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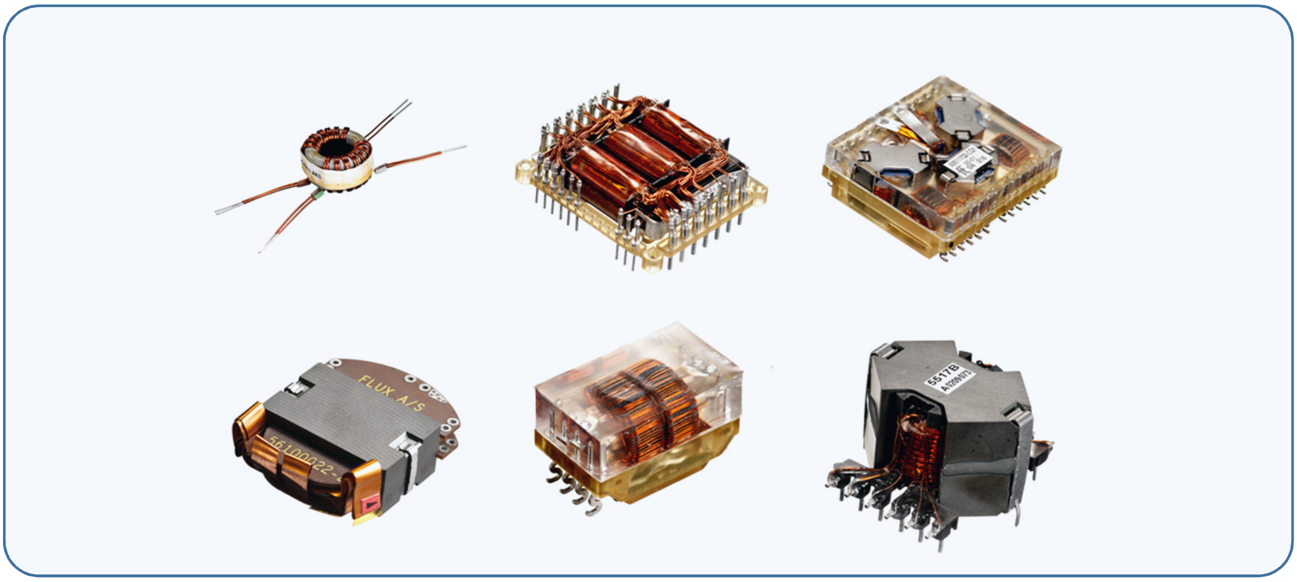

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1 INTRODUCTION

As electrical power propulsion units (PPU) have become a major part for the space industry the need for higher power components at higher voltages has increased. This project is based on a European Space Agency (ESA) development contract: “Planar and encapsulated SMD inductive electronic component qualification”, contract number: “4000122089/17/NL/CRS”. There are two design and development objectives of this project. Firstly, high power high voltage (HPHV) components for the PPU and the second being encapsulated inductive components. The project underwent four phases such as component specification, component design, production and verification testing.

1.1 Background

This section contains the preliminary studies, which are used to design the high power high voltage components and encapsulated inductors.

The high power high voltage components are based on a case study of an energy transfer system for power propulsion technology (PPT). The design takes basis in a 2.5 kW design previously completed by Flux A/S designed for ION propulsion technology. This PPT consisted of two parallel power-transferring circuits, thus transferring 5 kW to each engine. The drawback of using two 2.5 kW parallel power transfer system is the number of components needed, thereby increasing the mass. By increasing the individual component power level from 2.5 kW to 5 kW the number of components is reduced and therefore also the mass.

The encapsulated inductors are derived from industry components used for high power electronics equipment. The objective of this part of the project is to investigate the possibility to design and produce encapsulated inductors for space application. This will reduce the size and complexity of traditional high power inductors, which currently uses shaped cores or toroids with flying leads.

1.1.1 5 kW Case study

In this case a single 5 kW energy supply system is investigated.
The system consists of a boost converter connected to a full bridge converter driving the transformer.
The energy transferred to the secondary side is rectified to energize a load. The circuit of the energy transfer system is seen in Figure 1.

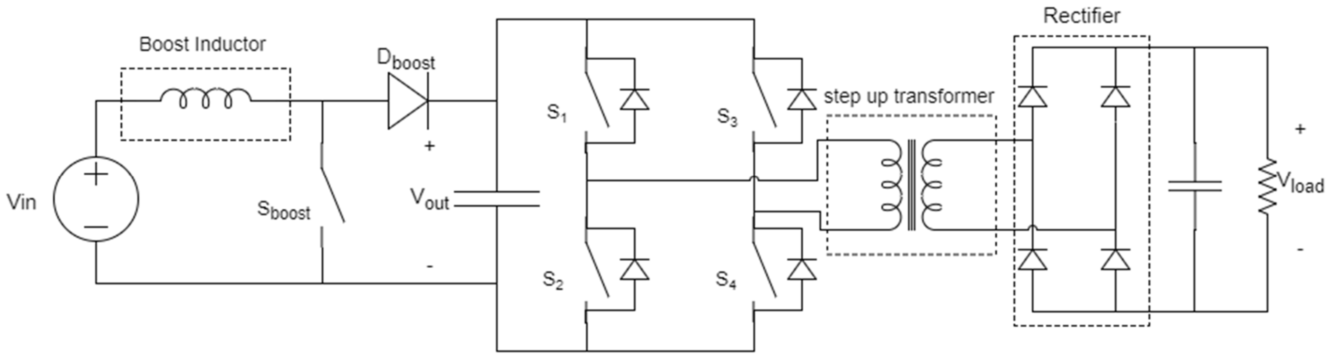

Figure 1 Converter schematic

From this case study, the maximum rating and electrical parameters are found.

1.2 Project Objective

The objective of this project is to design, produce and validate components designed to requirements. This is achieved through a design process, production of the components and a test phase.

Firstly, the component limitations were identified. Thereafter, the design of the components was performed. From the design, the production of the components was planned and executed. While the productions were ongoing the test equipment for the verification and validation tests was designed, built and tested. With the test equipment complete and validated, the validation and verification testing the components was performed.

2 DESIGN

In this chapter, the limitations and constraints of the components are presented. Firstly, any constraints and limitations which applies to both the high power high voltage components and the encapsulated inductor. Thereafter, the part specific constraints are presented, followed by the constraints and limitations of the mechanical design.

2.1 Generic Constraints and Limitations

Here limitations applying to both the HPHV components and the encapsulated inductor are presented. In this section the limitations include:

- Space regulations
- Wire limitations
- Temperature rating

The limitation of the space regulations concerning materials allowed in space and their chemical behaviour in vacuum. [1] [2] Amongst others, pure tin is not allowed in space, as pure tin has the potential to grows whisker in vacuums. This might short electrical connections, therefore lead or silver is mixed in the solder. The approved materials for space are listed in the DML. [3]

2.2 Specific limitations

The wire must be chosen based on the maximum allowed current density and the skin effect. A time varying magnetic field applied to a conductive material will induce a circulating current in the core of the material. [4]

In [5] standardised temperature classes are presented. The classes are defined from the maximum operating temperature (temperature rise plus maximum ambient temperature), the weakest material can withstand with a derating of 25ºC.

From [6] “All structural and mechanical parts shall be electrically bonded to each other, ensuring that, in order to control differential charging, there is a resistance of less than 10^6 Ω at each bond”. This applies to the core, which is glued to the case and might have electrically floating parts and must be considered.

The mechanical design of the high power high voltage inductor and transformer has to be compliant with the mechanical shock and vibration test from [7]. [5] Specifies the total component has to pass condition D (500g, half-sinus, 0.5ms) of [7].

3 PRODUCTION AND TEST READINESS

Firstly, is the proof of concept and the tests of new materials. Thereafter, the documentation and tool needed for producing the components are presented. Lastly, the full production process flow of the components is determined.

3.1 Proof of concept

When the winding tools for the transformer was produced a production trial for the winding was started. The production trial was made to evaluate the design of the winding tool and the dimension of the coil.

Since the product development of this project is outside the current domain special test equipment is needed to perform the specified tests such as life test, current stress step test and partial discharge test. In this Chapter the design of the special test equipment is presented

The Base theory of the high power test system is to recirculate the output power of the transformer back to the input with a large capacitor bank to store energy. Thereby, the DC supply will only supply the losses of the system.

3.2 Test readiness

The product development of this project is outside the current domain special test equipment is needed to perform the specified tests such as life test, current stress step test and partial discharge test.

The power burn-in system consists of a full bridge converter driving the transformer, a rectifier with buck chokes to reduce the voltage. Finally, an active buck converter connects the output of the transformer to the input with matching voltage. Furthermore, the active buck converter is used to control the feedback current, and thereby the power flowing through the transformer.

This test system is designed, developed and tested for a 10 kW system to accommodate the current stress step test.

Along with the power burn-in equipment a partial discharge test setup has also been designed. This was done in collaboration with a master thesis student from Aalborg University.

The partial discharge test is required to ensure the quality and integrity of the insulation of high voltage transformers.

This the power burn-in equipment and the partial discharge test equipment designed, developed, produced, and verified the required verification and validation tests can be performed as specified.

4 VALIDATION TESTING

At the TRR meeting the following tests were agreed on as validation tests:

Table 1 Validation tests

Serial number	Main Test
1	Mechanical shock (Condition D) and vibration (Condition H) [5], [6]
2	100 thermal cycles (-55 to +125°C) [5], [6]
3	Powered moisture resistance (Method 106F) [5]
4	accelerated life test (1000h@125°C) – based upon [6] and [7]
5	Overload test (112% power @ 100°C) [6]
6	Current stress step test (110% to 200% power) *(may be destructive)

The objective of the tests is to identify any weak points of the designs and to determine the limits of the designs.

The life test was performed and the temperature measures as seen in Figure *2*.

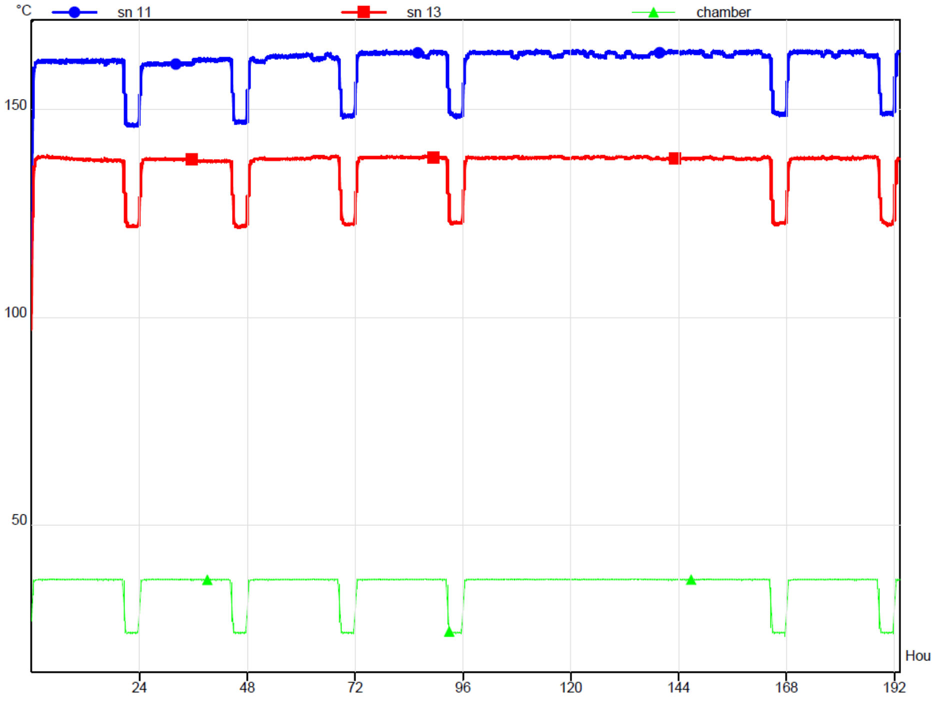

Figure 2 Life test temperature measurement of 1.5 cycle

Where Green is the chamber temperature, Red and blue is hotspot temperatures of the test vehicles.

4.1 Current Stress step test

The test starts at 110% rated power and is increased every 30 min monitoring the power transferred across the transformer, the losses of the system and the peak temperature of the component.

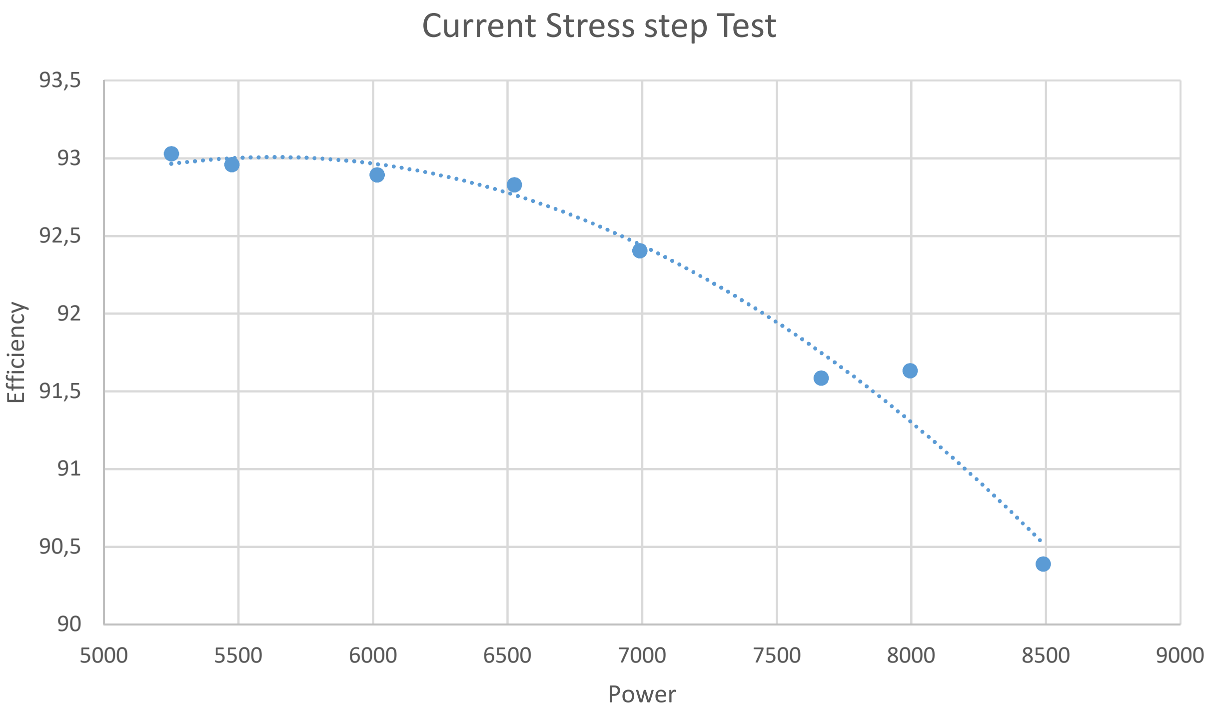

Figure 3 Results of current stress step test presented as efficiency over power

The test was terminated at 8500 W because the peak temperature of the component reached the curie temperature of the core material. If this temperature would be exceeded this would result in a magnetic short circuit of the core destroying the component and likely also the test equipment.

4.2 Encapsulated Inductors

Besides the tests specified in Table 1, the encapsulated inductors are tested for:

1) Inductance over DC bias
2) Permeability over frequency
3) Power over peak flux

With these tests the material used for the encapsulated inductors is identified and from this, strengths and weaknesses of the material can be concluded.

5 CONCLUSION

The designs of the components were made based on the case study.
In the case study a 2.5 kW reference design was doubled in the output power that was used to make the component specification.
With the specification in place the designs of each component were started. For the design, the applicable standards were identified and used as boundary conditions of the designs.

The design process started with an electrical design and covered as well mechanical and thermal design of the components.

After the designs were completed, production tools and manufacturing documentations were prepared.
The designs needed special tools for the production team to be able to manufacture the components.

While the components were being manufactured, test equipment was designed, produced, and tested. Due to the high power requirements, a special power burn in equipment was needed. The design engineers developed this internally in Flux A/S. The Power Burn In equipment was designed to recirculate the output of the transformer to the input of the converter reducing the power loss of the test equipment greatly. Furthermore, partial discharge is a crucial test for high voltage components. This however is a very specialized test, which not many companies can perform, therefore a collaboration with the high voltage department at Aalborg University was established. A student based his master thesis on the partial discharge test system for space applications, where he and the professors helped designing the partial discharge test system. [8]

With the components and test equipment manufactured and approved, the verification test was started. When the components were tested with mechanical shock and Power Burn In, the design yielded insufficient. Therefore, the electrical design of the transformer was improved along with the mechanical design of the high power high voltage transformer and inductor.

After the components were redesigned, all validation tests were passed. The transformer performed as intended up to 8.5 kW under Current Stress Step Test and mechanical shock and vibration passed at 500G.

To summarize, the components were manufactured and tested to specification. The power of the High Power High Voltage components was doubled compared to the case study, while only increasing the weight by 14% with an efficiency of 93% measured at 8.5 kW. The encapsulated was design, produced and validated according to the specification and the material properties determined.

6 REFERENCES

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