

Harnessing the full potential of induction heating with 3D printing

(A technical article from 2024, author: Max Wissing, Technology Manager, Protiq GmbH, Blomberg)

Additive manufacturing technology, also known as 3D printing, is already being integrated into production processes in numerous industries. Thanks to the progress made in recent years, the process and material portfolio of 3D printing offers a wide range of possibilities. In addition to classic prototypes, the direct manufacture of functional components and even series production are now possible. Industrial 3D printing processes can be used, for example, to additively manufacture high-strength steel components or components made of pure copper. The ability to additively process highly electrically conductive copper grades or pure copper has opened up new potential, particularly in the manufacture of induction heating systems.



▼ Additive manufacturing of induction coils from highly conductive copper materials opens up new possibilities for producing even very complex coil geometries.

All 3D printing processes have in common that components are built up layer by layer without the need for molds or semi-finished products. This fundamentally distinguishes the technology from traditional industrial production methods such as CNC milling, CNC turning, forming and joining. The layer-by-layer build-up makes it possible to manufacture components in one piece directly from 3D CAD data and also offers a high degree of design freedom in the production of complex geometries. At the same time, additive manufacturing at industrial quality requires a great deal of process understanding and know-how, especially when processing innovative metal materials. Copper in particular is considered difficult to process additively and has only truly penetrated the market in recent years. Protiq GmbH in particular has made a name for itself in the field of additive copper processing for more than 10 years. As the world's first provider, Protiq succeeded as early as 2013 in reliably processing a highly electrically conductive copper alloy with 99% copper content using the additive laser melting process (SLM). This success was based on years of in-house develop-

ment work. Since then, Protiq has continuously improved and further developed the process, so that in 2019 the company also became the world's first to offer pure copper.

The material contains no further alloying elements and conforms to the Cu-ETP material standard, with an electrical conductivity of 58 megasiemens per meter (MS/m) – or 100 percent IACS.

Protiq GmbH operates on the market as a reliable industrial manufacturing service provider and is the competence center for additive manufacturing within the Phoenix Contact group of companies. Having started out in additive manufacturing in 2010 and with more than 10 years of experience with additively processed copper materials, Protiq confidently regards itself as one of the market leaders in this field. Protiq supplies its 3D-printed components to all industries, e.g. mechanical engineering or renowned manufacturers of copper induction heating systems.

Protiq's developments represented a veritable revolution, especially for the manufacture of these heating tools.

Inductors are used in many industrial sectors for the efficient and precise heating of metal components. The



▼ The process developed by ProtIQ for processing highly conductive pure copper in selective laser melting (SLM) enables the production of new inductor designs and innovative coil cross-sections, demonstrated here in a sectional view.

coil geometry has a decisive influence on the heating pattern and is particularly essential in surface hardening. Complex and precise hardening requirements likewise result in increasing demands on the induction coils used. These demands continue to grow with the increasing use of FEM simulations and numerically optimized components. Traditionally, the coils used are often made by hand – by bending, cutting and brazing hollow semi-finished copper products. This places clear limits on the possible complexity of the coil, due to minimum bending radii, and on the necessary reproducibility. Alternatively, the coils are made from CNC-milled individual parts that are subsequently welded or brazed. All these processes are complex and labor-intensive and make the coils used very expensive. In addition, the process results in long delivery times of several weeks.

The advantages of additive manufacturing can address these drawbacks, so that 3D printing of induction coils represents an improvement on all levels.

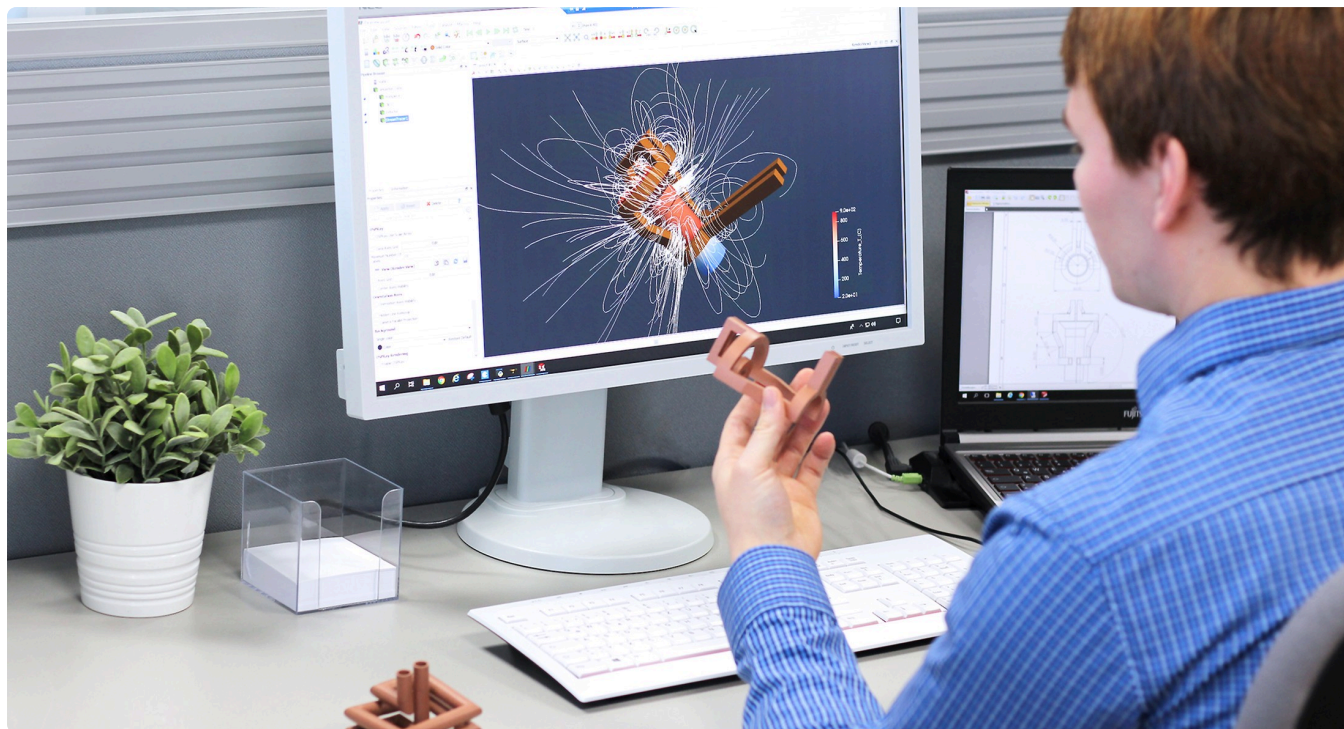
On the one hand, additively manufactured coils can be produced with significantly less manual effort. This is reflected both in lower production costs for the coils and in significantly reduced delivery times. At ProtIQ, these average between 5 and 8 working days, even for very complex coils.

On the other hand, the coils benefit from the increased geometric freedom in the design and manufacturing

process. Thanks to the layer-by-layer additive build-up, the coils can be produced as a whole, i.e. in one piece. This saves the manual effort of joining and also represents an improvement in the actual heating operation. The welded and brazed joints in conventional inductor manufacturing represent a significant weak point under cyclic mechanical and thermal loading. In addition, the flow of current and cooling water can be disrupted at brazed joints that are not ideally executed, leading to local overheating and further weakening of the joint. Over time, cracks form at these points, resulting in leakage or complete failure of the coil. Additive manufacturing eliminates the need for such weak points, which can extend the service life of the coils used many times over.

The greater design freedom of additive manufacturing also opens up additional potential. Because they are produced directly from CAD data, 3D-printed coils offer significantly higher repeatability than hand-bent coils. In addition, new coil shapes can now be realized that could previously not be produced due to manufacturing constraints in bending or milling. This makes it possible to achieve, for example, processes with shorter cycle times, improved homogeneity in complex heating tasks, or a general increase in efficiency.

With increasingly reliable FEM simulations of the induction heating process, digital potential for improvement in coil design and the heating process can be identified. Fully realizing this potential, however, often requires coil



▼ Coils optimized by FEM simulation enable more precise heating and reduced cycle times. Coils designed in this way can often only be produced by additive manufacturing.

geometries that can only be produced by means of additive manufacturing.

Experience has shown that additively manufactured inductors from ProtIQ can be integrated one-to-one into production to replace a conventionally produced coil. At the same time, 3D printing of coils requires a thorough understanding of the additive manufacturing technology and of parameter control. In particular, preparing the component data for production, orienting the coils in the build job layout and subsequently removing the support structures after additive manufacturing require a great deal of experience. This point carries additional weight because the coil bodies have to be produced hollow to ensure the required cooling water flow. Although the necessary industrial equipment is now available from well-known machine manufacturers, it is very expensive.

All this makes it difficult for individual companies to ensure economical in-house production with the necessary manufacturing quality and machine utilization.

This is where the many years of experience and the pooled capacities of manufacturing service providers such as ProtIQ represent a sensible alternative to in-house production, especially for the manufacture of additively produced copper inductors.

In addition to the widely used alloy CuCr1Zr, ProtIQ also offers the specially developed materials RS copper (RS-Cu) and pure, unalloyed copper. The pure copper meets the Cu-ETP specification and achieves an electrical conductivity of 58 megasiemens per meter (MS/m) in operation – or 100 percent IACS (International Annealed Copper Standard). Thanks to their high conductivity, additively manufactured coils made of this material stand out for particularly efficient process behavior. RS-Cu, a material developed specifically for additively manufactured inductors, is an alloy with 99% copper content that achieves an electrical conductivity of up to 50 MS/m. The material provides increased strength while still offering good electrical conductivity, and many customers value it especially for very complex inductor geometries. Optimized for the additive manufacturing process, the material enables the finest detail reproduction and the best surface quality compared with other additively processed copper grades.

As part of quality control, additively manufactured coils can be tested for conductivity and leak tightness. ProtIQ manufactures the coils leak-tight at water pressures of up to 20 bar for wall thicknesses of 1 mm and above. However, ProtIQ can also successfully produce coils from RS-Cu with wall thicknesses as thin as 0.5 mm. This

does, however, require a case-by-case assessment in consultation with the customer.

In addition to its own production, the eponymous ProtIQ GmbH operates the ProtIQ Marketplace, an online platform for additive and conventional manufacturing services. The marketplace provides users and production service providers with an interface in the field of industrial 3D printing and brings the players together in one place. The platform is specifically geared to the quality requirements and needs of industrial users. Unlike similar platforms, it places particular emphasis on transparency and data security. In addition to ProtIQ, more than 40 selected industrial manufacturing service providers are active on the platform. The marketplace portfolio comprises more than 12 different manufacturing processes with more than 160 materials made of plastic, metal or ceramic.

The ProtIQ platform offers its customers a fully digital process chain so that the efficiency of the additive manufacturing process is not impaired by traditional ordering processes. After uploading the 3D component data, users immediately receive automated, binding price information as well as an estimated delivery time. This enables them to compare different processes, materials and manufacturing service providers. An instant, quantity-dependent comparison of the production processes supports the final award of the order.

Within a few minutes, an official quotation can be generated and the order placed online.

To meet the requirements of large industrial users with established purchasing processes, ProtIQ also offers the option of an individually programmed API interface or ordering via proven e-procurement providers such as Meplato or SAP-Ariba.

For regularly recurring components, product configurators developed in-house give users of the ProtIQ platform additional value at no extra cost. The configurator for simple induction coils deserves special mention here. Users can create the coils themselves on the platform using interactive sliders and parameters and adapt them individually to their respective requirements. No experience with CAD systems or in design engineering is required for this. A plausibility check ensures that every configuration can actually be manufactured.

For more complex components that cannot be covered by the product configurators and for which the customer has no 3D data, ProtIQ provides support through a competent engineering service. The 3D data required for additive manufacturing can be created by ProtIQ either as part of a design service by a CAD designer, on the basis of a technical 2D drawing, or by reverse engineering using CT scanning.

In addition, the company stands out for its expert personal advice, so that special requirements and general conditions for the potential manufacture of the respective components can also be clarified.

Further information:

www.protiq.com