well suited for

Bobbins

machine winding. Whereas square leg E-cores and bobbin combinations do no allow the wire to lay flat as it is wound around the bobbin, which creates loops and gaps between the wire and the bobbin. This increases leakage inductance and can affect transformer performance.

The wire size or gauge is also an important consideration. Many bobbins are better suited for small diameter wire whereas others are designed for heavy wire. Also, consider the shape and style of the bobbin terminals. Make sure the size and gauge of the terminal is compatible with the wire size that will be terminated. Review how the bobbin design facilitates dressing of the wire from the winding to the terminal for soldering by utilizing slots or channels.

Bobbin capacity or fill should be calculated so that approximately 90% of the bobbin's capacity is filled with magnet wire. This will optimize the assembly by achieving maximum magnetic coupling.

The assembly of the bobbin and core combination is worthy of careful consideration. In most bobbin and core assemblies, the two parts of the core material must be joined through the bobbin. It is important that the cores are firmly pressed together to assure consistency in performance. Some cores are glued together, others are taped, and others have spring metal clipping devices designed for that core and bobbin combination. Each bobbin and core assembly option should be considered to determine which is best for your assembly capabilities.

Once the bobbin is wound, the winding leads need to be terminated. If the bobbin has no terminals, the "flying leads" need to be connected right to a terminal strip or to the p. c. board. If the bobbin has terminals, the wire leads need to be soldered to those terminals. Care must be taken at this stage not to damage the bobbin with the heat of the soldering process. The metal terminals will transfer the solder heat to the plastic surrounding and supporting the terminal. In thermoplastics, if the plastic is allowed to soften too much, the terminal may move out of alignment, making p. c. board insertion difficult.

With thermoplastic bobbins, careful hand solder techniques are generally used. If the wire has been stripped of its insulation first, a quick dip in a solder pot can solder the lead to the terminal can also be successful on a thermoplastic bobbin. If the solder dipping method is intended to strip the insulation from the wire while making the solder connection, a thermoset plastic should be used because of the higher solder temperature that is required.

Once the winding leads have been soldered to the bobbin's terminals, the bobbin will be soldered in a p. c. board. An important factor is whether the heat applied to the terminal while soldering the terminal to the p.c. board will reflow and weaken the winding lead to terminal solder connection accomplished earlier in the process. One method for avoiding this problem is to use a higher melting point solder to connect the leads to the bobbin terminals, then use a lower temperature solder to make the p. c. board connection.

Even with the 130° C polynylese solder strippable magnet wire, the preferred method is to either solder dip or mechanically strip the magnet wire close to termination pin, then wrap one to two turns minimum around the terminal. Hand solder at approximately 550°F (288°C) for five seconds with SN10 high temperature solder (88% lead, 10% tin and 2% silver). When the assembly is soldered to the p. c. board, use SN63, (63% lead and 37% tin) that has a melting point of below 400°F (204°C) This process will eliminate the reflow and weakening of the solder at the bobbin terminal.

Another method when using polynylese magnet wire is to wrap the unstripped wire around the terminal and elevate the solder pot temperature to around 700° F (371°C) using SN10. The bobbin terminals are dipped into the solder and allowed to soak for two seconds. This will strip and solder the wire to the terminal in one step. This method is better with thermoset bobbins because they can tolerate the heat. If a thermoplastic is used, the process must be accurately controlled to eliminate plastic softening and terminal misalignment.

Safety Regulations

There are additional safety agency requirements covering construction of the entire transformer or inductor. Several agencies have responsibilities that cover a variety of applications, market segments, and geographic areas. These regulations are concerned with insulation and spacing to protect against an electrical short in the winding over time and with thermal aging. In many cases, these safety concerns are addressed by the spacing and margins built into the bobbin. UL 1446 regarding motor, transformer and coil insulation is the primary specification in the U. S. that governs the insulation requirements of these products. UL 510 is another important regulation for electronic tape flammability, which will often be part of a transformer or inductor design.

The European Safety Agency has its own safety regulations that are covered by specification VDE 0805. VDE horizontal bobbins that meet European specifications are becoming more popular. These types have molded-in margins, wire separation slots for termination, and other modifications needed to meet VDE requirements. These regulations are European, so European bobbin manufacturers like Miles Platts, Philips and Siemens have the best VDE bobbin selection.

VDE requires 3750Vrms dielectric between the core and windings, and

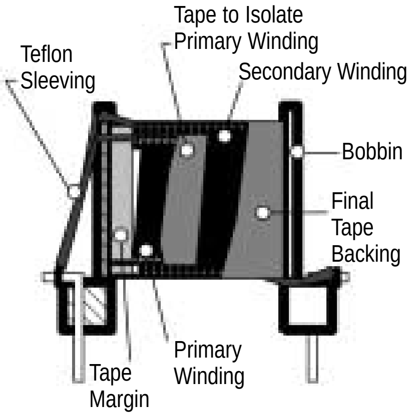

Figure 2. *Cross-section of a core and bobbin configuration.*

from winding to winding. To accomplish this effectively, a 3mm-isolation margin must exist on each side of the bobbin. If the bobbin does not include this feature, the margins need to be added to the bobbin. (*Figure 2*). The margins are usually built using solid film adhesive tape slit to 3mm in width. P.Leo 1H818 or 3M 44 polyester film/mat are recommended. Porous tapes, such as glass and acetate cloth is not allowed. The margins must be level or taller than the build of the winding. A sleeving to insulate the ends of the magnet wire must be added as the leads extend into the margin and egress out of the bobbin in preparation for connection to the bobbin terminals. Teflon sleeving, such as Weco #TT and Wire Management Products #TFT is recommended.

Three layers of 2.2mil Polyester tape now can be wrapped the full width of the bobbin to cover and insulate the primary winding from the soon to be added secondary winding. Polyester tapes such as P.Leo 1P801 or 3m 1350 are good choices. Margin build up must be repeated for secondary windings to be wound over the primary winding. The process is the same as before. The teflon sleeving for the secondary winding is required as before. It is important to note that a 6mm-creepage barrier must exist between the lead from the primary winding and the lead from the secondary windings. The final backing is three layers of 2-mil polyester tape covering the secondary winding, same as covered the primary. The transformer is now ready for solder termination, core assembly, testing and varnish impregnation.

Core and Bobbin Combinations

Core and bobbin combinations can be divided into two groups, depending on whether they are used in telecommunication or power conversion applications. Lower power and low heat dissipation, but high-shielding requirements characterizes the

Core	Sizes	Core Description	Bobbin Description
Pot	7 x 4, 9 x 5 11 x 7, 14 x 8 18 x 11, 22 x 13 26 x 16, 30 x 19 36 x 22, 42 x 29 mm	Oldest type. Some sizes being discontinued due to declining popularity. Sizes 22/13, 26/16, and 30/19 used in power converters, although the RM core is a more popular alternative. **Cost:** moderate due to lower production volumes and more complicated shape.	Low cost glass filled thermoplastic with through-hole terminals most common. Few surface-mount available. **Cost:** relatively low cost.
RM	RM4, 6, 8, 10, 12, 14	Offer larger wire egress slots than a pot core. Can accommodate larger magnet wire. Take up less p. c. board space than pot cores. **Cost:** relatively low.	Many through-hole options in thermoset and thermoplastic . No surface mount versions are available. **Cost:** relatively low.
EP	EP 7, 10, 13, 17, 20	Gaining in popularity, provide very good magnetic coupling in a compact space. Sizes EP 7 and EP 13 are most popular. **Cost:** moderate.	Surface-mount and through- hole. Surface-mount popular in thermoplastic LCP. Through-hole popular in thermoset. **Cost:** moderate.
E	E 187 through E80	Largest selection of power ferrite shapes. Square or rectangular center leg limits switching under 150 kHz because of inefficiencies that cause high leakage inductance. Open shape requires shielding core with copper foil for EMI suppression. **Cost:** relatively low.	Vertical or horizontal, surface-mount and through-hole, thermoset and thermoplastic, and multi-section. **Cost:** relatively low.
ETD	ETD 29, 34, 39, 44, 49, 59	Round center post makes the winding of magnet wire or foil easy. Most often used in high power switching frequency to 600 kHz. Shape good for improved magnetic coupling. **Cost:** moderate to high.	Vertical or horizontal with through-holes, thermoset and thermoplastic. Surface mount not available. Multi-section available. Large terminals allow larger diameter magnet wire. Easy to use. **Cost:** moderate to high.
PQ	PQ2016, 2020, 2610, 2614, 2620, 2625, 3214, 3220, 3230, 3535, 4040	Round center posts and circular geometry makes these cores very popular. Also provide excellent shielding, good magnetic coupling, ease of winding and ease of assembly. **Cost:** moderate to high.	Horizontal with through-holes; Thermoset and thermoplastic. Surface mount not available. Large terminals allow larger diameter magnet wire. Easy to use. **Cost:** low to moderate.
EFD	EFD10, 15, 20, 25, 30	Low profile, with high effective area, (Ae) makes them desirable for lower power switching transformers. Provide good coupling and shielding. **Cost:** moderate to high.	Horizontal orientation with through-holes and surface-mount terminals. Available in themoset and thermoplastic. **Cost:** moderate.

Table 4. *Core and bobbin combination characteristics.*

telecommunication group. Higher power and heat dissipation and energy storage requirements characterize the power group.

Table 4 tabulates the characteristics of the core and bobbin combinations. Other core and bobbin combinations, not shown in Table 4 have many good features, including EPC, ER, and LPC. These types currently have limited popularity and availability.

When designing and specifying a bobbin and core combination, attention is initially paid to the performance of the core. The designer must realize that the bobbin, and not the core, will have the greatest impact on the nature and ease of the winding operation, the winding lead termination, safety regulations and p. c. board insertion. The bobbin will have a larger impact on the cost of manufacturing the assembly than the core. Moreover, the bobbins will be at least as important as the core to the long-term success of the transformer or inductor in operation. When the power transformer is properly designed assembled, finished and tested it will be one of the last components to fail in any system.

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