Improvement of Energy Efficiency of Electromagnetic Relay

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Abstract of doctoral dissertation

The doctoral dissertation titled "Improvement of Energy Efficiency of Electromagnetic Relays" is dedicated to developing new relay designs that significantly reduce energy consumption, addressing industry requirements and eco-friendly legal regulations. The research described in this dissertation was conducted as part of the "Implementation Doctorate" program, in collaboration with RELPOL S.A., the largest manufacturer of electromagnetic relays in Poland.

The primary source of energy consumption in electromagnetic relays is the electromagnet coil. Although the relay coil power is low (on the order of a few watts), in mass production and with global application, cumulative energy consumption can reach tens of gigawatts. Thus, improving relay energy efficiency has become a significant scientific and technical issue.

A literature review indicated potential for energy savings in relays by implementing bistability. Bistable relays require power only during switching (state change), unlike traditional relays, which require continuous energy to maintain the switched state. Solutions for achieving bistability through the use of permanent magnets and optimizing electromagnet parameters are well-known and widely discussed in the literature. However, market analysis and applications of bistable relays revealed that while numerous modern relay designs exist, broad implementation remains challenging due to high production costs. These costs stem from complex construction and low-scale manufacturing.

Accordingly, the research objective was set to propose solutions that would significantly reduce electrical energy consumption on the control side of electromagnetic relays. This goal was pursued with an additional requirement that the proposed solutions be easily and efficiently implementable in production.

The thesis of the dissertation was formulated as follows:

It is possible to significantly reduce the energy consumption of a standard electromagnetic relay by introducing low-cost modifications that do not substantially alter the relay's fundamental structure or production technology.

Thus, the assumptions were not only aimed at enhancing device energy efficiency but also enabling high-volume production without significant modifications to existing production lines.

The study utilized a commonly accepted research methodology encompassing magnetic circuit analysis, numerical analysis, and experimental research. In the design phase, the Equivalent Circuit Method (ECM) and the Finite Element Method (FEM) were employed. ECM allows for the analysis of magnetic systems by reducing them to equivalent magnetic circuits with lumped elements, facilitating quick comparison of alternative relay concepts. FEM, used in two- and three-dimensional simulations, provides a more detailed representation of magnetic elements and an analysis of their behavior in designed operating conditions. FEM studies analyzed the impact of the computational mesh on solution convergence and stability, selecting appropriate simulation parameters. The

accuracy of the simulations was validated through experimental tests conducted on a custom test bench.

The study examined various bistable relay technologies available on the market, including models such as Omron MY2K, Finder 2Z, and Releco C3-R20, which differ in construction, electrical parameters, and methods of achieving bistability. Critical analysis of these designs allowed for a more conscious search for new, better solutions.

An important achievement of the work was the proposal of a new concept and design for a bistable electromagnetic relay using a permanent magnet. The new design, based on the RELPOL S.A. R4N relay, focused not only on improving energy efficiency but also on minimizing structural changes of construction and enabling mass production. Ultimately, implementing the bistable function was reduced to adding two additional components (a magnet and an additional yoke) to the existing relay. Adding these components did not require changing of the relay's other parts. This design was patented (Pat.245744B1), which confirm the novelty and inventive level of the solution. Finally, the developed design was also introduced into mass production, which demonstrates the practicality of the solution.

In the course of developing the bistable relay, FEM methods were used to simulate the impact of material changes and it's thickness on the relay's electromagnetic parameters, which allowed for iterative optimization of the design. Test results on relay prototypes showed that the proposed design gives substantial energy savings on a large scale. The prototypes underwent functional laboratory tests and environmental tests in conditions close to real-world operation, enabling an assessment of their reliability and durability. Measurements included, among others, the holding force of the armature and an analysis of the activation and reset voltages of the relay, allowing for calibration of the electromagnetic parameters of the new solution. Additionally, the impact of different permanent magnet configurations on the relay's bistability was analyzed, and the system was adapted to high-volume production requirements, which is critical for cost competitiveness. The results of these analyses are presented and discussed in this dissertation.

The conclusions of the study indicate that the designed relay is not only highly energy-efficient but also meets stability requirements across a wide range of environmental conditions, such as variable temperatures and different load types. Comparative analysis demonstrated that the new RELPOL S.A. design is as energy-efficient as competitive models available on the market while ensuring production flexibility and integration with automated production lines. This solution addresses the ecological and economic market demands, potentially lowering operational costs and reducing CO_2 emissions in relay production and operation.

Thus, this dissertation makes a significant contribution to the field of electrical engineering by providing a new energy-efficient relay solution and by demonstrating methods for analyzing and designing magnetic circuits in specific case. The analysis of potential benefits (energy savings, CO_2 emissions reduction) presented in the dissertation further underscores the need for continued ment of energy-efficient relays, which should be widely implemented.