TEKNOLOGI JOURNAL

LPPM Universitas Putra Indonesia YPTK Padang
Lubuk Begalung Main Street, Padang, Zip Code: 25221, Sumatera Barat, Indonesia
Volume: 15, Issue: 1, Page: 1-7, June 30th, 2025, e-ISSN: 2541-1535
Available online at website: https://jitekin-upiyptk.org/ojs/index.php/Teknologi/index

Latest Development of Molded Inductor in Terms of Improvements in Material Options and Manufacturing Process

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Abstract

This paper presents a comprehensive review of the development of molded inductor technology, highlighting its advantages over conventional inductors. Molded inductors have emerged as a critical component in modern electronic systems due to their superior performance in high-temperature environments, high power density, compact design, and enhanced mechanical integrity. These benefits are largely attributed to the unique construction process, in which the magnetic core is molded directly around the wire and lead frame, eliminating the need for pre-fabricated cores. Such an approach results in improved structural strength and electrical efficiency. In addition to exploring the technological superiority of molded inductors, the paper examines their current applications across various industries. These include the automotive sector, power electronics, industrial automation, and consumer devices, where the demand for miniaturized yet powerful and reliable components continues to grow. The discussion then shifts to the current manufacturing processes employed in producing molded inductors. This includes automated coil winding, precision molding using magnetic powder and resin mixtures, and post-molding treatments such as heat curing and surface finishing. the paper concludes with practical recommendations for manufacturers. These include adopting automated production lines, implementing stringent quality control and testing protocols. Such strategies are essential for remaining competitive in a rapidly evolving technological landscape and meeting the rising expectations for performance, reliability, and sustainability in electronic components.

Keywords: Molded Inductors, Electrical Applications, Material Options, Manufacturing Process, Automated Testing and Quality Control.

1. Introduction

Molded inductor technology represents a significant advancement in the evolution of inductor design and fabrication methods. Unlike traditional techniques, this approach utilizes a molding process that allows manufacturers to form precise and complex geometries. One of the most notable benefits of this method is its ability to maintain consistent inductance values even under high current conditions. This stability is critical in power electronics, where performance reliability is essential. Additionally, the compact nature of molded inductors aligns with the industry's push toward miniaturization, especially in applications such as mobile devices, automotive systems, and power modules. The precision of the molding process enables the integration of intricate internal structures without compromising size or thermal performance, making it an ideal solution for high-density circuit boards. This innovative manufacturing technique not only enhances electrical performance but also supports mechanical durability and thermal efficiency—attributes that are increasingly important in modern electronic environments [1],[2].

A key distinction between molded inductors and conventional inductors lies in the method of core integration. In traditional inductor designs, manufacturers typically utilize pre-fabricated magnetic cores, which are then assembled with wire windings during production. In contrast, molded inductor technology employs a more integrated approach, where the magnetic core material is directly molded around the wire windings and lead frame. This process eliminates the need for a separate core component and allows for seamless encapsulation of the inductor's internal elements. As a result, the inductor benefits from enhanced structural integrity, better heat dissipation, and improved electrical performance. Furthermore, this manufacturing method supports the development of more compact and mechanically robust components, which are essential in high-frequency, high-power, and space-constrained electronic applications. By molding the core material in place, the design can be optimized for thermal management and electromagnetic shielding, providing superior reliability and efficiency compared to conventional inductors [1],[3],[4].

Unlike conventional inductors, which typically rely on pre-manufactured magnetic cores sourced from external suppliers, molded inductors are constructed using a process where the magnetic material is directly formed around the coil wire and lead frame during the manufacturing stage. This innovative technique integrates the core into the inductor structure itself, rather than assembling separate core and coil components. Such an approach not only streamlines the production process but also enhances the overall performance and mechanical strength of the component. By molding the core in situ, manufacturers gain greater flexibility in shaping the inductor to fit compact and irregular layouts, which is especially advantageous for densely packed electronic circuits. Moreover, this method reduces interface resistance between components and improves thermal conductivity, making it ideal for high-current and high-frequency applications. The result is a more robust, reliable, and space-efficient solution compared to traditional inductors that depend on standard core geometries [5], [6].

2. Advantages of Molded Inductors

Molded inductors present a range of unique advantages that contribute to their growing adoption in contemporary electronic systems. A standout feature of these components is their exceptional thermal endurance, which enables them to maintain stable functionality even under elevated operating temperatures. This thermal robustness gives engineers the flexibility to design circuits that can perform reliably in high-temperature environments or under conditions where heat accumulation is significant, without risking component degradation or failure. Such resilience is particularly critical in demanding sectors such as automotive electronics, industrial control systems, aerospace, and power conversion devices, where exposure to extreme temperatures is common [7],[8].

The ability to function effectively in these challenging thermal conditions not only enhances system reliability but also expands design possibilities, allowing for higher power output and greater compactness without the need for extensive cooling mechanisms. As the demand for miniaturized and high-performance electronic solutions continues to rise, the capacity of molded inductors to withstand thermal stress positions them as an indispensable component in next-generation technologies [8],[9],[10].

The ability of molded inductors to withstand high temperatures makes them particularly well-suited for applications where effective heat dissipation is difficult to achieve, including those in automotive systems, industrial machinery, and power electronic devices. These environments often subject components to prolonged thermal stress, requiring inductors that can maintain performance without degradation. Beyond their thermal stability, molded inductors also demonstrate outstanding resistance to moisture, which significantly enhances their durability and reliability over time. This moisture resistance helps prevent corrosion and electrical failure, even when the components are deployed in humid, wet, or chemically aggressive settings [11],[12].

Such a feature is crucial for electronics used in outdoor installations, marine equipment, and other rugged environments where exposure to water, condensation, or fluctuating temperatures is inevitable. By offering both thermal and environmental robustness, molded inductors provide a reliable solution for engineers designing for longevity and consistent performance in harsh or unpredictable operational conditions. This dual resilience broadens their applicability across a wide range of industries, supporting the advancement of durable, high-efficiency electronic systems [13],[14].

Molded inductors are also widely recognized for their ability to support high power density, allowing them to manage substantial amounts of energy without requiring excessive space. This characteristic is particularly advantageous in electronic systems where component miniaturization is a key design goal. Because these inductors can maintain excellent electrical performance within a compact physical structure, they are especially valuable in applications with limited space availability—such as mobile devices, wearables, compact power supplies, and tightly integrated circuit boards. Their ability to handle high power in small dimensions helps engineers achieve efficient layouts without sacrificing energy capacity or thermal performance. As a result, molded inductors are an ideal solution for modern electronics that demand both high functionality and reduced size. The combination of compactness, thermal reliability, environmental resilience, and energy efficiency makes molded inductors not only versatile but also essential in the development of next-generation high-performance technologies across various industries, from consumer electronics to automotive and telecommunications [15],[16].

3. Application of Molded inductors

Molded inductors are increasingly utilized in automotive systems, particularly in electric vehicles (EVs) and hybrid vehicles. Their high-power density, thermal stability, and compact design make them ideal for use in powertrains, battery management systems, and electric motor drives. Molded inductors can efficiently handle high currents and operate reliably in the demanding thermal and mechanical environments typical of automotive applications, enhancing overall vehicle performance and energy efficiency [17],[18].

In the telecommunications industry, molded inductors are used in a variety of applications, including signal filtering, power conversion, and RF (radio frequency) circuitry. Their ability to provide stable inductance in compact sizes makes them essential for mobile phones, base stations, and satellite communications systems, where minimizing space while maintaining high performance is crucial. Additionally, molded inductors' resistance to moisture and high temperatures ensures reliable operation in outdoor and harsh environmental conditions [19],[20].

Molded inductors are commonly found in consumer electronics such as laptops, smartphones, tablets, and gaming consoles. The growing demand for smaller, more efficient devices drives the use of compact, high-density components such as molded inductors. They are particularly useful in power supply circuits, where they help manage power conversion, regulation, and distribution. Their small footprint allows for integration into tightly packed circuit boards without sacrificing performance, making them indispensable in modern portable electronics. In power electronics, molded inductors are key components in applications such as DC-DC converters, power supplies, and energy storage systems. Their high current-carrying capacity and compact design enable efficient energy conversion while minimizing power loss and heat generation. Molded inductors also contribute to improving the power density of power electronic systems, allowing for more efficient designs in applications ranging from industrial machinery to renewable energy systems, such as solar inverters and wind turbine controllers [21],[22],[23].

The industrial sector benefits greatly from molded inductors, which are used in automation systems, robotics, and motor controls. These systems require inductors that can operate in high-temperature, high-vibration environments while maintaining consistent electrical performance. Molded inductors' robustness and moisture resistance make them suitable for use in factory automation, control panels, and precision equipment, where reliability and longevity are essential for continuous operation and safety [24],[25].

4. Manufacturing Process of Mold Inductors

In molded inductors, the magnetic core material is directly formed around the coil windings and the lead frame during the manufacturing process. This approach, often referred to as integrated core construction, eliminates the need for a separately assembled core component. By encapsulating the internal structure in a single, continuous molding step, the inductor achieves a more compact, mechanically stable, and thermally efficient design. This integration not only enhances electrical performance by minimizing air gaps and improving magnetic coupling but also strengthens structural durability, making the inductor more resistant to vibration, thermal expansion, and environmental stress. The seamless combination of core and coil in a unified body enables better space utilization on printed circuit boards (PCBs), supporting the miniaturization trend in advanced electronic devices. Additionally, this construction method allows for greater consistency in production, reducing variability and enhancing product reliability across applications in the automotive sector [26],[27].

The production of molded inductors follows a meticulously organized process that combines advanced engineering techniques with materials science. The process begins with the creation of detailed electrical and mechanical specifications tailored to the specific requirements of the intended application, similar to setting clear goals for a structured educational program. Following this, copper wire is precisely wound into coils, ensuring uniformity in the number of turns and tension, and then affixed to a lead frame. The lead frame plays a dual role, providing both the structural foundation for the coil and a means for electrical connectivity, ensuring that the inductor functions efficiently in its final application. This initial stage is crucial as it establishes the basic structural and electrical properties, laying the foundation for further manufacturing steps that enhance the inductor's performance and durability [28],[29].

The coil and lead frame assemblies are then positioned within molds, where a magnetic powder combined with resin is either injected or compressed to form a solid structure that encapsulates the components. This molding process eliminates the necessity for a separate pre-formed core, as the magnetic material is directly integrated around the coil and lead frame. By using this approach, the molded inductor benefits from improved structural strength, as the core and coil are seamlessly fused together, enhancing the component's durability and performance. This method also contributes to the reduction of air gaps and improves magnetic coupling, which further optimizes the inductor's efficiency. Moreover, the integrated molding process allows for precise control over the shape and size of the inductor, which is particularly valuable in applications requiring compact, high-density designs. The result is a more robust, space-efficient inductor that is well-suited for high-current, high-frequency, and thermally demanding environments [30],[31],[32].

5. Improvements in the Manufacturing of Molded Inductors

Recent developments in the production of molded inductors have focused on leveraging advanced materials and state-of-the-art processing technologies to enhance performance, efficiency, and reliability. The use of high-performance magnetic materials, such as ferrites and specialized metal alloys, has significantly improved the energy density and thermal stability of molded inductors. These materials are carefully selected for their ability to handle high currents while maintaining consistent inductance across varying temperatures and operating conditions [36].

In addition to material innovations, advanced processing technologies have played a pivotal role in refining the manufacturing process. Techniques such as precision molding and injection molding allow for the creation of more intricate, compact designs that offer higher performance within smaller form factors. These technologies enable the precise integration of the magnetic core around the coil and lead frame, reducing air gaps and improving magnetic coupling. The result is an inductor that operates more efficiently, with less heat generation and greater durability [37],[38],[39].

Furthermore, advances in automation and quality control systems have streamlined production, ensuring standards for electrical performance and mechanical integrity. Automated systems provide higher precision in winding, molding, and testing processes, reducing the potential for human error and increasing the consistency of the final product [40],[41],[42]. This process is further supported by the implementation of automated testing systems and stringent quality control measures, ensuring that the final inductors meet high standards of reliability, precision, and performance [43].

6. Improvements through Material Options

Ferrites

Ferrites are ceramic compounds made from iron oxide combined with other metallic elements such as nickel, zinc, or manganese. These alloys are widely used in molded inductors because of their high magnetic permeability, low electrical conductivity, and excellent performance in high-frequency applications. Ferrite cores are typically used for low to medium-frequency applications due to their superior efficiency in reducing energy losses [44],[45],[46].

Manganese-Zinc (Mn-Zn) Alloys

Manganese-zinc alloys are commonly used for cores in inductors due to their high magnetic permeability and excellent performance at higher frequencies. These alloys provide better efficiency in applications requiring high inductance and are suitable for high-power inductors. Mn-Zn cores are commonly used in power supplies and switching regulators [47],[48],[49].

Nickel-Zinc (Ni-Zn) Alloys

Nickel-zinc alloys are preferred for their low core loss and high-frequency performance, especially in high-power, high-efficiency applications. Ni-Zn inductors are often used in applications such as telecommunications and signal processing, where high-frequency stability is critical [50],[51].

7. Improvements through Manufacturing Process

High-Precision Molding Methods

Advanced molding techniques, including precision injection molding and compression molding, play a critical role in the production of molded inductors. These processes allow for the creation of intricate shapes with exact specifications, essential for achieving high-performance components. Precision molding ensures that the magnetic core is accurately formed around the winding and lead frame, minimizing air gaps and optimizing magnetic coupling, which leads to greater efficiency in compact designs where space is limited [52].

Automated Winding and Component Assembly

The winding process is crucial to the performance of molded inductors. Automation is employed in winding to guarantee uniformity in the number of turns and tension of the coil, ensuring consistent inductance and reducing variations across different batches. After winding, the components are automatically assembled into the mold, which reduces human error, accelerates production time, and improves overall accuracy in the assembly process [53],[54].

Integration of Molding and Core

Following the winding and assembly steps, the components are placed into molds where a resin mixture with magnetic powder is either injected or compressed. This step encapsulates the coil and lead frame, forming the magnetic core in situ. Using automated molding systems ensures uniform resin distribution and consistent pressure during the molding process, eliminating the need for pre-made cores. The integration of the core directly into the inductor during manufacturing leads to stronger and more compact components [55],[56],[57].

Controlled Post-Molding Curing and Heat Treatment

After the inductor is molded, it typically undergoes post-molding heat treatment to stabilize the magnetic properties of the core material. Controlled heating systems and curing ovens are used to ensure the inductor is heat-treated at precise temperatures, preventing overheating and preserving the integrity of the materials. This critical step enhances the performance of the inductor and guarantees its ability to function optimally even in high-temperature environments, ensuring long-term durability [58].

Automated Testing and Quality Control

Once the molded inductors are produced, they undergo extensive quality control and testing to verify their performance. Automated systems measure key electrical properties such as inductance, resistance, and the inductor's current-handling capabilities. Thermal testing is also conducted to evaluate the inductor's response to varying temperature conditions. Environmental tests, including moisture resistance and vibration tests, are applied to ensure that the inductors can withstand the harsh conditions found in industries such as automotive, industrial, and aerospace. Automated inspection ensures that each component meets strict quality standards and adheres to the required specifications [59].

Author Contributions Statement

Name of Author	C	M	So	Va	Fo	I	R	D	W
Nanang Fatchurrohman	✓	✓			✓	✓		✓	✓
Ismayuzri Ishak			✓	✓	✓			✓	✓

Conflict of Interest Statement

Authors state no conflict of interest.

Informed Consent

We have obtained informed consent from all individuals included in this study.

Data Availability

The data that support the findings of this study are available from the corresponding author, [R], upon reasonable request.

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