Thermoplastic insulation in power transformers

ABB has developed and successfully tested thermoplastic radial spacer insulation for oil-filled transformers. By applying the injection molding technique and a new flexible molding tool, a rapid and cost-effective production method was developed to give customers a robust and reliable alternative to pressboard.

In 2011, ABB corporate research centers initiated a collaborative project to identify new material for use in transformer spacer construction.

In response to changing market conditions, ABB has expanded its transformer product family investing in innovation, product and process improvement →1. Currently, ABB is exploring the suitability of new materials for transformer components and redefining production processes to develop the best products possible →2.
Pressboard has been the product of choice for spacers and insulation transformer components. Developed in the early mid-twentieth century, pressboard is lightweight and well-suited for the demanding mechanical and electrical requirements of transformers. Hence, research and development to investigate the usefulness of other materials was, for a long time, neither considered economical nor technically feasible [3].

Pressboard is used for spacing in most types of transformers today, ranging from small distribution transformers to large power transformers. The only exceptions to these applications are for special transformers, which require extremely high operating temperatures [4,5] or extra-safe solutions, such as traction transformers. In such cases, high performance man-made aramid-based materials are used because of its high strength and nonconductivity.

Radial spacer – small but significant
One of the key insulation components of the typical oil-filled disk-type transformer is a radial spacer. This relatively small element is placed in the heart of the transformer windings and assures the correct distance between each of the transformer’s stacked winding disks →2. The spacer must be capable of carrying a constant mechanical load, which arises from the clamping forces and – in case of a short circuit – an additional large load caused by electro-dynamic forces. Moreover, the spacer must be able to withstand operation temperatures from 98 °C to 110 °C [1,2] and rapid increases in temperature of short duration due to possible overloads. Furthermore, these structures must resist interaction with the transformer oil.

Thermoplastic spacers have excellent dimensional stability and reliability, which guarantees the long-term mechanical performance of the winding.

01 ABB’s power transformers are constructed with the expertise and experience of over 100 years.
Plastic alternatives
After decades of using pressboard as a base material for transformer insulation, ABB believes that the manufacturing market is ready to explore additional innovative materials to improve customer choice. The availability and rapid development of plastics with unique properties suggest applications that have never been possible before. Modern plastics have improved mechanical and thermal properties such as high RTI index, high deflection temperature and high compressive strength; this makes plastic a potential candidate to act dually as a support and insulation material for transformers. Furthermore, breakthroughs in manufacturing processes allow simple and energy efficient production, which increases the attractiveness of plastics.

Generally, plastics are characterized by low rates of water absorption from ambient humidity – in some grades of thermoplastic, water uptake might even be < 1 weight percent — advantageous because water molecules inside the insulation material negatively impact its electrical properties and could impact spacer and winding assembly. Therefore, pressboard spacers and other insulation components are dried: initially, following the winding assembly phase and a second time, just prior to their impregnation with oil [6]. Evacuation of the absorbed water from the insulation elements can result in dimensional change due to shrinkage. Hence, a special sizing procedure is applied to achieve the desired dimensions of the assembled winding following the drying process. Both the drying and sizing processes require time, effort and a considerable amount of energy [6]. The use of new materials such as plastic could eliminate or diminish the need for these steps, thereby saving energy and accelerating production efficiency.
Drawing on more than 100 years of experience in transformer production and development in many production facilities, ABB knows that in today’s competitive marketplace, utility, rail and other transformer customers trust ABB’s know-how and expertise when it comes to insulation. Plastics with superior thermal features and the ability to absorb negligible amounts of water would be ideally-suited as radial spacers and would enable a sleeker production process, which could eliminate or reduce the need for the first drying step and possibly the sizing step. The improved operational efficiency and lower manufacturing costs that result, could translate to real savings for customers who seek alternative radial spacers.

Thermoplastics were considered an ideal insulation material for power transformers due to their molecular structure that allows them to melt and remold repeatedly when heat is applied and because they are easy to manufacture. They are increasingly used for diverse electrical devices in the low voltage product segment and have been recently introduced to medium and high voltage applications where they are installed as housing in embedded poles, having replaced conventional epoxy, to provide mechanical support and electric insulation.

The behavior of transformers with thermoplastic spacers was successfully verified under the most onerous operation conditions, such as network short circuit events.

Thermoplastics
In 2011, ABB corporate research centers, initiated a collaborative project with the aim of identifying a material for use in spacer construction that would allow new functional capabilities, thereby providing customers with an improved tangible alternative to pressboard in power transformers. Additionally, the teams sought a quicker, more reliable and cost-effective production method to ensure high precision of produced elements.
Based on the vast range of thermoplastic grades currently available, surprisingly few have been evaluated for their feasibility in power transformers. Those tests conducted, verified the excellent properties of thermoplastics: stable mechanical behavior under load conditions, even during overload, chemical compatibility or resistance to degradation from interaction with oil, low moisture uptake and customary electrical withstand. Thermoplastic spacers were crafted, and installed within the winding stacks and tested →4, 5a and found to have excellent dimensional stability and reliability, thereby guaranteeing a long-term mechanical performance of the winding →5b.

Thermal behavior was also successfully tested. The tolerance of high temperatures means that the risk of thermal failure related to the winding hot spot is greatly reduced. Use of thermoplastics as spacers therefore make transformers tough and robust.

Efficient process

ABB sought a production method that was fast enough to provide the required large number of spacers (thousands per single transformer) and flexible enough to enable continual variation in the size of the spacers for each manufactured unit due to client order requirements and a rapid response time. Furthermore, the manufacturing process had to ensure superior production precision, homogeneity and excellent reproducibility.

The injection molding technique, conventionally used for processing thermoplastics, was chosen and yet proved to be technically challenging because of the variety of spacer sizes to be produced. This technique has been primarily used for mass production of objects with a fixed geometry. During the process, liquid polymer is injected into the molding cavity with its specific dimensions — only a specific element size can be produced using a single molding tool. Transformers designed and optimized for specific orders and requirements necessitate a flexible manufacturing process in terms of size of the winding and spacers. ABB developed a special molding tool to solve this challenge →6.
04 Thermoplastic radial spacers are stacked and placed within the transformer windings.

04a Thermoplastic radial spacers are shown.

04b Thermoplastic radial spacers provide additional support and electrical insulation to winding stacks.

05 The installed thermoplastic spacers provide stability.

05a Assembly of the transformer winding stacks using thermoplastic spacers.

05b Transformer winding ready for use.

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Tests of thermoplastic spacers in power transformers

Rigorous studies of transformers with thermoplastic spacer components yielded exemplary results. To date, transformers with thermoplastic spacers have passed all routine and type tests, including temperature rise with overload tests and dielectric tests. The behavior of transformers with thermoplastic spacers used to separate the stacks of winding was successfully verified under the most onerous operation conditions, such as network short circuit events. Full short circuit tests, were conducted and repeated with success as were visual inspections of the active parts of the components and the individual windings.

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The modular tool, equipped with adjustable walls, provides the ability to change the spacer length over a continuous range, thereby completely covering the size range required for power transformers. The tool is equipped with multiple molding cavities allowing simultaneous production of a few spacers in less than one minute per single injection cycle.

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ABB developed a special molding tool equipped with adjustable walls to change the spacer length over a continuous range.

ABB’s simulation support team applied their knowledge and experience of advanced multiphysics simulation techniques to the design process, thereby eliminating the traditional trial and error optimization iterations traditionally performed and accelerating the design process.

Finally, after optimization of the process parameters was performed, the tolerances of the spacer thickness could be successfully reduced to ± 0.015 mm — ensuring precision of production, reproducibility and homogeneity of the prototype.
**Future Insights**

The addition of an entirely new thermoplastic radial spacer to ABB’s palette of power transformer insulation products ensures customers can access the right spacer.

ABB’s research teams effectively responded to the availability of new materials to develop a reliable and cost-effective product to stabilize and electrically insulate the transformer winding. The production process has been perfected and simplified; new and modifiable tools help to further stream-line the manufacturing process. The elimination of some production steps while maintaining product quality and improving reliability means a better product for customers.

The significance of using thermoplastic for this new product extends beyond its application for radial spacers. The success of this material, newly adopted for spacers, helps to pave the way for the use of advanced materials for insulation components in the future.

**References**


