

Chapter 3: Anatomy of a Transformer

A White Paper from Lundahl Transformers
www.lundahl.se

Presented by ProSoundWeb
By Ken DeLoria

LUNDAHL
- TRANSFORMERS -

Introduction

As discussed in the previous segments of this series, transformers play a vital role in professional audio, in large part because of the galvanic isolation achieved by magnetically coupling two (or more) coils of wire around a metallic core. The basic concept is simple: electromotive force generated by AC signals passes through the transformer, but ground references do not.

But like many “basic concepts,” the design and manufacture of an ideal transformer is a complex undertaking. A tour of Lundahl’s modern facility in the town of Norrtälje, about 70 km north of Stockholm, Sweden, provides highly interesting, not to mention highly useful, insight on the process.

Governing Factors

There’s more than one way to manufacture a transformer; in fact, the topologies and underlying methods are numerous. The differences from one transformer type to another can be significant, with governing factors that include material selection as well as mechanical and electrical choices made during the design phase, encompassing wire gauge, core size and more. Most important is the topology of the design; i.e., how the coils and core material are constructed and assembled together. Combined, these factors determine the performance characteristics of the final product.

For most manufacturers, design topology is limited to the type of machinery that can be purchased to produce the final product, including the crucial aspect of coil winding. Yet transformer companies typically limit their production operation to common bobbin-style winding machines, spools of wire, and off-the-shelf transformer “cans.”

On the other hand, Lundahl determined early-on that a dual, open-ended coil topology provides many benefits over standard bobbin winding. These include better electromagnetic coupling, lower unwanted capacitive coupling, freedom from industry-standard form-factors, and more. The problem was that the machinery needed to manufacture transformers using Lundahl’s preferred topology simply did not exist.



Figure 1: CNC milling machine in Lundahl’s machine tool fabrication shop where production equipment is designed and manufactured.

As a result, the company not only designs and manufactures its own transformers; it also designs and builds the actual machinery that, in turn, is used to manufacture the transformers. This is done not because Lundahl has a penchant for building machinery, but rather, because the specialized machines it needs are not available for sale. Lundahl operates a full-time tool shop and fabrication facility in the basement of its factory solely to build and maintain production machinery. The shop is equipped with top flight CNC milling and drilling machines, metal lathes, metal saws, and other essential tools (Figures 1, 2, and 3). Almost nothing in the process is farmed out, not even the software that controls the servo motors, sensors, and pneumatic valves on the various production machines. The resultant production lines are elegant, efficient, and reliable.

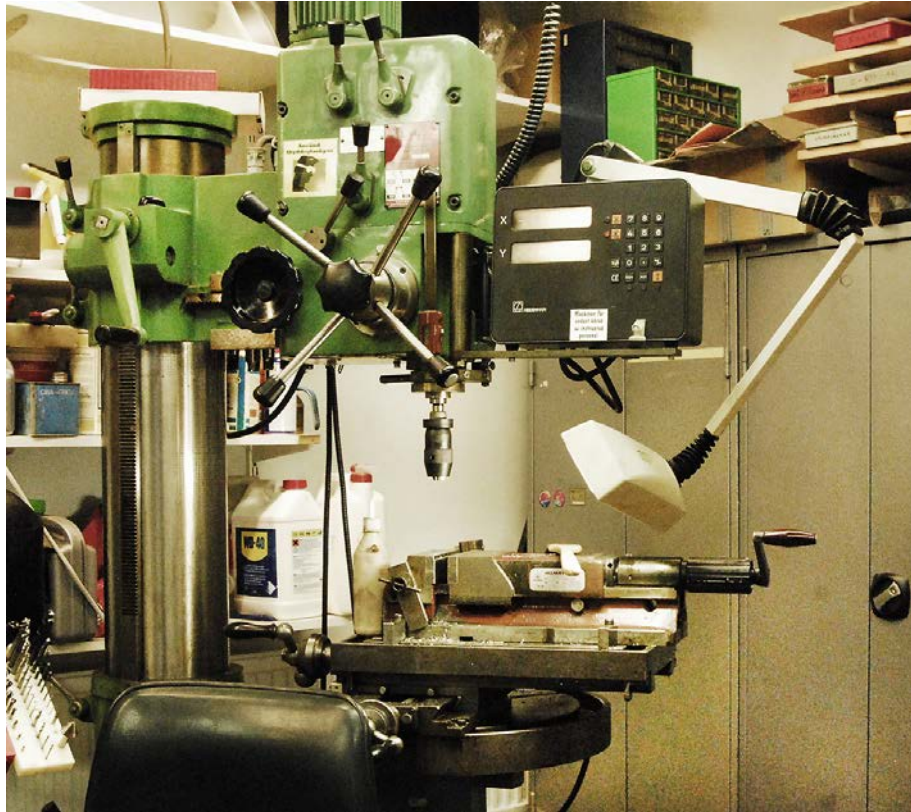


Figure 2: A CNC drilling machine.

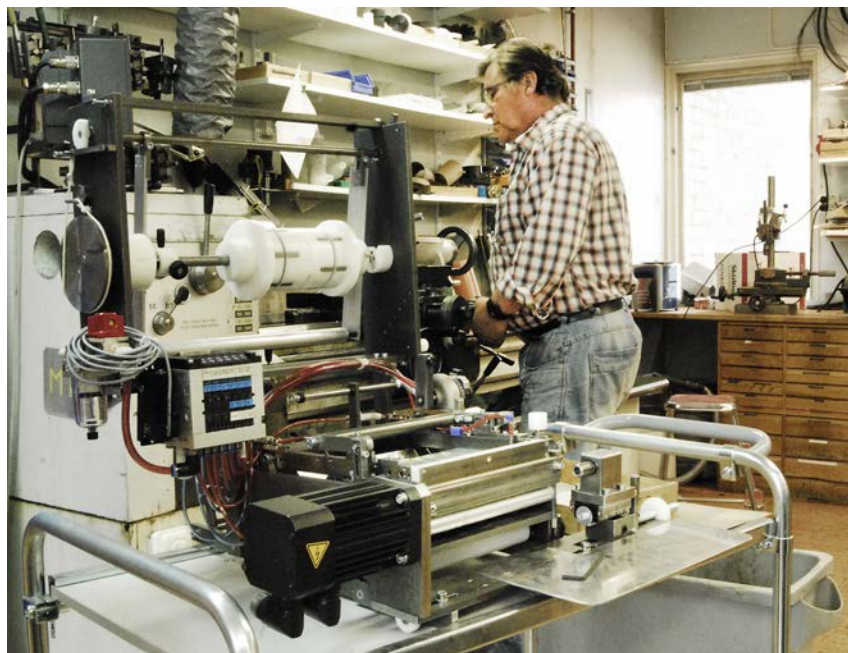


Figure 3: A senior machinist operating a metal lathe with prototype coil-winding machine shown in foreground.

Coils & Foils

This leads us to the construction details that make a Lundahl transformer unique. Recall that the foundation of any transformer consists of at least two coils -- the primary and secondary windings wrapped around a core material. The typical method is to wind the coils using bobbins, something like the bobbin on a sewing machine, and then place the core material inside the bobbins.

By contrast, Lundahl uses a method called stick winding. To produce a stick-wound coil, a mandrel that resembles a stick is temporarily placed on a custom built Lundahl winding machine (Figures 4, 5, and 6). During the winding process, copper wire is wound onto the insulation surrounding the mandrel. Lundahl's specialized machinery automatically inserts insulation material between each individual layer of copper wire in order to reduce internal capacitance and increase high voltage tolerance.

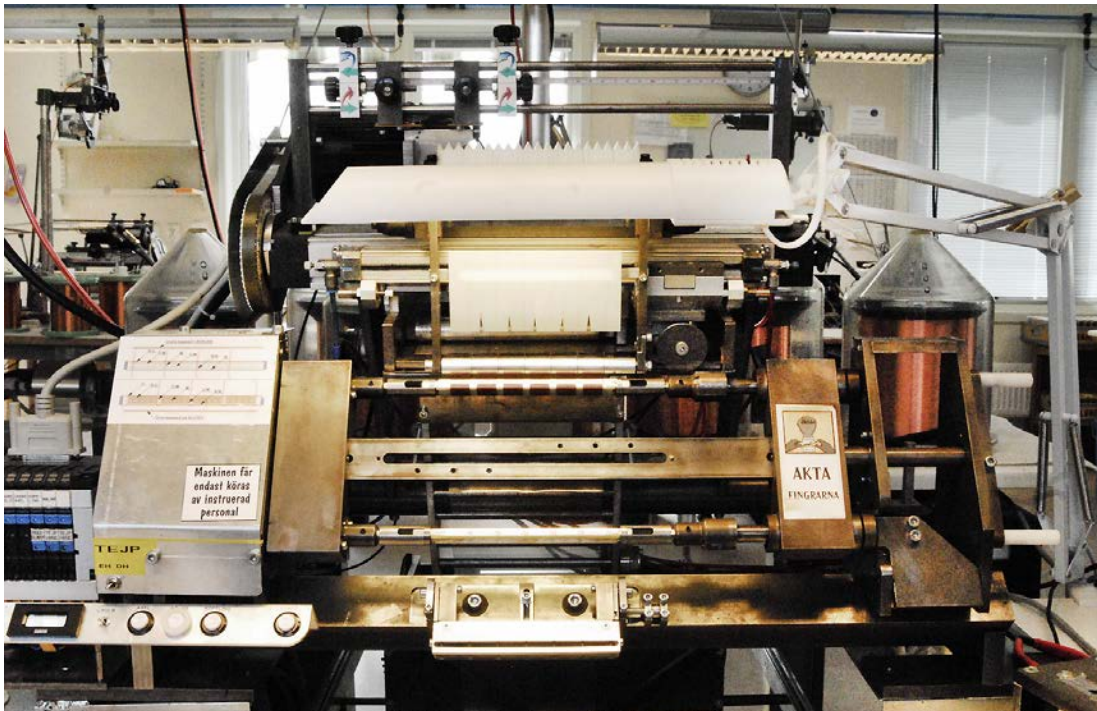


Figure 4: Front view of a Lundahl coil-winding machine.

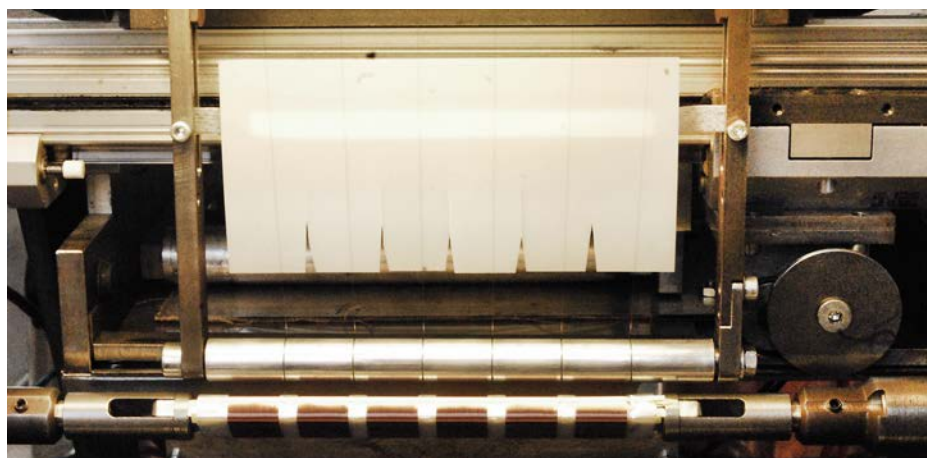


Figure 5: Close-up showing reusable mandrel and "stick" winding method.

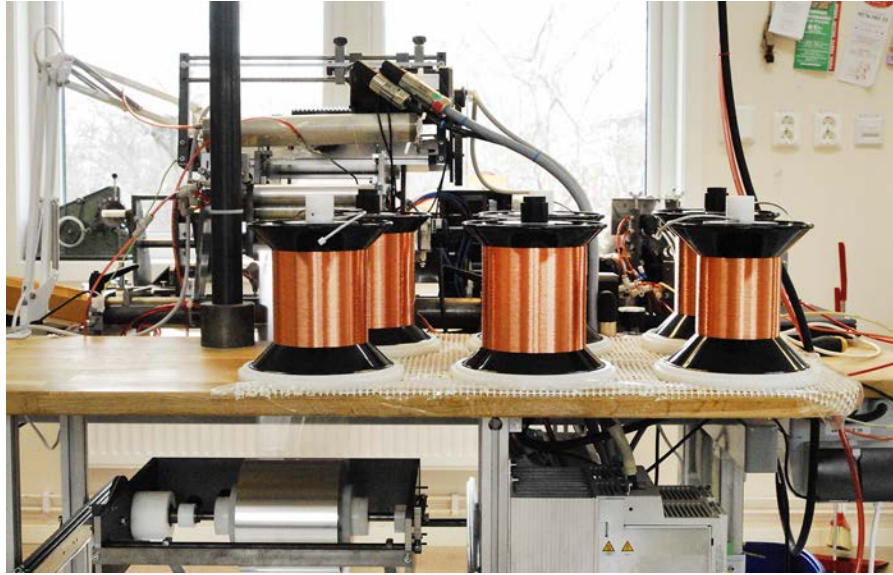


Figure 6: Rear view of a Lundahl coil-winding machine showing wire spools.

A computer control system driven by custom software written by Lundahl, controls the number of wire turns based on the design specifications of the specific transformer model that the winding machine is running at that time. When the prescribed number of wire turns have been completed, the mandrel is removed, and the resultant “stick” with the completed coils of wire moves on to the next fabrication process.

The turns ratio, that is the number of turns in the primary coil relative to the secondary coil, determine if the transformer is a 1:1 isolation type, or is intended to step-up, or step-down, the primary voltage. Lundahl provides many different models with varying turns ratios to meet the diverse needs of microphone manufacturers, pre-amp manufacturers, splitter manufacturers, console manufacturers, press pool manufacturers, and others who require transformers as a critical component in their products.

Numerous models have dual primary coils and/or dual secondary coils, and some even have quad coils for the primary, the secondary, or both. This allows the coils to be connected in parallel or in series by the equipment manufacturer, thereby altering the turns ratio as needed for different applications.

Most models are also equipped with internal Faraday shields, carefully factored into the design topology. Figure 7 shows a machine built by Lundahl that installs the Faraday shielding, which provides significantly increased common mode rejection.

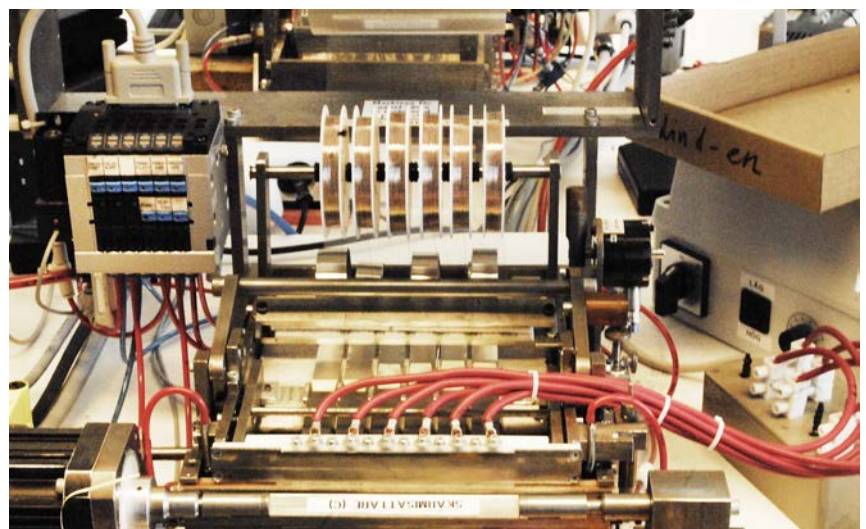


Figure 7: Awesome complexity! Front view of a Lundahl machine that inserts Faraday shields in the transformers for significantly improved CMR (Common Mode Rejection).

In addition, transformers are manufactured in different sizes, ranging from very small for use in microphones to much larger form factors for use as interstage and output transformers in tube amplifiers. Consequently, Lundahl has also developed varying sizes of winding machines to accommodate the wide range of products that the company offers (Figures 8 and 9).

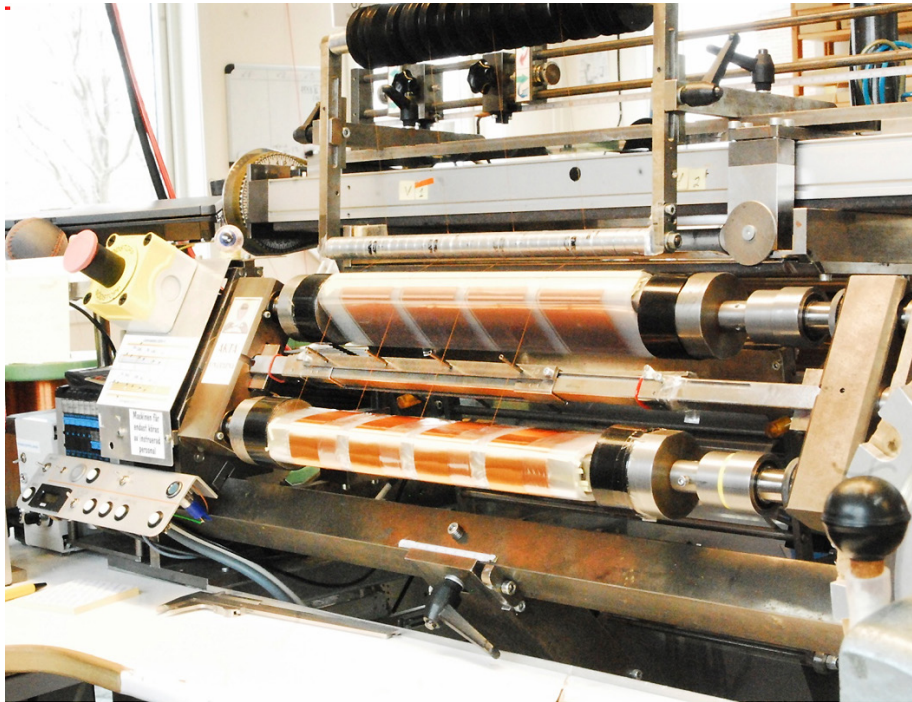


Figure 8: Front view of a Lundahl coil-winding machine for larger format transformers.

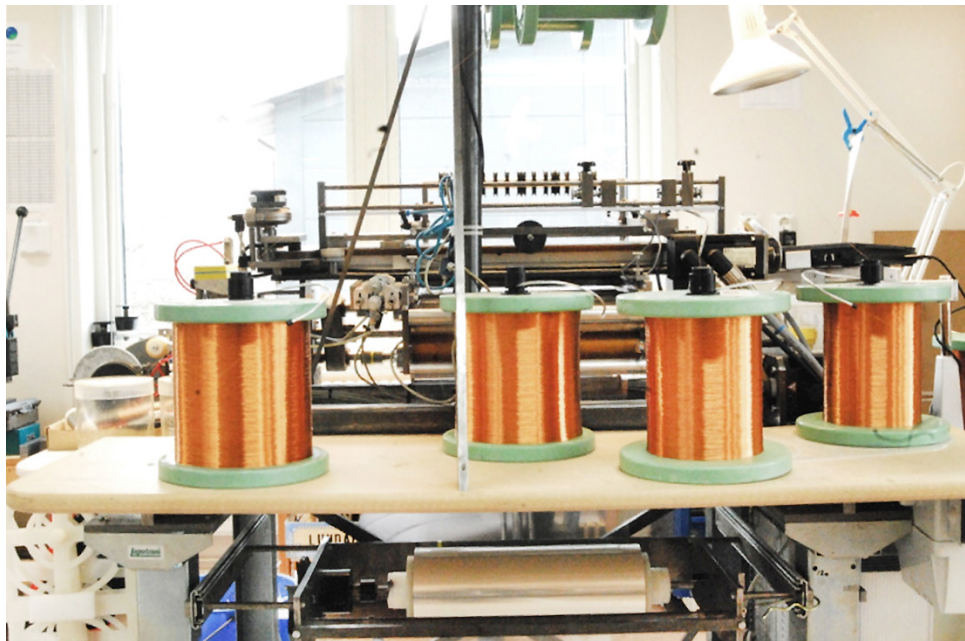


Figure 9: Rear view of large-format Lundahl coil-winding machine showing wire spools.

And, not all transformers are wound with copper wire. Lundahl's high-end moving coil step-up transformers are available with high purity silver wire windings. Despite the small difference in electrical conductivity between copper and silver (approximately 6 percent), the sonic differences can be substantial.

Core Of The Issue

In addition to the primary and secondary windings, another critical component is the core. Audio transformers use stacked cores (made from E- or U-shaped laminations) or C-cores, which are constructed of steel bands that are typically wound into an oval shape. When the oval is cut into two halves, the halves look like the letter "C," hence the name.

This is another aspect where Lundahl is not content to simply purchase pre-made cores or to farm out the fabrication work, but rather, wind the cores from a variety of sizes and types of material to meet exacting specifications. As with the coil winding machines, the machines that wind the steel bands into cores are manufactured by Lundahl exclusively for their own use in production.

Different core materials possess different properties, presenting the design engineer with a range of choices when optimizing a transformer for a particular purpose. For example, amorphous steel has low internal losses and is widely used in high voltage power transformers, but is also used in the specialized transformers that Lundahl manufactures for audiophile tube amplifiers, an application in which amorphous steel is considered very desirable.

Conventional crystalline alloy steel is more commonly used for pro audio applications. When power efficiency is not the governing design goal, cores of varying Ferro-magnetic alloys have certain advantages in respect to wide frequency response and low distortion characteristics. One Lundahl customer ran a double-blind listening test to characterize and grade the performance of differing core materials; as it turns out he was rather surprised by the results.

The bottom line is that different core materials are known to result in different sonic signatures, but it's not so simple to say that one material is categorically better or worse than another.

The world of transformers is not a simple one. In addition to core materials, there are many other factors that effect transformer sound quality, including the selection of other materials, the precision fit of the coils and core, the uniformity of the windings, the use of layered insulation; the quality of the assembly work, and more.

While the majority of Lundahl's product line is designed and manufactured to be as sonically transparent as possible, there are some exceptions. For example, the LL1940 tube microphone transformer uses a silicon-iron C-core, unusual in its intended application. The result is a transformer with more "sound character" compared to a classic mu-metal lamination transformer.

Owning the Process

Experiencing first-hand the complex series of steps required to manufacture audio transformers to the standards noted in this paper is like entering another world. Spools of wire finer than a human hair run through robotic-looking winding machines, while the line operators confidently and efficiently perform their tasks (Figures 10 and 11).



Figure 10: Lundahl coil-winding machine in use.



Figure 11: Production worker operating a custom-built fabrication machine.

Machines form and shape the packaging cans, spot welding the ends together in a quick, semi-automated sequence, while others manufacture the cores, and still others the hollow pins that become the transformer's I/O connection points. Industrial ovens, running a three-day heating-and-cooling cycle, cure the epoxy resin that bonds the internal components together and eliminates oxidation, ensuring that each transformer will enjoy decades of longevity. Other, higher temperature ovens are used to anneal the C-cores and the nickel housings, removing molecular stress in the materials in order to improve the magnetic properties.

After the coils are wound, the core has been shaped, slit, and is ready for assembly, the pieces are put in place and the basic transformer now begins to take shape. The extremely fine copper wire leads are inserted into the Lundahl-manufactured hollow connecting pins, to be soldered later in a submersion process. Quality control is comprehensive with every single production unit receiving a series of tests to insure that it meets the factory's rigid performance specifications (Figure 12).



Figure 12: Test station with trays of production units ready for QA (quality assurance) testing.

Note that the manufacturing cycle of a given Lundahl transformer can be a full week, from start to finish. It's an exhaustive process, and one that requires a high level of investment. Yet by controlling the entire process, from raw materials to finished goods, Lundahl has positioned itself as a premium provider of a key component in the world of audio and systems.

About The Author

Ken DeLoria is senior technical editor for ProSoundWeb and Live Sound International magazine, and has had a diverse career in pro audio over more than 30 years, including being the founder and owner of Apogee Sound.