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ELEMENTS ON NUMERICAL AND EXPERIMENTAL STUDY OF POWER BUS MANUFACTURED IN COPPER LAMINATES

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BIOGRAPHY

Evandro Rostitolla Bortoloto *is a master's degree student in Mechanics Engineering, with focus on Automation at UNITAU - Universidade de Taubaté/SP. Evandro has graduated from ETEP Faculdades in São Jose dos Campos – SP in Mechanical Engineering in 2016. In 2012, Evandro finished his Industrial automation technician at Colégio Técnico Industrial de Santa Maria/RS and graduated in Management of Industrial production from International university of Curitiba/PR in 2010. Currently, Evandro is working with project research and development at Tecsys do Brasil LTDA at the Smart Power division and energy segment with the following responsibilities: products, equipment and solar systems projects, structural calculus, thermal analysis, power bus and heat dissipation systems, electrical vehicles development, rechargeable stations, antennas specifications, radio frequency systems, technical drawing development and detailing, suppliers development, materials specifications, manufacturing support and industrial management, manufacturing procedures and planning, productivity increasement and cost reduction. Nonetheless, Evandro works with radio link installations, support to clients, lectures, courses and staff training, machining and tooling implementations, computerized numerical control equipment and conventional machines. Large experience and expertise in telecommunications towers projects, Self-supporting and stationary structures, CNC machine programming, conception and development of tooling for thermal plastic and thermo fixes injections, RTM, RTM-Light processes, vacuum forming, cutting, folding, stamp and drawing, special support projects and antennas sectorial: yagi, omnidirectional, collinear arrangement of dipoles, yagis arrangement, patch panels, coaxial jumpers ,band pass filters, high and low pass, power dividers, surge suppressor, off-set parabola, cast e focal point, radio frequency products in the range of 138 to 6000MHz, HDTV, digital and single channel radios, public safety, Wi-fi e Wimax. Finally, Evandro was responsible for the metrology and mechanical prototyping sector, laser scanning, touch measuring, optical three-dimensional, roughness, hardness and climate tests and in the process of technological transferring China/Brazil.*

PRESENTATION

Thesis presented to the Post Graduation program of University of Taubaté, in partial compliance with the requirements for the Master's Degree in Mechanical Engineering.

This work presents elements about the numerical and experimental study on power bus manufactured on copper laminates aiming to assist electronic projects developments which may use printed circuit board. In order to achieve this goal, researches and academic support from professors at University de Taubaté were the key to write this technical document based on scientific and technical standards of the Brazilian Association of Technical Standards (ABNT), being new reviews recommended for future use.

The level of development established for each subject seeks to contribute to better projects with printed circuit board as well as to relate them with the other subsystems involved; aiming to take it as a useful and attractive reference for future interested ones.

SUMMARY

ELEMENTS ON NUMERICAL AND EXPERIMENTAL STUDY OF POWER BUS MANUFACTURED ON COPPER LAMINATES

Abstract: *This work presents elements on numerical and experimental study of power bars buses in copper laminates, with a goal of designing electronic systems designs that use printed circuit board, thus contributing to improve layouts, automate manufacturing processes and reduce costs of production. To evaluate the performance and robustness of the proposed application, there is no method of experimental tests in them, and the results obtained are tests are systematically compared with those obtained from equations contained in a dedicated technical standard. The positive results obtained in the tests carried out suggest that the type of material proposed in the aforementioned study, when submitted to an intense flow of electric current presents adequate performance for the intended purpose. It is concluded that the use of copper laminates in the manufacture of power bars, allows the development of new configurations in electrical and / or electronic projects, also favoring that manufacture follow as world trends of assembly.*

Keywords: *Copper laminates; Buses; Power Electronics; Surface Temperature; Electric current.*

1. INTRODUCTION

1.1 Contextualization

The worldwide energetic matrix represents quantitatively all forms of energy available composed mostly of non-renewable sources such as coal, natural gas and oil (RIBEIRO, 2017).

The searching for endless sources of energy obtained from natural and renewable resources such as solar, wind, water and geothermal contributes to the increasing use of electrical energy in the global market, stimulating the development of new products that make use of these kind of energies (FOGAÇA, 2017).

In addition, the technological growth on the research for more efficient systems which lose less energy to the environment during the transformations process, have helped to develop new materials and different applications (CUNHA, 2014).

One prominent segment is the so-called integrated circuits for power electronics, manufactured from semiconductor materials and originated around 1958, with the inventions of Jack Kilby e Robert Noyce, allowing for the time, several transistors to be printed at the same time on a single tablet (DINGMAN, 2013).

The power electronics is related to efficiently controlling the energy process in electronics systems, with great relevance in the development of new typologies of energy converters, destined to the most varied segments, including the connection of the renewable energy generating sources to the electrical networks of distribution and transmission. The construction of these electronic power systems is given by interconnecting components leading them to respond to electrical signals in order to perform a certain function (MARCELINO, 2013).

This interconnection is generally carried out by buses made of copper laminates which goes through many industrial processes. They also are heavy and require specialized work to make the assembly and execute the correct maintenance operations. Given these, cost, time, quality and repeatability factors are affected by the constructive way of such systems (PINTO, 2013).

In this context, this work presents elements on numerical and experimental study of power buses manufactured on copper laminate aiming to assist electronic projects development which may use printed circuit board.

The validation of the purpose of this study was obtained though observation in practical tests performed with prototypes developed for the given purpose. Positives results obtained from these tests suggest that the use of the certain types of materials in the aforementioned study is satisfactory and adequate for the given purpose.

1.2 Research Problem

The main reference for calculating power bus on copper laminated is the technical standard IPC 2221 (*Association Connecting Electronics Industries*) which specifically relates to electronic circuits in general.

On the other hand, the technical standard IPC 2221 does not consider type of material used, superficial finish of the power buses, installation locations, characteristics of the fluid in contact with the material, among other characteristics and conditions. Therefore, it is not recommended for electronic power systems.

1.3 Objectives

1.3.1 General Objective

This paper has the goal to present numerical and experimental elements on the study of power bus manufactured on copper laminates aiming to assist electronic projects development which may use printed circuit board. Also, the power busses may be used to connect power electronic devices, such as, rectifier modules, inverter modules, chopper's, motors, among other.

1.3.2 Specific Objective

This paper has the specific objective to evaluate the surface temperature reached by power buses prototypes manufactured in copper laminate according to the electric current intensity applied.

1.4 Object of the Research

Information and techniques related to the calculation and dimensioning of pathways in copper laminates for power electronics were investigated, being carried out in the main current norms that approach the subject, in specific literature related to the materials, in the main research mechanisms, in tools that approach the project and development of the application proposed in the work.

1.5 Delimitation

This research was delimited by the test on FR-4 (FR – flame resistant) laminate in stationary state, with natural convection, arranged vertically in a quiescent environment, at room temperature of 25º C and relative humidity of 50%.

1.6 Justification

Due to continuous technological growth of electronics components for power electronics, the electrical and thermal efficiency of new devices has strongly increased fostering the miniaturization of these items and allowing the manufacturing processes automation.

The construction of the power buses on copper laminates allows that components assembly follow the world trend of SMT (Surface Mounted Technology) technique, where high performance insertion machines called Pick and Place are used, contributing to the cost reduction, repeatability, low contamination degree, components reliability, among others.

1.7 Hypothesis

Given the bus's surface area is one of the main parameters to define the heat transfer rate, and for being related to the main working mechanisms (convection and radiation), presume that, extending the superficial area would be more efficient rather than increasing the thickness or the cross-sectional area of conductors, fact by which laminates would attend the application, once they have thin conductor layer, and it is possible to determine the width in function of the circuit electrical current.

1.8 Structure of the Work

This paper is divided into five chapters with the main goal to propose elements to assist the use of copper laminates in the design of printed circuit boards for power electronics.

The chapter 2 presents the literature review with necessary orientations for the development of the proposed subject.

The chapter 3 describes this works' methodology, the materials, equipments and the steps taken during testing the prototypes.

In the chapter 4 are presented the results collected through the experimental tests. Also, it has a graphic with the temperature for each bus according to the electrical current applied.

The chapter 5 presents the conclusion about the results and suggestions for future works in the area addressed.

Following, there are presented some bibliography references used to elaborate this paper.

2. LITERATURE REVIEW

According to Marcelino (2013), power buses are mainly used for interconnection between components for energy transfer. In general, they are manufactured in overlaid copper plates and insulated by a plate between them, usually constructed of fiber glass, working as a capacitor that accumulates the electrical charges and helps to control the electromotive forces involved called induction.

Mehl (2015) defines that copper laminates are, in general, one flat plate with insulated layers called substrates and conductive material films with a variety of types and thickness, measured in ounces [oz] which represents the unit of mass by square foot.

According to Silva (2013), the laminates are classified according to the position of the conductive film on substrate, as following:

- Simple face: conductive film in one face only, superior or inferior;
- Double face: conductive film in both faces, superior and inferior;
- Multilayer: conductive layer in internal layers of the substrate;

Micropress (2015) defines that laminates are available in standard sizes and after a sequence of processes such as cutting, drilling, metallization, application of protective varnish, among others, the final geometry is obtained.

For Reichert (2015), laminates can be manufactured by a number of methods, such as thermal process and chemical etching, ultraviolet and corrosion by chemical etching, CNC milling, and a combination of several techniques.

IPC 2221 (2003) standard establishes general conditions for circuits conception on copper laminates which is the dominant references for conductive tracks dimensioning onto material for maximum electrical current of 35 ampères.

For Gussow (1996), electrical current I [A] is the result of the difference of electrical potential existing between two points of the conductor material where there will be displacement of electrons.

According to Halliday (2009), each material offers a certain resistance to the displacement of the electrons which is measured in ohms [Ω] represented by the letter *R*.

Hart (2012) assumes that the resistance occurs due to the collision between electrons with atoms of the conductor material, increasing its state of agitation and causing the temperature gain known as Joule Effect.

Sontag at al. (2003) claims that temperature is the capacity to produce effect and measures the average kinetic energy of each particle in a system, due to its vibration movement, rotation and translation, being defined only for systems in thermal equilibrium.

According to Torres (2012), the temporal variation of the work carried out by the electrical current in a determined gap of time can be defined as electric power measured by Watt [W] and represented by the letter *P*.

Porto (2014) establishes that existing a temperature difference between two systems, the thermal energy transference will occur throughout the border between them, through the processes called conduction, convection or radiations.

Kreith e Bohn (2003), define conduction as heat transfer though the environment, occurring from the most energetic particle to the less energetic and the energy transferred rate depends on the enviroment.

For Ávila (2013), heat transfer by convection occurs between a surface and a fluid at different temperatures, depending mainly of the properties of the fluid.

According to Braga (2004), the heat transfer by radiation occurs though the environment by electromagnetic waves, and it does need a medium for mass transportation, being strongly dependent on the radiation property of the surface generate heat.

3. METHODOLOGY

3.1 Research Methodology

This research is applied in the identification and selection of new materials and manufacturing techniques for power buses used in electrical and electronic systems. It explores the relationship between the surface area of the energy conductors according to the electric current intensity and the temperature increasement, contributing to the use of techniques proposed in this article.

The research was developed with quantitative methodological strategy, with numerical representation of the temperature in the surface of the buses collected during the tests, so the methodology was based on different bibliography references and focused on the application of the knowledge obtained in prototypes manufactured for this purpose.

The essential elements involved in a system of conversion of electrical energy were used for the analysis of the results, aiming to present the main concepts and principals of these systems, using copper laminates to interconnect the components.

With the mentioned tests, it was possible to measure and observe the main variables inherent to the operation of power circuits, performing a close association with an action or solution for a problem, which the research is involved.

3.2 Methods

Table 1 presents the main properties of the laminate FR-4 largely used in the electronic industry for its excellent electrical and mechanical properties, chemical and heat resistance, great dimensional stability, high electrical insulation and low water absorption.

The substrate or insulation material is basically composed by epoxy resin and a fiberglass fabric, forming a rigid, strong, anti-flame plate and resistance to fissures and the conductive film made of copper through processes of electro deposition or high temperature elongation.

Table 1 – Properties of FR-4

Properties	Method IPC-4101	Condition	Unit	Value
Deformation	2.4.22.1	A	%	Max. 1,5
Torsion	2.4.22.1	A	%	Max. 1,5
Work Temperature	---	---	°C	130
Substrate Thickness	---	---	mm	1,6
Conductor Thickness	---	---	oz	1
Number of Layers	---	---	---	2

Source: MICROPRESS (2015)

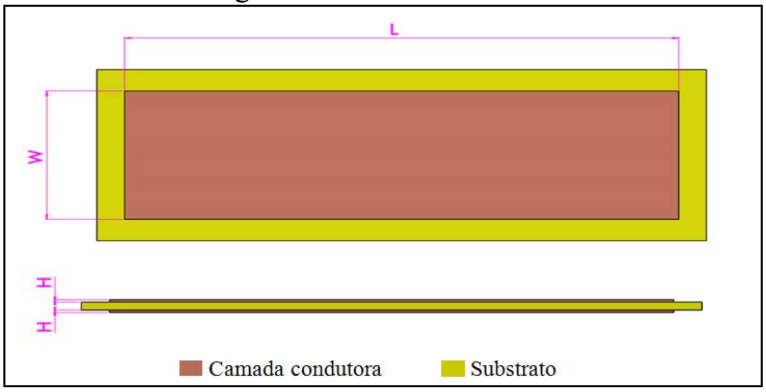
The prototypes with this material, shown in figure 1, were submitted to tests representing the real condictions and the limits of operation for the bus to analize and measure the performance and the stability of each component with the goal to prove the concept, the understanding of the requirements and usability from a technological and architectural point of view.

Figure 1 – Bus Prototypes

Source: AUTHOR (2017)

All power bus was manufactured with the same standard laminate, properly inspected by specific manufacturing processes, guaranteeing the tolerances established in the technical standards for this type of product. Thus, it is possible to assure that all pieces are equivalent in the thickness H [m] and length L [m], according to figure number 2.

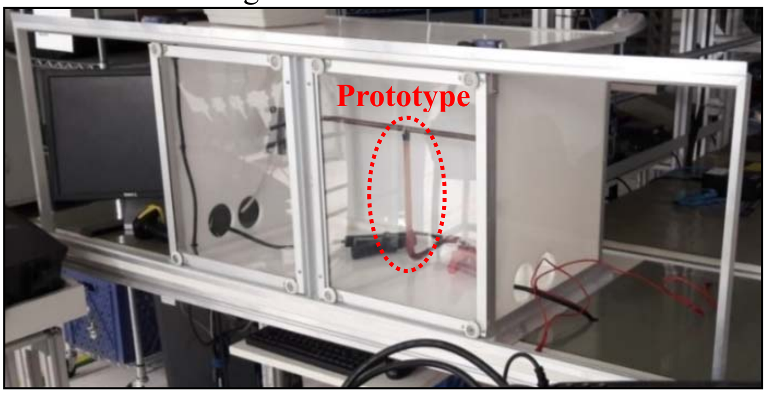
Figure 2 – Bus Dimensions



Source: AUTHOR (2017)

The environment properties were kept in stable range during the test due to the use of a cabin for the characterization of electric equipment in medium voltage, located in a clean room and heated, according to figure 3.

Figure 3 – Cabin Test



Source: AUTHOR (2017)

Each part has a determined width *W* [m], manufactured due to the method used for comparative analysis of the measured data, where different and standardized electrical current intensities *I* [A] were applied, according to table 1.

Table 2 – Test Parameters

Description	Letter	Unit	Value									
Width	W	m	0,005	0,010	0,015	0,020	0,025	0,030	0,035	0,040	0,045	0,050
Lenght	L	m	0,2									
Electrical Current	I	A	5 a 50 amperes (escale of 5 em 5)									
Room Temperature	T_{amb}	°C	25									

Source: AUTHOR (2017)

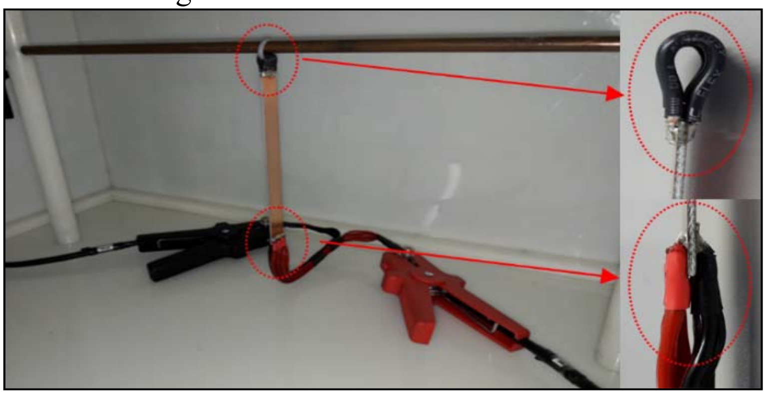
Electric current was applied to each power bus with an adjustable power source, according represented in figure 4. The power source allows to apply and maintain the desired value of the without time necessary for the system to be in permanent operation mode.

Figure 4 – Electrical Current Source

Source: AUTHOR (2017)

On both sides of the bus, electrical with thermal insulation power cables are installed, ensuring that heat dissipation to the medium occurs only on the faces of the bus, as shown in figure 5. It also guarantee input and output of the electric current for the same ends, while in the other far, a conductor was installed to interconnect both face, ensuring the continuous flow of electrons and assisting the fixation in the test cabin.

Figure 5 – Power Cables Installation



Source: AUTHOR (2017)

After assembly and installation, the tests are performed, following the steps shown in figure 6 and described below:

- Step 1: Close the access doors to the interior of the cabin.

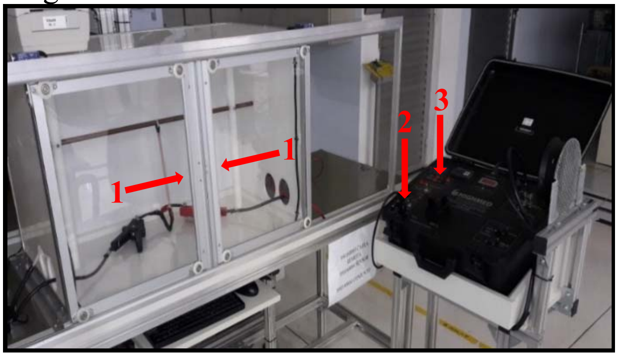
- Step 2: Turn the power supply on.

- Step 3: Select the value of the electric current to be applied.

- Step 4: Wait for the required time to the prototype enter into steady state operation, depending on each test condition.

- Step 5: Read the surface temperature of the track (prototype).

Figure 6 – Connection with the Power Source



Source: AUTHOR (2017)

The temperature was monitored with an infrared thermometer, figure 7, which measures the radiations of infrared energy on the power bus surface with no need of physical contact between the parts.

Figure 7 – Infrared Thermometer

Source: AUTHOR (2017)

The limit temperature established for the test was 200º C granting the integrity of the elements used in the construction of the prototypes. Other values were obtained by polynomial regression as the search for the solution of linear algebra matrix System, where, if *x0, x1,..., xn* are *n+1* distinct number and *f* is a function whose the values *f* of these numbers are given, so there is a unique polynomail *p(x)* with maximum degree *n*, as foloowing:

$$p_n(x) = \sum_{k=1}^{n} y_k . L_k . (x) \qquad (1)$$

where:

$$L_k(x) = \frac{\prod_{\substack{j=0 \\ j \neq k}}^{n} (x - x_j)}{\prod_{\substack{j=0 \\ j \neq k}}^{n} (x_k - x_j)} \qquad (2)$$

The results obtained using the above method are shown and complete the table below, the red color used differentiates them from the results tested.

4. RESULTS

The results collected in the tests and obtained with the aid of the polynomial regression are presented in table 2. For each width W [m], it is shown the superficial temperature Ts [°C] according to the electrical current I [A], applied in each power bus, and being completed by the variation ΔTs, according to the room temperature T_{amb} [°C].

Table 1 – Surface Temperature

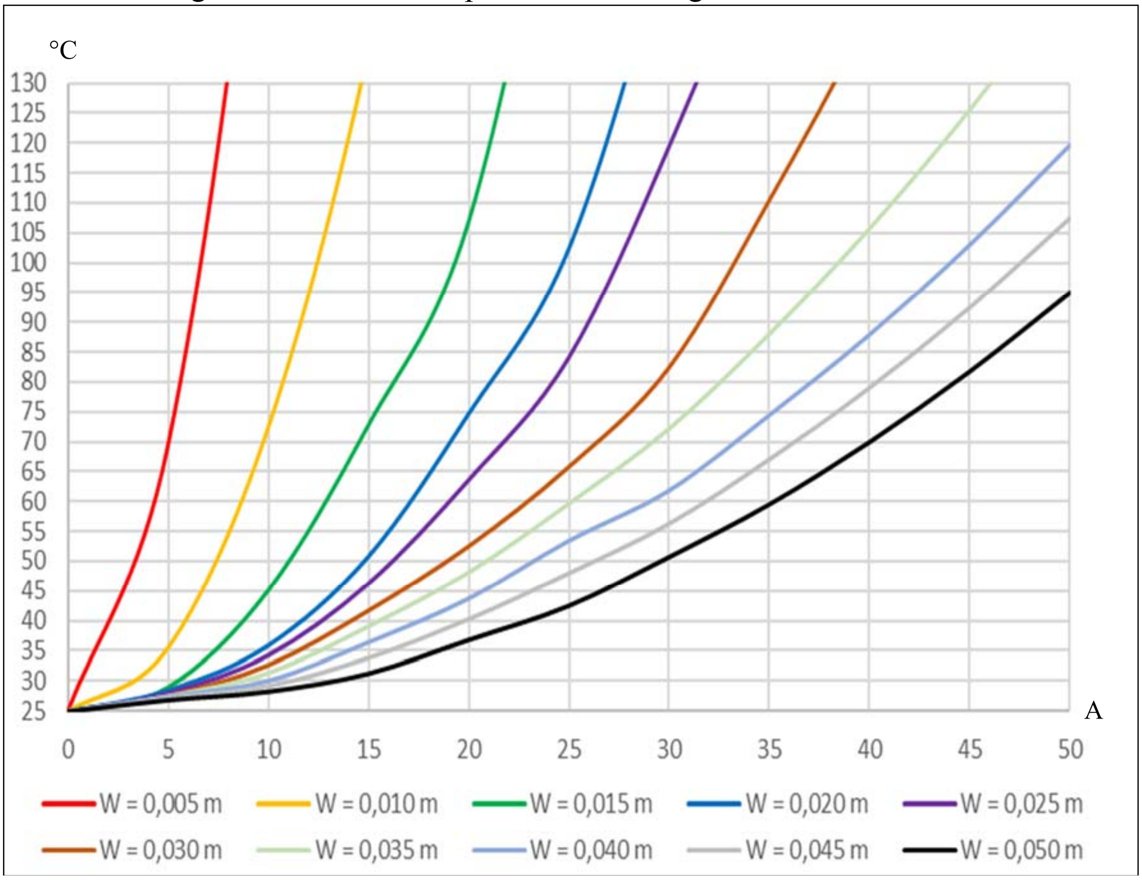
W = 0,005 m			W = 0,010 m		
I [A]	T_s [°C]	ΔT_s	I [A]	T_s [°C]	ΔT_s
5	69,50	44,50	5	35,60	10,60
10	188,00	163,00	10	72,50	47,50
15	380,50	355,50	15	135,50	110,50
20	647,00	622,00	20	224,13	199,13
25	987,50	962,50	25	338,48	313,48
30	1402,00	1377,00	30	478,20	453,20
35	1890,50	1865,50	35	643,07	618,07
40	2453,00	2428,00	40	832,87	807,87
45	3089,50	3064,50	45	1047,36	1022,36
50	3800,00	3775,00	50	1286,34	1261,34
W = 0,015 m			W = 0,020 m		
I [A]	T_s [°C]	ΔT_s	I [A]	T_s [°C]	ΔT_s
5	29,00	4,00	5	28,50	3,50
10	45,20	20,20	10	36,00	11,00
15	72,90	47,90	15	50,90	25,90
20	107,00	82,00	20	74,80	49,80
25	183,90	158,90	25	102,50	77,50
30	287,60	262,60	30	156,50	131,50
35	435,16	410,16	35	224,46	199,46
40	632,72	607,72	40	314,01	289,01
45	887,92	862,92	45	428,26	403,26
50	1208,43	1183,43	50	570,35	545,35

W = 0,025 m			W = 0,030 m		
I [A]	T_S [°C]	ΔT_S	I [A]	T_S [°C]	ΔT_S
5	28,05	3,05	5	27,60	2,60
10	34,35	9,35	10	32,70	7,70
15	46,35	21,35	15	41,80	16,80
20	63,70	38,70	20	52,60	27,60
25	84,20	59,20	25	65,90	40,90
30	119,50	94,50	30	82,50	57,50
35	161,77	136,77	35	110,52	85,52
40	216,48	191,48	40	141,87	116,87
45	284,49	259,49	45	180,87	155,87
50	367,28	342,28	50	228,51	203,51
W = 0,035 m			W = 0,040 m		
I [A]	T_S [°C]	ΔT_S	I [A]	T_S [°C]	ΔT_S
5	27,55	2,55	5	27,50	2,50
10	31,40	6,40	10	30,10	5,10
15	39,15	14,15	15	36,50	11,50
20	48,20	23,20	20	43,80	18,80
25	59,70	34,70	25	53,50	28,50
30	72,20	47,20	30	61,90	36,90
35	88,02	63,02	35	74,48	49,48
40	105,67	80,67	40	87,94	62,94
45	125,47	100,47	45	102,98	77,98
50	147,42	122,42	50	119,62	94,62
W = 0,045 m			W = 0,050 m		
I [A]	T_S [°C]	ΔT_S	I [A]	T_S [°C]	ΔT_S
5	27,20	2,20	5	26,90	1,90
10	29,20	4,20	10	28,30	3,30
15	33,90	8,90	15	31,30	6,30
20	40,35	15,35	20	36,90	11,90
25	48,05	23,05	25	42,60	17,60
30	56,35	31,35	30	50,80	25,80
35	67,11	42,11	35	59,61	34,61
40	79,07	54,07	40	70,03	45,03
45	92,51	67,51	45	81,84	56,84
50	107,45	82,45	50	95,04	70,04

Source: AUTOR (2017)

Figure 8 graphically displays the values from the table 2, allowing quick visualization and easy interpretation of the results. The upper temperature limit was determined based on the technical data of the substrate used, so that it does not exceed the critical zone of operation, undergoing changes in the properties of the material, which can cause power bus destruction.

Figure 8 – Surface Temperature according to Electrical Current



Source: AUTHOR (2017)

In conclusion, notice the non-linear behavior of the temperature due to the electric current for each bus width. This characteristic is consistent with the algebraic expressions of heat transfer mechanisms, where the net rate of heat exchange by radiation is represented by a fourth-order equation

With the graphic it is possible to select the ideal configuration of the power bars in a system, ensuring that the laminate operates in a safe condition while maintaining the reliability and integrity of the system.

5. CONCLUSION

The positive results obtained in the practical tests carried out support the hypothesis that extending the surface area is more efficient than increasing the thickness or cross-sectional area of the conductors, suggesting that the copper laminates, when used for the manufacture of power bus, allow the improvement of the layouts of these systems, serving as a resource for the development of new configurations in electronic projects, minimizing the acquisition costs, as well as additional expenses with installation and maintenance, besides the reduction in weight, quantity of parts, pieces and the necessary physical space to install the equipment.

The technique proposed in this study allows the exploration of new segments and markets, through the miniaturization and wide manufacturing capacity of the circuits, contributing to a greater participation of companies in an increasingly competitive and globalized market, besides the rational use of because it uses the ideal amount of material in each application.

Finally, the expressiveness and details contained in the table and the graph provide an intuitive and illuminating medium for the designers of these systems, allowing them to carry out their activities in an easy and systemic way, with the minimum occurrence of errors.

As the temperature rise in the buses is related to the thermal energy dissipated, which is directly related to the characteristics of the material surface and the properties of the medium, it is suggested for future work that the influence of these parameters be analyzed, allowing greater gains in the use of copper laminates in electrical power systems.

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